A Qualitative Study on Microwave Remote Sensing and Challenges Faced in India

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Abstract: ***Over the past few decades remote sensing has expanded its limits with exponential rise in technology that facilitates accurate data fetching in real time. In view of some of the major problems faced by developing nations, particularly India with its recent advancement in space technology, remote sensing has a vital role to play in resolving many such problems. In the light of recent Global Space Programs where several satellites have been launched for large area mapping using microwave sensors, microwave remote sensing can play a vital role as India experiences a large number of disasters every year. Also, majority of Indian population relies on farming for their livelihood. Microwave remote sensing can have significant effects in both these two scenarios as opposed to its conventional counterpart, optical remote sensing under diverse conditions and facilitate better results in terms of disaster management, prediction and increasing crop yield. The current paper brings out the various details on the work done by using active microwave remote sensing, with specific illustrative examples, for disaster management support, crop management techniques and the challenges associated on carrying out such researches in a diverse terrain like India.***

Keywords: Microwave remote sensing, ground based scatterometer, synthetic aperture radar.

1. Introduction

Over the years remote sensing has found diverse applications and is widely popular as a reliable data source with potential to solve many problems through prediction of climatic conditions, rainfall, cloud cover, etc and mapping of associated physical parameters and features on the earth surface. Remote sensing plays a vital role in studying areas dependent on large area vegetation e.g. during kharif season when crops get affected and yield of wheat is reduced remote sensing helps in assessing the prevalent conditions to propose a suitable solution. For crops requiring high rainfall (groundnuts, coffee, tea etc.) rainfall estimation, soil moisture and roughness detection can be done and unnecessary damage of crops can be averted. Rainfall estimation also helps in proposing a flood management architecture which is a dire requirement in countries like India where devastation caused by flood is a major concern. Prediction of natural hazards like cyclones, earthquakes and tsunamis and post disaster management is another area where remote sensing finds immense applications viz. predict the movement of clouds for rainfall detection or assessing climatic conditions. Moreover, studying different characteristics of waves scattered from the ground becomes necessary to determine soil quality, moisture content, physical crop parameters, etc.

Conventional methods using optical technique poses a challenge during night and diverse climatic conditions. Hence is the need of devising methods, techniques and sensors for reliable data collection during night as well as in cloud covered areas. Microwave remote sensing using microwave radiation (wavelength from about one centimeter to few tens of centimeters) enables observation in all weather conditions; an advantage over its optical counterpart [1]. The fundamental parameter in microwave remote sensing is the dielectric constant of the material on which other electrical parameters like emissivity and scattering coefficient depend. The values of the required variables can be derived through pre-determined knowledge of how the land surface interacts with electromagnetic radiation. The information is obtained by measuring these parameters as well as estimation using the theoretical models. Understanding these three electrical parameters (dielectric constant, emissivity and scattering coefficient) of the target material is extremely important.

There are two types of microwave remote sensing: passive remote sensing and active remote sensing. The passive type receives the microwave radiation emitted from objects on the ground [1]. Microwave radiometer is a passive microwave sensor. The basic principle governing the process of detection by the radiometers is the Rayleigh Jeans approximation of Planck's law. The behavior is guided by the electromagnetic emission from a black body at a given temperature T° K as governed by Planck's law [2]. Active sensors provide their own source of microwave radiation to illuminate the target. Active sensors are generally divided into two categories: imaging and non-imaging. The most common form of imaging active microwave sensor is Radio Detection & Ranging (Radar).

In this paper, the theoretical concepts behind active microwave sensor (air borne, space borne or ground based) and its prospects in various remote sensing applications have been highlighted and the details on previous work done in the use of active microwave remote sensing for disaster management support, crop management techniques are discussed. Also, a report on the challenges associated on carrying out such researches in a diverse terrain like India is provided after a detailed analysis of various works carried out; particularly in India.

2. Principle of Active Remote Sensing Sensor

Active microwave sensors receive the backscattering which is reflected from the transmitted microwave which is incident on the ground surface [1]. Synthetic Aperture Radar (SAR), microwave scatterometers, radar altimeters are active microwave sensors. Here the characteristics of scattering can be derived from the radar cross section calculated from received power Pr and antenna parameters (Pt, Gt, Ar) and the relationship between them, and the physical characteristics of the object.

