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Hyperspectral Remote Sensing for Tropical Rain Forest

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Abstract: Problem statement: Sensing, mapping and monitoring the rain forest in forested regions of the world, particularly the tropics, has attracted a great deal of attention in recent years as deforestation and forest degradation account for up to 30% of anthropogenic carbon emissions and are now included in climate change negotiations. **Approach:** We reviewed the potential for air and spaceborne hyperspectral sensing to identify and map individual tree species measure carbon stocks, specifically Aboveground Biomass (AGB) and provide an overview of a range of approaches that have been developed and used to map tropical rain forest across a diverse set of conditions and geographic areas. We provided a summary of air and spaceborne hyperspectral remote sensing measurements relevant to mapping the tropical forest and assess the relative merits and limitations of each. We then provided an overview of modern techniques of mapping the tropical forest based on species discrimination, leaf chlorophyll content, estimating aboveground forest productivity and monitoring forest health. **Results:** The challenges in hyperspectral Imaging of tropical forests is thrown out to researchers in such field as to come with the latest techniques of image processing and improved mapping resolution leading towards higher precision mapping accuracy. Some research results from an airborne hyperspectral imaging over Bukit Nanas forest reserve was shared implicating high potential of such very high resolution imaging techniques for tropical mixed dipterocarp forest inventory and mapping for species discrimination, aboveground forest productivity, leaf chlorophyll content and carbon mapping. **Conclusion/Recommendations:** We concluded that while spaceborne hyperspectral remote sensing has often been discounted as inadequate for the task, attempts to map with airborne sensors are still insufficient in tropical developing countries like Malaysia. However, we demonstrated this with a case study focused on a mixed hill dipterocarp forest in Kuala Lumpur, Malaysia and discuss the work in the context of reducing uncertainty for carbon monitoring and markets.

Key words: Airbone, spaceborne, hyperspectral, remote sensing, tropical mixed hill dipterocarp forest

INTRODUCTION

Tropical rain forests represent some of the most biological diverse, structurally complex ecosystem on Earth. The identification of tree species is a key element in the definition of habitats of key fauna that use specific trees for food and shelter. Remote sensing is beginning to play amore active role in efforts to detect, monitor and manage forests. Monitoring forest health and stress from remotely sensed images is of concern for forest management. The art monitoring system aimed at forest tree species identification using airborne and the spaceborne sensors are potentially key tools for the development of sustainable development policies. Spectrally continuous hyperspectral remote sensing data can provide information on forest biochemical contents, which are important for study vegetation stress, nutrient cycling, productivity and species recognition etc. Remote sensing measurements have the potential to provide a cost effective means to examine the complexity of forest and generalize findings from plot scale. Broad band measurements collected by satellite sensors such as SPOT HRV and Landsat TM can be used to distinguished broad groups of communities level different stages of succession, but lack the capability to perform identification of individual species. The introduction of hyperspectral sensors which produce much more complex data and provide much enhanced abilities to extract useful information from conventional data stream. However, it is also demand more complex and sophisticated data analysis procedures of their full potential to be achieved.

Species discrimination: The discriminating forest species using hyperspectral indices at leaf and canopy scales study done by Cho *et al*.[3]. They used a few hyperspectral indices evaluated in the study included

Normalised Difference Vegetation Indices (NDVI), Carter Index (CI), Vogelmen index (VOG), Gitelson and Merzylak Index (GMI), Photochemical Reflectance Index (PRI), Carotenoid Reflectance Index (CRI) and Red Edge Position (REP). Among these indices, Red-Edge Positions (REPs) extracted by the linear extrapolation I method were least sensitive to the change in measurement scale. With respect to species discrimination, the canopy indices were better discriminators then the leaf indices. They suggested this is for air- or spaceborne remote sensing of species assemblages. However the Photochemical Reflectance Index (PRI) showed the highest potential to discriminate species at the canopy scale, while the linear extrapolation REPs showed the highest potential to discriminate the same species pairs at both scales. Generally the spectral indices are sensitive to the change in scale of spectral measurement from the leaf to canopy. Differences between leaf and canopy indices appear to affect the ability of the spectral indices to differentiate species at both levels. The canopy indices were better discriminators of species than leaf indices. Even though, the PRI showed the highest potential to discriminate species at the canopy scale. But the REP in general showed the highest potential to discriminate the same species pairs at both scales. The Hyperspectral indices might provide new possibilities of differentiating plant species or communities.

Earlier, Helmi-Zulhaidi *et al*.[5] used HyMap to extract REP using Linear and Lagrangian approaches of classifying vegetation species. They found, both approaches generated similar results in extracting coniferous and broadleaved species, but different in estimating grassland. This could be due to the Lagrangian technique more accurate of it sensitivity to soil background reflectance effects. The broadleaved tress can be distinguished from the coniferous by consider their REP. They also noted that different ages of the coniferous trees can be distinguished easily by consider the wavelength of their REP. These led the potential application of hyperspectral remote sensing and red edge position analysis for detecting different vegetation types and ages in forested area.

