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IMAGING SPECTROSCOPY FOR CROP MONITORING IN NIGERIA: A REVIEW

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ABSTRACT
Reliable information on crop statistics is vital for agricultural policy design and decision making. Diverse tools have been employed to achieve this aim. The utilization of satellite data for agricultural purposes has been well adapted. These applications include vegetation mapping, crop growth monitoring, crop yield prediction, crop disease assessment, stress detection, and component identification in plants, etc. The interest in Imaging Spectroscopy for agro–based applications is increasing. It is a promising approach that incorporates traditional imaging and spectroscopy in a single system to acquire spatial and spectral data jointly from a feature or an object. The current paper is a review of literatures on Imaging Spectroscopy for crop monitoring in Nigeria. Finally, this review demonstrates the fact that, combining both spectral and spatial information in one system, data acquired through Imaging Spectroscopy guarantees the ability to accurately classify different land feature types and even subclass types. Hence it is applicable in crop monitoring.

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1. INTRODUCTION

Agricultural sector of various countries have certainly boost their respective economy significantly. One obvious example is the African countries where agriculture affords employment opportunities to over 60% of its people, in addition to contributing almost 30% to the GDP [1]. Also, it is usual to regard Nigerian economy in the early 1960s as fundamentally agricultural when judged by its percentage contribution to the GDP, and the percentage of the country's workforce that was directly and otherwise engaged by the sector. Later on and currently though, the oil sector heavily dominates Nigerian economy, yet, Nigerian agricultural sector has remained essential to the country. It affords the key foundation for food and employment, with 60–70% of the country's population being employed by the sector [2]. Of course, it is a significant segment and the basis of resources used in the processing industries and a major source for the country's foreign earnings [3].

Nigerian government rebased its economy in 2014 based on the international norms, which suggests that every country does so at five years interval, so as to adequately capture the data on its economic activities. This was long overdue because, the previous rebasing of Nigerian GDP took place more than two decades earlier. The official figure of the new rebased GDP of Nigeria indicates a GDP of ₦82 trillion naira ($509.9 billion). This represents a significant increase by 89%, making Nigeria to become the 26th economy in global ranking, and the largest economy in Africa. Previously, the percentage constituents of agricultural and service sector have been 33 and 26 percents respectively. But, the new GDP shows the following percentages: agriculture (22), services (51), oil and gas (15), manufacturing (6.7), telecommunications (8.7), and nollywood (1.2). From this information, it is clear that, even though the percentage contribution of agricultural sector reduced by 11%, it still remain the highest single contributor to the GDP.

Agriculture is essential to modern society because it meets our needs for foodstuff and fibre [4]. It will continue to hold the key to growth, employment and poverty reduction [5] based on its impact on socio–economic and industrial component of any nation [6]. Every national government has its agricultural policy and makes effort for the citizens to have access to sufficient and excellent food [7]. Sustainable agricultural development is a crucial goal of global society. It balances the land resources with crop requirements, and particularly considers optimization of resource utilization [8]. For Nigeria, the core of agricultural policy is self–sufficiency in fundamental commodities, especially those that, it has proportional benefit in local production such as tuber crops. Moreover, Nigeria has the potentials to feed much of Africa as well as Chaina and India [5].

Frequent survey and monitoring of agricultural production hardly provide accurate, low cost, and timely information that is sufficient to meet agricultural production and management requirements. The conventional approach– sample survey can't meet the requirements of information society anymore [9]. Of course, agricultural monitoring, estimation, and other significant informational results are most times not obtained until the season ends, at which point it becomes relatively obsolete and only relevant for historical purpose. Therefore, there is need to employ strategies or tools such as satellite methods for collecting timely and up–to–date data at regular intervals.