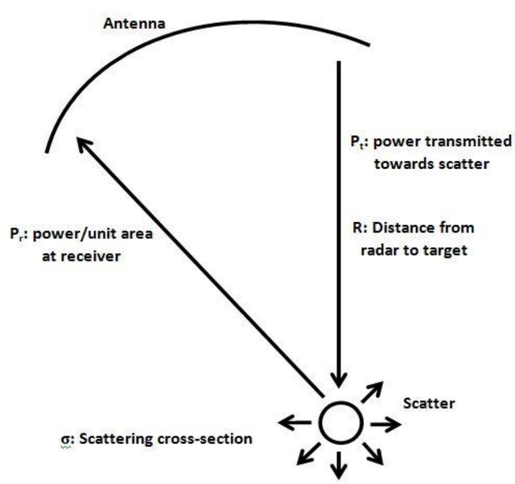

Figure1: Concept of radar equation.

The radar equation is given by

$$P_r = \frac{P_t G_t^{\,2} \lambda^2 \sigma}{(4\pi)^3 R^4} \qquad (1)$$

Here, G_t is antenna gain and λ is wavelength of the transmitting signal. Fig. 1 shows the concept of radar equation.

3. Ground based Scatterometer and Measurement of Scattering Coefficients

A scatterometer or diffusionmeter is a scientific instrument to measure the return of a beam of light or radar waves scattered by diffusion in a medium. Radar scatterometers use radio or microwaves to determine the normalized radar cross section of a surface. They can be mounted in aircrafts, space or satellites, or even in the ground. Scatterometers actively transmit electromagnetic pulses to the Earth's surface and measure the backscatter response, or the power of the return pulse scattered back to the antenna. Researchers can derive various geophysical variables from the backscatter response. Fig. 2 shows the block diagram of a general ground-based scatterometer. As seen from the block diagram, the basic components of a scatterometer include dual polarimetric horn antennas, signal generator, power meters and a computer. In the transmitter, signal from the generator is transmitted to the ground via the horn antenna. This signal upon reaching the ground is reflected and scattered which is received by the receiving horn antenna and is measured by the power meter.

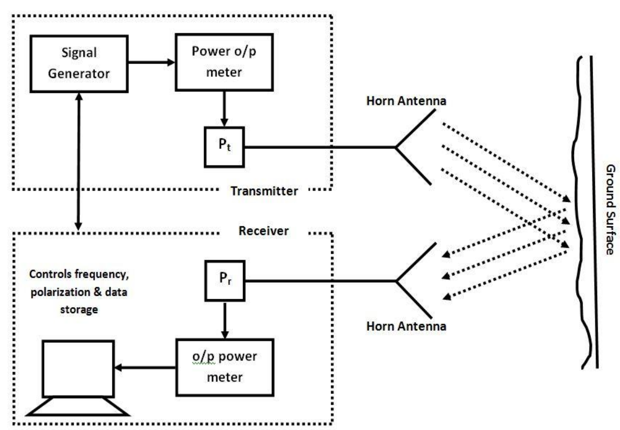

Figure2: Block diagram of active microwave sensor.

The computer controls the frequency and polarization as required for the purpose and stores the data acquired from the scatterometer. Generally, the scattering coefficient, that is scattering area per unit area, is a function of incident angle and the scattering angle. However, in case of remote sensing, the scattering angle is identical to incident angle because the receiving antenna of the scatterometer is located at the same place as that of the transmitting antenna. Therefore, in remote sensing only backscattering may be taken into account [1].

The backscattering coefficient depends upon the surface roughness and incidence angle.