A comparison study of different altitude and classification methods by Salvatori *et al*.[8] using Multi Infrared Visible Imaging Spectrometer (MIVIS) showed that the Maximum Likelihood (ML) provides better distinction compared to Spectral Angle Mapper (SAM) algorithms. However, visual inspection of classified images showed that the different spatial distributions of forests formations depend on image spatial resolution. The spectral signature of each landscape unit is not only functions of the specific plant species but also depends on the surface morphology and these parameters become most important as target-sensor distance decrease. The standard deviation is statistically significant only in near-infrared region. This trend is related to the regular spatial model distribution trees, infect the regular interaction among plant-soil-plant homogeneously influences canopy reflectance, although pixel size increase.

Leaf chlorophyll content: Developments in hyperspectral remote sensing have provided new indices or indicators of biochemical and biophysical properties. Recent hyperspectral remote sensing allows retrieving the C_{ab} concentration of vegetation using appropriate optical indices[7]. A new optical index named Area under curve Normalised to maximal Band depth between 650-725 nm ($ANMB_{650-725}$) is proposed to estimate the chlorophyll content of a Norway spruce (Picea abies L. Karst) crown. $ANMB_{650-725}$ is based on the reflectance continuum removal of the chlorophyll absorption feature between wavelengths of 650-725 nm. Suitability of index and sensitivity on disturbing factors was tested using a 3D Discrete Anisotropic Radiative Transfer (DART) model coupled with a leaf radiative transfer model PROSPECT adjusted for spruce needles. The results of the $ANMB_{650-725}$ abilities within a coniferous forest canopy were compared with the performance of the chlorophyll indices ratio TCARI/OSAVI. Test results, carried out with the DART model simulating hyperspectral data with 0.9 m pixel size, showed a strong linear regression of the $ANMB_{650-725}$ on spruce crown C_{ab} concentration ($R^2 = 0.9798$) and its quite strong.

It has been proven earlier by Cho and Skidmore[2], the REP is affected by biochemical and biophysical parameters has been used to estimate foliar chlorophyll or nitrogen content. The extracting REP from hyperspectral data, to mitigate the discontinuity in the relationship between the REP and the nitrogen content by the extensive of a double-peak on the derivative spectrum. Based on a linear extrapolation of straight lines on far-red (680-700 nm) and NIR (725-760 nm) flaks of the derivative spectrum. The REP defined by the wavelength value at the interception of the two lines. The output is a REP equation, $REP = -(c_1-c_2)/(m_1-m_2)$, where c_1 and c_2 and m_1 and m_2 represent the intercepts and slopes of the far-red and NIR lines, respectively. Far-red wavebands at 679.65 and 694.30 nm in combination with NIR wavebands at 732.46 and 760.41 nm were identified as the potential combinations for calculating nitrogen-sensitive REPs for spectral data set.

Estimating aboveground forest productivity: A number of field studies across diverse biomes have documented strong linkages among foliar chemistry, particularly nitrogen concentration on a mass basis and rates of net photosynthesis and soil N availability. These results are indicative of the tightly coupled nature of C and N dynamics in N-limited systems and suggest that foliar N concentration could provide a useful indicator of ecosystem productivity. The remote sensing of foliar chemistry has been generally restricted to small experimental areas. While the use of high-spectral-resolution reflectance methods for the direct measurement of nitrogen, lignin, cellulose and other chemical constituents of foliage has become an accepted laboratory technique. The application of a single calibration equation across multiple contiguous images covering a large, forested landscape has not been achieved[9].

Smith *et al*.[9] noted that from analysis of AVIRIS spectral data focused primary on whole-canopy N concentration, it was the strongest linear correlate of productivity across the forest types. In aggregate, AVIRIS predicted values for independent productivity data show good agreement with measured values (R^2 = 0.86, SEE = 31.42 gm^{-2} $year^{-1}$) and predicted values fall well within the observed precision with wood production can be measured at the stand level (SEE = 38.31 gm^{-2} $year^{-1}$). This initial effort does demonstrate the potential of hyperspecytal image data to detect with reasonable accuracy and precision important components of forest ecosystem function across a large and heterogeneous landscape.

A comparison between AVIRIS and AISA airborne hyperspectral imagery was done to map above-ground forest carbon in Canada by Goodenough *et al*.[4]. They noted that biomass obtained from AVIRIS hyperspectral data agreed with ground measurements of biomass with an r^2 of 0.90. The AISA with its higher spectral and spatial resolution offers the potential to separate ground cover (*salal*-a broad-leafed bush) from the forest overstory. The *salal* can have high reflectance of 80% at 800 nm. This give the accurate map forest biomass, because it is important to identify the understory and stratify the forests by understory type. For the AISA and AVIRIS comparisons, spectral relationships were established between the AISA (adjusted to AVIRIS spectral and spatial resolution) and AVIRIS sensors for selected calibration targets. This between sensor calibrations placed the AISA data on the same calibration basis as the AVIRIS data. The calibrated reflectance data were used to generate forest species classifications, end member fractions and biomass estimates for the test site. Average classification accuracies exceeded 89% in mapping major forest species. These products were used to create a map of above-ground carbon for the forested portion of the test site.