The underlying principle of using remote sensing is in its capacity to differentiate dissimilar features [10]. Multispectral satellite system utilization has been the most common technique in terms of application. But, the coming out of hyperspectral system or Imaging Spectroscopy has introduced an improved remote sensing application. Imaging Spectroscopy deals with the capture of imageries such that, each energy spectra is measured at the remote sensing sensor for every spatial resolution element within the imagery [11]. Hyperspectral sensors are capable of recording data in tens or hundreds of wavelengths or spectra channel in a very narrow and continuous nature [12], and thus has been prominent in agriculture, and specifically in crop monitoring. This paper is meant to conduct a review of imaging spectroscopy application for enhancing crop monitoring, with specific attention to Nigerian agricultural sector.

GSJ: Volume 7, Issue 4, April 2019
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2. Fundamentals of Imaging Spectroscopy

The greatest interest of remote sensing experts has been to identify ground features or objects on imageries. By and large, detection of objects on imageries is based on their spectral reflectance. But, several objects on the earth surface are characterized by similar features, implying that, the objects provide similar percent reflectance. The significance of spectral resolution is apparent as it affects the quantity and category of thematic information that can be obtained from satellite data. Moreover, spectral resolution determines the bandwidth distinctness and sensor sensitivity to clearly discern grey levels [13].

Dissimilar classes of earth surface features or object as well as details located within satellite imageries can frequently be differentiated by comparing their responses over discrete ranges of wavelength. Finer spectral resolution results in narrow wavelengths for specific channel or band, while the case for coarse spectral resolution is opposite. The recent development related to satellite platforms culminate in new and important alterations, and challenges in the methodology of remotely sensed data analysis, integration, and the efficient spatial modelling of these data [14]. A satellite sensor is typified not only by the number of its spectral bands, but by the position of the channels within the electromagnetic range. The three main categories of spectral imaging are: panchromatic, multispectral and hyperspectral. Utilizing multispectral imagery normally ends in higher measure of discriminating power as compared to the use of any single band. Therefore, the perfect solution would be 'Imaging Spectroscopy' in which satellite sensor is characterized by several amount of spectral channels, each with a small bandwidth of about 10nm.

Imaging Spectroscopy emerged from the combination of two distinct, but related photonic technologies (i.e., conventional imaging, and classical spectroscopy) in a single system which often includes large datasets and requires new processing methods. It was introduced in 1980s and it brought an enhanced insight into spectral properties of Earth's surfaces [15]. Hyperspectral sensors are made up of plenty constricted and adjoining spectral channels throughout the visible and infrared wavelengths [16]. These greater spectral properties of hyperspectral approach as compared to other multispectral data permits detail assessment of vegetation [17, 16]. The several narrow bands of imaging spectrometers provide a continuous spectral measurement across the whole electromagnetic range and consequently are further responsive to slight variations in reflected energy. Hyperspectral datasets or *hypercubes* are represented in three–dimensional datacube from the materials within a given scene, in which the spatial information are indicated by two dimensions, while the spectral information is represented by the third dimension. Spectral imaging provides a high spectral resolution from hyperspectral images by decomposing the reflected sonar radiance into large number of bands with minor spectral characteristics; as such, spectra of the various features indicates almost constant profile [10]. The values recorded by imaging spectrometer can be transformed, through suitable calibration, to radiometric quantities that are associated to the scene phenology such as radiance, reflectance, and emissivity, etc. Furthermore, Imaging Spectroscopy sensors such as Hyperion, FTHSI and others offer rich information on the surface radiance [18, 19].

3. Processing and Analysis of Hyperspectral Datasets

Apart from preprocessing, the methods of processing are similar for all hyperspectral data weather airborne, satellite, or laboratory [20]. The electromagnetic radiation for remote sensing systems normally covers some distance of atmosphere. In ideal case (without interfering atmosphere), the solar rays illuminates the earth, and the earth's surface normally absorbs a part of the energy received, while the residual energy is reflected into the space. Thus, the measured radiance is subject to atmospheric perturbations– absorbtion and scattering. However, atmospheric correction converts the 'Top of the Atmosphere' (ToA) signal to the surface reflectance which gives the approximation in terms of surface spectral reflectance for each band as it would have been measured in real world. There have been recent development and launching of hyperspectral systems characterized by in–built module for radiometric rectifications. Yet, the Inertial Measurement Units (IMUs) of the sensors needs calibration against the earth's local magnetic field; otherwise the orientation of the Unmanned Aerial Vehicle (UAV) can be compromised [21].