From the radar equation in (1)

$$\sum \sigma_i = \frac{P_r (4\pi)^3 R^4}{P_t G_t{}^2 \lambda^2} \quad (2)$$

Scattering area per unit area σ^0, is called the backscattering coefficient.

$$\sigma^0 = \frac{\sigma_i}{A_i}$$

In case of snow and soil, volume scattering occurs along with surface scattering. Volume scattering occurs when electromagnetic radiation transmits from one medium to another medium [1]. There will always be an error in the measurement of surface scattering coefficient because of the effect of volume scattering.

4. Active Remote Sensing Applications

Several researches are going on in the field of microwave remote sensing for various applications, in and around the world. In this section a detailed survey of some previous works carried out by various researchers across the globe on active microwave remote sensing are provided. The different applications or areas on which active microwave remote sensing can be applied has be classified into three sub categories as follows:

3.1 Agricultural Applications

As explained in section I remote sensing finds wide application in crop management techniques with consistent and efficient observation of crops and agro-ecosystems. Recent conditions associated with climate change has made timely assessment of crop conditions (e.g., planted area, growth, productivity, damage) critical for diagnosis and decision making for precision crop management and food security [3-6]. The negative impacts of agriculture, such as air and water pollution by N2O, e.g., [7] and NO3, e.g., [8] from farming practices, can be minimized based on geospatial information on actual crop and farmland status, e.g., [9]. Microwave remote sensing offers some potential improvements over its counterparts (visible and near-infrared remote sensing) due to its all-weather day-and-night imaging capabilities and because radar waves penetrate into the vegetation canopies. In [10], the comprehenship relationship of backscattering coefficient values from two current X band SAR sensors (COSMO-SkyMed and Terra SAR-X) with canopy biophysical variables were investigated to access growth and yield in paddy rice. SAR images over a period of four years were acquired at Vertical-Vertical (VV) polarization and shadow incidence angles. In [11], an L, C and X-band full polarimetric ground based scatterometer is used to examine the backscattering coefficients of rice crop. In four different polarization modes backscattering coefficients were calculated by applying radar equation for the measurement at incidence angles between 20° and 60° and compared with rice growth data such as plant height, stem number, biomass, dry weight and leaf area index. The study revealed that at large incident angles, range of backscattering coefficients are higher than that at small incident angles. VV polarized backscattering coefficients are higher than that in Horizontal-Horizontal (HH) polarized data in early rice growth stages. However, after panicle initiation stage, HH polarized backscattering coefficients are higher than that in VV polarized data. Rice biomass retrieval using ground based active microwave sensors is reported in [12]. A neural network algorithm trained with pairs of multipolarization radar backscattering and biomass data to invert biomass of rice plants using quad-polarization radar datasets of ground-based scatterometer and spaceborne RADARSAT-2 has been studied. The backscattering data are simulated from a Monte Carlo backscatter model that uses the outputs from a growth model of the rice plant. RADARSAT-2 SAR images acquired on four different dates during the same growth period are analyzed to delineate rice paddies within the study area and to invert biomass using the neural network. A similar work [13] investigates the relationship between C-band backscatter measurement on the physical structure of rice fields and its growth stages. Seven C-band scatterometer acquisitions at full polarization, with incidence angle from 0° to 60°, were measured. The dates were chosen so as to coincide with RADARSAT-1 image acquisitions. Based on the result, a close agreement of backscattering coefficient between the scatterometer and RADARSAT-1 was obtained. Another work [14] used a ground-based multifrequency (L, C, and X-bands) polarimetric scatterometer system capable of making observations every 10 min on a soybean field over an entire growth cycle. The results obtained from this work could be directly applicable to systems such as the proposed NASA Soil Moisture Active Passive (SMAP) satellite. The diurnal variations in the vegetation water content of a maize canopy and their influence on radar backscatter is studied in [15]. A water-cloud model was used to investigate the influence that the observed differences in vegetation water content would have on backscatter at a range of frequencies and angles. The results from this study helps in understanding the mechanisms that control vegetation and leaf water content. The knowledge of leaf water content dynamics can be applied to improve soil moisture, biomass, and fuel load retrieval algorithms and shed additional light on how microwave remote sensing could be used to monitor water stress in agricultural canopies.

Apart from the various works reported above, one of the major applications of remote sensing in agriculture is determining various parameters of the soil. This helps in understanding the soil moisture requirement for growth of particular vegetation. The polarimetric radar backscatters of a soybean field were measured using a ground-based X-band polarimetric scatterometer in an angular range from 20° to 60° in 2009 and 2010 [16]. The backscattering coefficients were also obtained using the COSMO-SkyMed (Spotlight mode, HH mode) from July to October 2010. It was found that the estimated backscattering coefficients agree quite well with the field-measured radar backscattering coefficients. The surface scattering from the underlying soil surface was retrieved. Then, the soil moisture of the soybean field was retrieved from the surface scattering using the empirical surface scattering model. The extracted soil moisture contents were compared with the in-situ measured soil moisture contents. Another work using X-band scatterometer for estimating bare soil surface is carried out in [17]. Parameters such as soil moisture and roughness were examined in the work.

3.2 Natural Hazards and Disaster Management Applications

Impact of natural disasters on life and property and the ability to predict them would be one of the main contributions of remote sensing technology. The impact of natural disasters can be reduced through a proper disaster management which can be successful only when adequate knowledge is obtained about the expected frequency and magnitude of hazardous events. Roopa. V in [18] presented a review on remote sensing applications in disaster management like earthquakes and tsunamis. Disaster management consists of two phases before a disaster occur viz. ‘disaster prevention’ and ‘disaster preparedness’ and three phases after the occurrence viz. ‘disaster relief’, ‘rehabilitation’ and ‘reconstruction’. Remote sensing information collected in natural disaster management contain spatial component (geographic component, such as maps, satellite imagery, GPS data, aerial photography etc). All these data obtained will have a different projection and co-ordinate system, and need to be brought to a common map-basis, in order to superimpose them. After gathering the information, organizing technologies like remote sensing and Geographic Information Systems (GIS) in disaster management can be accessed [19]. Gillespie et al. in [20] also presented a review on assessment and prediction of natural hazards from satellite imagery. The study was made in three major areas based on the movement of earth (earthquake, mass movements), water (floods, tsunamis, storms) and fire (wild fires). Again in regions like Arctic and Antarctica measurement of atmospheric parameters for disaster management is crucial. Fundamental measurement parameters for these regions are the snow depth and the surface properties of the snow pack. For snow height measurements, different types of sensors like ultrasonic telemeters or laser systems are available and are already in use. However, the use of high-frequency radar sensors is a promising approach compared with acoustical and optical systems as the millimeter waves are nearly independent of hydrometeors such as fog, snow, and precipitation. In [21], a small and lightweight frequency-modulated continuous-wave (FMCW) radar system is used for the determination of snow height by measuring the distance to the snow surface from a platform. Another work employing the SAR for remote sensing of natural environment in discussed in [22]. Here, results from the analysis of 3-D L-band airborne SAR acquisitions acquired in March 2014 over the Mittelbergferner glacier, Austrian Alps were presented. The measurements were carried out during the European Space Agency (ESA) campaign AlpTomoSAR. The campaign included coincident in situ measurements of snow and ice properties and Ground-Penetrating Radar (GPR) data acquired at 600 and 200 MHz over a total length of 18 km. Radar data were acquired by repeatedly flying an L-band SAR along an oval racetrack at an altitude of about 1300 m over the glacier, such that two data stacks from opposite views were obtained. Data from all passes were coherently combined to achieve 3-D resolution capabilities, resulting in the generation of 3-D tomographic SAR (TomoSAR) cubes, where each voxel represents L-band radar reflectivity from a particular location in the 3-D space at a spatial resolution on the order of meters. TomoSAR cubes were finally corrected to account for wave propagation velocity into the ice, which was a necessary step to associate the observed features with their geometrical location, hence enabling a direct comparison to GPR data. The

TomoSAR cubes show the complexity of the glacier subsurface scattering. Most areas are characterized by surface scattering in proximity of the ice surface, plus a complex pattern of in-depth volumetric scattering beneath and scattering at the ice/bedrock interface [22].