Numerous techniques and algorithms exist to analyse hyperspectral imaging data, some of which have already been incorporated in commercial packages for remote sensing image analysis. This is aimed at optimally reducing the enormity of the information whilst maintaining essential spatial and spectral information with the power to categorize vital chemical or physical areas of a scene. The utilization of spectral libraries of common material (mostly minerals) for feature–based hyperspectral data analysis is widespread [22, 23, and 24]. But,

GSJ: Volume 7, Issue 4, April 2019
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they have not fully achieved their prospects as they require broad interaction by spectroscopy expert to establish diagnostic features. Also, feature–based techniques generally ignore spectral mixing, and consequently, it is appropriate for definite materials under narrow circumstances.

4. MAJOR CHALLENGES IN USING IMAGING SPECTROSCOPY DATASETS

Hyperspectral datasets has enormous numbers of spectral band, and thus, contain vast information about various objects. It is however faced with inherent drawbacks such as high–dimensionality of signal as well as complexity of dataset which requires high processing effort. Of course, analysis of bulky amount of channels available with any hyperspectral sensor is complex and time consuming [25, 26]. The intense sampling of the spectral range regarding the electromagnetic band may afford a very rich and detailed source of information; yet, it is constrained by the problems of theoretical intricacy, amplified computational load, and optimization of enormous numbers of variables. Also, problems and factors that may impinge on accurate vegetation cover classification are linked to technical features of the remote sensing systems and to the choice of appropriate classification technique. Moreover, the biophysical properties of a certain locality and the vegetation itself affects mapping. Chlorophyll and the water content of crops greatly impact the spectral uniqueness of crops, and therefore, they change during their growth. Accordingly, time–series datasets during growth as regards crops under investigation is inevitable in order to attain better identification. Previous study indicates the problem in crop classification linked to the differences in spectral reflectance due to uneven crop maturation and differences in the growth phase of plants within a single field or among different surfaces (caused by different date of sowing) [27]. Spectral reflectance is also influenced by soil humidity, and surface elevation.

Detection of crops or recognition of alterations on agricultural surfaces is performed by multitemporal classification [28]. Although, a number of high spatial resolution satellites abound, in some cases, the spatial resolution is less than the size of most land object types, and so mixed pixels are unavoidable [10]. Remotely sensed data comprises a mix of pure and mixed pixels. When a band is measured by a sensor, the result is usually the combination of the spectra of all materials that the sensor can view. Pure pixel includes a single feature, while mixed pixel (or mixels) encompasses more than a feature. This spectral mixing take places at all scales, ranging from the microscopic scale of mineral grains, where mixing is typically non–linear, to kilometre scale land cover. Mixels is a serious issue against LULC classification, and change detection [29, 30]. Its presence makes it hard to classify crop residues, which are important for various soil–related requirements including protection of soil erosion; enhancement of soil structure; increasing organic matter content; influencing water infiltration into soil, evaporation, and temperature.

5. CPROP MONITORING

An ideal target of national early warning for food security would be to develop a methodology for monitoring vegetation crop growth, and estimating end of season crop yields [31].This is because agricultural system relies on timely and latest information on crops, for optimum production [32]. Food production will be enhanced when proper and adequate farm information and innovations are made available to farmers for efficient production [7]. Crop information is quite essential for important to crop–related decisions and including acreage estimation, crop production evaluation, and detection of disaster vulnerable crops, etc. For example, crop/vegetation index map produced regularly is essential for monitoring crop health. Information on cropping system, areal extent of crops, crop yield and crop rotation/sequence practice are important in identification of agricultural areas with low to medium productivity [31, 33]. Unfortunately, accurate and up–to–date reports of regional crop conditions, production estimates, as well as areal extents are often difficult to obtain in Nigeria as the major part of the agricultural sector, reportedly 80%, is involved in traditional farming techniques, and the methods of production estimation are archaic and rudimentary at best [32]. This method depends on the timely gathering of information through field and aerial surveys, i.e. operational systems. Remote observation from space/air– borne platforms is more effective than conventional manner of acquiring information for large–scale land coverage requiring short revisiting periods [12].