3.3 Surveillance Applications

Because of reliability in data obtained in remote sensing surveillance is another domain where it has widespread applications. Notarnico et al. in [23], performed an experiment using an FMCW C-band ground based scatterometer to monitor soil roughness and moisture changes. Eight experiments were carried out under different conditions and measurements were taken at different incident angles. A sensitivity test was performed over the acquired data sets which showed that the scattering coefficients depends more on the incidence angles in case of surface roughness than for soil moisture. This is also validated by theoretical models and other similar data sets. In [24], a ground based bi-static forward scatterometer has been used to generate co-polarized specular data at CJ, X and Ku- bands for tracking low flying objects in the presence of strong ground bounce return from water bound areas. The measurements were carried out in three types of water surfaces i.e tap water, natural lake water and saline water. The basic purpose of this work is to map and monitor the natural resources and to provide timely inputs for the planners to develop appropriate strategies for optimum utilization of the resources. Turner et al. [25], presents a review on remote sensing applications for studying biodiversity and its conservation. The potential of modern sensors to identify areas of significance to biodiversity, predict species distributions and model community responses to environmental and anthropogenic changes is an important research topic. There are two general approaches to the remote sensing of biodiversity. One is the direct remote sensing of individual organisms, species assemblages, or ecological communities from airborne or satellite sensors, other is the indirect remote sensing of biodiversity through reliance on environmental parameters as proxies. Such approaches derive relevant information in a comprehensive manner sustainable to the purpose [25]. Vehicle detection and traffic monitoring is another key area where active microwave remote sensing can be applied. Parulekar et al. in [26], discusses about few remote sensing techniques to detect and monitor vehicles for intelligent transportation. Traffic surveillance can predict traffic flow and is immensely helpful for prevention of crowded traffic in urban areas.

5. Work in India

India is one of the few countries in the world that uses space technology and land-based observations for generating regular updates on crop production statistics and providing inputs to achieve sustainable agriculture [27]. The core areas related to remote sensing in agriculture includes land monitoring, crop area estimation and production forecast, drought assessment and monitoring, inland fishery development, cropping systems analysis, etc. Indian Space Research organization (ISRO)'s Radar Imaging Satellite (RISAT)-1 is a state of the art Microwave Remote Sensing Satellite carrying SAR Payload operating in C-band (5.35 GHz), which enables imaging of the surface features during both day and night under all weather conditions. It is India's first space borne active imaging SAR which enables applications in agriculture, particularly paddy monitoring in kharif season and management of natural disasters like flood and cyclone [28]. Hybrid polarimetric SAR (RH, RV) data from Risat-1 in FRS-1 mode was used for estimation of rice crop in Achanta mandal of West Godavari district, Andhra Pradesh [29]. The data corresponding to reproductive stage of the rice crop was analyzed. The data was subjected to Raney hybrid polarimetric decomposition to understand the contribution of various backscattering mechanisms in the rice crop. The decomposition parameters were subjected to supervised minimum distance classification for rice crop discrimination. A comparison was made with spatial distribution of rice crop derived from in-season Resourcesat-2 LISS-IV data. K. Roychowdhury in [30] presented different methods of classifying landcover using dual polarimetric Sentinel -1 data collected during monsoon and winter months. Four broad landcover classes such as built up areas, water bodies and wetlands, vegetation and open spaces of Kolkata and its surrounding regions were identified. Polarimetric analyses were conducted on Single Look Complex (SLC) data of the region while ground range detected (GRD) data were used for spectral and spatial classification. Unsupervised classification by means of K-Means clustering used backscatter values and was able to identify homogenous landcovers over the study area. The results produced an overall accuracy of less than 50% for both the seasons. Higher classification accuracy (around 70%) was achieved by adding texture variables as inputs along with the backscatter values. Goswami et al. [31] examined radar backscattering coefficients for bare soil and vegetation covered soil using X-band full polarimetric scatterometer. The results obtained will help to distinguish the land cover types such as bare soil, soil covered partially by vegetation and soil completely covered by vegetation.

Indian satellite sensors provide vital information to study and understand the important constituents of the atmosphere, the ocean and their dynamics as well. Oceansat-2 is one such satellite. It is the first Indian active sensor operating in the Ku band. The satellite data products are operationally used by Indian Meteorological Department (IMD), National Centre for Medium Range Weather Forecasting (NCMRWF), Indian Institute of Tropical Meteorology (IITM) and Indian National Centre for Ocean Information Services (INCOIS) for providing information and advisory services on weather, climate and ocean [27]. The Decision Support Centre (DSC) established at National Remote Sensing Centre (NRSC) under Disaster Management Support Programme (DMSP), is another body which addresses five natural disasters viz., Flood, Cyclone, Forest Fire, Earthquake and Landslide [27]. B. Amudha et al. in their work [32] identified certain new and salient features of the NEM rainfall (RF) utilizing the very high resolution (333 m × 333 m) Radar Estimated Rainfall (RERF) data generated by the Doppler Weather Radar (DWR) at Chennai for the 12 year period (2002-13), over a circular area of 100 km radius spreading over both land and ocean. Jenamani et al. in [33] presented an analysis of radar echoes and rainfall during the unexceptional rainfall event of 26th July, 2005, Mumbai. Data from IMD and 3-hourly accumulated TRMM grid point rainfall data available at very high resolution were used for the study. The study also attempts to find whether areas of highest rainfall contours and time of occurrences of highest rainfall intensity in rainfall map matches with areas of highest reflectivity and time of cloud tops reaching highest heights correspondingly by plotting both data in suitable geographical maps and comparing them graphically. Such type of validation study for Indian region will help in understanding the complex relationship between cloud characteristics and rainfall they produced and certainly will have tremendous application in the forecast verification when it will be simulated from various NWP models by various centers in their experimental studies in future [33]. The authors of [34] investigated the potential of active and passive microwave remote sensing in the estimation of soil moisture. Two tests were performed: firstly the AMSR-E and TRMM datasets of four consecutive years (2002-2005) were used for determining the spatial and temporal variation of soil moisture over Indian region and theoretical models were developed to analyze the data; secondly the scattering models derived from the first case were applied to active datasets obtained from ENVISAT ASAR data over Mumbai region during monsoon season. The theoretical and experimental concepts were tested on field experiments conducted over Bhavnagar and Kheda regions of Gujarat. Performance of the sensors and the scattering models were analysed. Again G. Kumar in [35] presented a study on the heights of Cb cloud around Guwahati. Existence of very high cumulonimbus clouds over northeastern India is fairly well known. These clouds create instabilities in the atmosphere and are often accompanied by severe turbulence, heavy electric discharge, icing etc. and pose serious hazards to air navigation. As such they deserve special attention and knowledge of their heights is required in air navigation. For the study, an E.E.C, X-band radar installed at Guwahati Airport was operated every year from 15th March to 15th October and hourly observations were taken daily from 0000 UTC to 1300 UTC. Seven years radar data of the period 1997-2003 for April to September months have been analyzed in the study. Another important study conducted by the authors of [36] was quantification of spatial and temporal changes between Indian Antarctic Research station Bharati and Amery ice shelf by monitoring the ice margins using RISAT-1 SAR data. The Antarctic Ice margins between Larsemann Hills and Amery Ice shelf is a potential region for ice loss as there are a number of glaciers in this area. During 33rd Indian Scientific Expedition to Antarctica (ISEA), an aerial survey conducted from Indian research station Bharati on Larsmann Hills to Amery has shown that lot of disintegration is taking place especially on glacier fronts and a remarkable change was observed on Polar Record Glacier Tongue (PRGT) and Polar Times Glacier Tongue (PTGT). The above study was conducted to monitor the calving and disintegration of large ice bergs on the glacier tongues of PRG and PTG and quantify the large scale changes happening there. Spatio-temporal change detection was carried out by comparing the feature's geographic locations from geometrically rectified SAR data from RISAT-1 (Dec. 2013), Radarsat-2 (Feb. 2013), and Antarctic Mapping Mission products of Radarsat-1 (1997 & 2000). The results obtained were verified against in-situ ground observations made during summer period of 33rd ISEA (Dec. 2013 - Feb. 2014) and MODIS images from NSIDC archive [36].