Satellite–based studies were initially applied in mining and geology, and later on, adapted for agricultural uses. While numerous studies focused on the relationship between optical properties and pigment concentration of leaves, others have focused on discrimination between plant stresses imposed by limiting water, insufficient nitrogen fertilizer, or both. Since the advent of satellites for Earth observation in the 1970s, repetitive and spatially continuous remotely sensed data have been providing valuable information on the actual status of ecosystems [34, 35], helping to detect changes in land cover[36] and to reveal trends [37, 33]. Furthermore,

GSJ: Volume 7, Issue 4, April 2019
ISSN 2320-9186

remote sensing data hold a strong potential to be used as input to models for predicting ecosystem dynamics in the varying ecological conditions [38]. Of course, this technology revolutionized the techniques of acquiring crop information, which are used to establish the condition of crops and to provide several indices for mapping cropped areas and monitoring crop yield [39]. Laboratory observations using spectrometers have shown that specific absorption features of individual dried, ground leaves may be found with a high bandwidth at 10nm or smaller. In this way, and in addition to the main absorption features caused by pigments and water, significant amount of minor absorption features were found [40]. And of course, the minor features are interrelated to concentrations of leaf macrobiotic compounds such as cellulose, lignin, protein, sugar and starch. The absorption characteristics of these organic compounds are quite weak in the range 400–2400 nm. The narrow bands are able to measure the correct characteristic absorption peaks of plant pigments and thus afford superior information connected to plant health [25].

Progress in remote sensing technology has revolutionized the methods of collecting and producing crop information since valuable information can now be provided in quick time. We can now improve efficiency and accuracy of traditional agricultural statistics and agricultural condition monitoring systems considerably. Today, satellite sensors can afford remotely sensed data in real–time concerning in–season crop phenology, soil water and drought, and other essential variables. Imaging Spectroscopy from satellites and aircrafts offers important information to evaluate the spatiotemporal changeability of plants condition with respect to local and global scales because of the powerful relations between vegetation and the optical radiation through atmospheric processes. This has led to a variety of farming and ecological significance such as leaf pigments retrieval [41], and leaf diseases early detection [42], as well as water content and chemical composition of plants, and identification of tree species [43].

6. Prospects of Agro–based Utilization of Imaging Spectroscopy in Nigeria

Various challenges which require urgent and decisive consideration both at research as well as policy levels are confronting the agricultural sector of Nigeria. The farming community requires basic understanding such as total acreage of land, the distribution of soil types over their farmland, and the location of water resources around the farm, etc [44]. Also, understanding the timing of intermittent events in the life cycle of a crop is pertinent for a variety of activities. Moreover, agricultural system relies on timely and the latest knowledge on crops, for optimum production [31]. It is equally essential to recognize and map crops so as to organize an account of spatiotemporal data of crops for predicting crop yield; acquire crop production statistics; facilitate crop rotation records; map soil productivity; detect factors that influence crop stress; evaluate crop damage from storm and droughts; delineate their size; and monitor farm activities [45]. Maps depicting crop yield is an exceptionally practical product in which its straightforwardness conceals the truth that, intricate investigation and extremely large quantity of information have been used in its creation. It clearly shows area of soaring and low yields, and comprises the foundation for regional/provincial production estimates [30]. As mentioned earlier, the traditional approach of field survey and aerial photography to obtain agricultural information in Nigeria is less effective. This is because, it is difficult to compare and validate information acquired by various organisations, which generally use different methods for appraising agricultural production. Also, estimates of production are accessible only near to harvest period. It is equally time–consuming and costly, since it requires frequent field and aerial surveys. Thus the deployment of remote sensing to obtain agricultural information is justified and recommendable.