Indian space-based inputs have also immensely contributed in conserving forest and environment. Few works related to conservation and monitoring of forest and environment are reported in [37], [38] and [39]. In [37] space borne SAR data was used for vertical profile retrieval of forest vegetation. Forest height plays a crucial role to investigate the bio-physical parameters of forest and the terrestrial carbon. SAR tomography, which is an extension of cross-track interferometric processing is a recent approach to separate scatterers in cross range direction, thus generates its vertical profile. The test was conducted in Teak forest in Haldwani forest division of Uttarakhand state of India. SAR tomography is a spectral estimation problem, and hence, Fourier transform and beamforming based spectral estimations were applied on the dataset to obtain their vertical profiles. In [38], estimation of above ground biomass (AGB) for central Indian deciduous forests was done using ALOS PALSAR L-band data in conjunction with field based AGB estimates from empirical models. Such a study is useful to reduce uncertainties in carbon budgeting. Another similar work for estimation of forest height using PollnSAR based scattering information is presented in [39].

6. Challenges Faced

The challenges involved in the field of research in microwave remote sensing have kept it out of reach of scholars in developing countries like India in spite of its inherent advantages. Most of the works are simulations, performed in standard tools involving processing of satellite imagery and building theoretical models. In [30], the author established the utility of Sentinel-1 SAR data in landcover classification. It has also compared the different methods of classification and established that texture data combined with backscatter values are more useful in feature identification from SAR data. But polarimetric decompositions using surface scattering of SAR data is the most accurate method for landcover classification in urban and peri-urban areas. In [34], results were obtained from both passive and active sensors, on detection of soil moisture and the conclusions made would be helpful in future research.

In view with the geographical map of India and the North East in particular remote sensing posses a different challenge in itself. The region is characterized by diverse agro-climatic and geographical situations. Major chunk of the land has more than 15% slope, undulating topography, highly eroded and degraded soils and inaccessible terrain [40]. It has a predominantly humid sub-tropical climate with hot, humid summers, severe monsoons and mild winters. Also, the region is cloud covered for most of the time.

Along with the west coast of India, this region has some of the Indian sub-continent's last remaining rain forests, which support diverse flora and fauna and several crop species [41]. Thus, this region in particular requires real time information update pertaining to the conservation of the diversity. Such studies on agriculture, climate changes, conservation of forest and environment becomes difficult under optical methods because of extreme climatic conditions and cloud cover and thus microwave remote sensing has the upper hand over its counterpart.

Researches in the field of remote sensing outside India have enabled them to utilize the advantages of microwave remote sensing and various works already done in this field have helped to foster their technology further. We also see that most of the work discussed in Section IV uses data acquired from a ground based scatterometer of different frequency bands (L, C or X) depending upon the work. To validate the results from the physically acquired data either theoretical models or imagery from satellite data are considered. However, the costs for imagery from these satellites are often high. Also, the hardware components in a scatterometer are expensive. In general, imagery from the newer and higher spatial resolution hyperspatial satellites is more expensive than lower resolution imagery. Although the overall trend is toward declining imagery costs still small quantities of satellite imagery requires special software and hardware tools thereby increasing the overall cost of research [25]. This could be one reason for not adopting active microwave remote sensing by researchers in India. However, it is found that increase in computational power is driving down the costs of necessary computer hardware while the costs of remote sensing and GIS software are also declining [25]. Fortunately, new software tools are making remote-sensing data more accessible. Another point to emphasize is the tremendous importance of getting accurate information to validate what the remote-sensing data products appear to be telling the user. Such 'groundtruth' information might come from researchers in the field, ground-based sensors, or even higher resolution remote-sensing sources (e.g. aerial photography). Atmospheric phenomena, mechanical problems with the sensor and numerous other effects might be distorting one's view [25].

In view of these it can be said with absolute certainty that, if properly harnessed, microwave remote sensing can be the pathway to solve and eradicate several of the age old problems prevalent in India. However, limitations faced by researchers have kept this key potential out of reach of the general masses.

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