One of the most important and recent progresses in remote sensing is the advent of imaging spectroscopy [12]. Spectral features of surfaces are the basic principles for land cover classification using remotely sensed data [13]. The larger quantity of spectral channels provides the probability to generate in–depth information about the scenery and characteristics of diverse land cover types [13]. Generally, increasing productivity by optimization of resources necessitates the current agriculture practice. Imaging Spectroscopy is a suitable alternative for revealing crop performance, water and nutrient (nitrogen) requirement of the crop, and the timely discovery of disease. The high spectral characteristics of hyperspectral data and field spectrometers, as established by the fundamental spectroscopy approaches used in laboratory investigation of organic and mineral spectra, is a plus for application to agricultural landscapes in developing the layers for modeling the response of crops management [46]. The continuous spectral response of vegetation is used to know the biochemical and structural variations among plant species, plant populations and ecosystems. The integration of the spectral information provided by spectroscopy and the spatial information provided by conventional imaging culminates to an improved knowledge on the composition and distribution of

GSJ: Volume 7, Issue 4, April 2019
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components in the product. Hyperspectral data are normally helpful when performing some complex tasks, such as minute target recognition, material identification, discrimination among very similar classes, and estimation of biochemical or geophysical parameters, for which dense sampling of the selected electromagnetic range is especially diagnostic [25].

Hyperspectral data provides a good number of rudimentary forms used in decomposing broad–bandwidths for replicating existing satellites, or determining the definite channels and widths for tuned–filter instruments [48]. Furthermore, the hyperspectral narrow band offers substantial enhancements of information content in discrimination of land cover types, and recognition of plant stress, and crop moisture disparity. Moreover, the narrow bands have the capacity to determine the exact characteristic absorption peaks of plant pigments and thus offer better information related to plant health. The use of spectrometers to appraise the reflected radiation of plants presents novel prospects to approximate imperative carbohydrates of plants [47]. The pluses of using imaging spectroscopic data encompass the selection of particular bands for indices, and the utilization of the broad spectrum of spectroscopy analyses. Laboratory and field spectroscopic approaches have proven reasonable accuracies for identifying and quantifying vegetation and soil biophysical components and have been extended to field spectrometer, airborne and satellite Imaging Spectroscopy. These spectroscopic techniques has the capacity to increase the information derived from a dense hyperspectral dataset and thus applicable for determining spectral bands useful in hyperspectral imaging spectrometers, as well as broad–band instruments, for precision agriculture production and soil management.

7. CONCLUSION

Agriculture is the most important field of production in both ancient and contemporary times, as it demonstrates a multiplier influence on the socio–economic and industrial framework of our societies. The agricultural sector of Nigeria plays significant role in food production, contributions to GDP, and provision of employment opportunities. Sustainable agriculture in general and crop production in particular could be achieved by adopting a variety of tools. For example, there are records of tremendous success in the utilization of remote sensing method in combination with conventional, as well as frontier technologies such as GIS.

Remote sensing of agriculture has shown great prospects especially in enhancing the agricultural statistics system all over the world. Studies on the use of satellite data for improving the estimator of crop yield obtained from general crop estimation surveys have become widely accepted. Imaging spectroscopy has opened a vista for acquisition of enhanced maps of model parameters by inverting the model for each pixel. Such maps provide a deeper insight into how these effects actually affect the estimation process as compared to the results obtained from one or several leaf disk(s) (each of which contains numerous pixels). It is applicable to estimate of plant moisture and nutrient status by absorption modeling and strength measurements using estimated values averaged within one or several leaf disk(s) of hyperspectral data.

Combining spectral and spatial information has been an issue addressed since the development of multiple spectral remotely sensed images. Although the spectral features revealed by multiple spectral images are actually coarse. Spectral imaging in a real sense achieves this aim by the spectral splitting technology. With dramatically increasing spatial and spectral resolution combined in a single system, Imaging Spectroscopy covers large quantity of information that it depicts the land–cover more powerfully than other remote sensing technology. And it promises the ability to classify different land object types and even subclass types. Hence it is applicable in crop related assessment.

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