Asner and Vitousek[1] used airborne imaging spectroscopy and radiative transfer modeling to detect the nitrogen-fixing tree in a Hawaiian forest. That study also highlighted the difficulty of detecting smaller patches and sub-pixel cover fractions in the forest. A subsequent bottom-up analysis of the spectral separability of trees in Hawaii showed that the invasive tree species and many others, are systematically unique from most native species. However, that study recorded spectral signatures from only the largest tree crowns and under constant illumination conditions. Further analyses showed that shadows, terrain and non-photosynthetic vegetation caused great uncertainty in any top-down mapping efforts. In response to these substantial limitations and the continuing need for more robust invasive species maps for conservation and management of Hawaiian forests and deployed a new hybrid airborne remote sensing system combining LiDAR and imaging spectroscopy to map the three-dimensional spectral and structural properties of Hawaiian forests. The spectral and LiDAR data were fully integrated using new in-flight and post-flight fusion techniques, facilitating an analysis of forest canopy properties that best determine the presence and abundance of invasive tree species in Hawaiian rainforests. In this first study, we limited our approach by using spectral endmember bundles derived from canopies of known species within each image. This approach worked well, allowing for the mapping of each invasive tree with relatively high accuracy. Indeed, our field evaluation studies showed b6.8and b18.6% error rates in the detection of invasive tree species at 7 and 2 m^2 canopy cover thresholds in a very densely populated rainforest environment. However, the next test of the approach will involve combining species-specific bundles for application across an ensemble of hyperspectral images containing many more native and invasive trees. Until then, our current results show that the integration of imaging spectroscopy and LiDAR remote sensing sensors and measurements provide enormous flexibility and analytical potential for studies of invasive species and biodiversity in tropical forest ecosystems.

Monitoring forest health: The significant different of vegetation reflectance at the red portion of the spectra can be used to predict vegetation conditions.

Laudien *et al*.[6] reported that airborne and field based multispectral hyperspectral remote sensing using Vegetation Indices (VI) can detect the plant vitalities instead of common multispectral. The deterioration of fine root precedes the expression of canopy; hyperspectral imaging may be a useful tool for identifying the early stages of decline complex of the vegetation[10]. Smith *et al*.[10] evaluated a number of algorithms by Kodak's hyperspectral group to maximize detection of tree decline including maximum likelihood classification, spectral angle matching, spectral mixture analysis, multi-layer feed forward neural network and linear Finite Impulse Response (FIR) filters. They confirmed that FIR filter achieved an accuracy of better than 83% to detect a class defined by loblolly pine with both previsual and visual decline. Hyperspectral measurements were required to detect and map Ares of loblolly decline. Attempts to reduce the spectral resolution resulted in significantly lower classification accuracies. They postulated that the forest stand component (healthy needles, chlorotic needles, cones, branches and bark) controlled largely by the crown geometry.

Challenges in hyperspectral imaging of tropical forests: Hyperspectral remote sensing of ecosystem is not a new, a large number of studies have focused on a range of ecosystem properties and processes over the years. On the other hand, airborne and space-based hyperspectral remote sensing of tropical forests is still very new, with only a few studies recently published. These efforts highlight the potential contribution of imaging spectroscopy to studies of tropical forest biochemistry, physiology and diversity. The hyperspectral remote sensing can serve as an interactive, exploratory tool for probing tropical forests, allowing for both new and improved knowledge about their structure and function. However numerous challenges remain, including issues of sensor design and accuracy, algorithm development and even the very basic of tropical forest ecology and taxanomy.

Imaging spectrometer design is a key issue in the quest for more quantitative approaches to remote sensing. Some spectrometer operates only in the visible and near-IR (400-1100 nm), other full-range instruments (400-2500 nm). Applied to tropical forests, visible-NIR spectrometer provide access to pigment, water and some nitrogen chemistry. Full-range systems extend this capability to include leaf water, protein-N and some carbon constituents. The engineering issues have a direct impact on the precision and accuracy of any biochemical, physiological or diversity product derived from hyperspectral imagery.

The basic know-how for hyperspectral analysis of ecosystem is also involving, but much progress is yet to be made the full potential of high-fidelity imaging spectroscopy. A good example of this problem can be found by further considering tropical forest physiognomy with respect to hyperspectral reflectance signatures. The most direct measurement of tropical rain forests should be those made at sufficiently high spatial resolution and may lay in the fusion of hyperspectral and structural measurements approaches.

CONCLUSION

The hyperspectral imaging was shown to be a considerable technique to identify individual species, provide new indices or indicators of biochemical and biophysical properties and estimate aboveground forest productivity in the tropical rainforest. More analysis needs to be done to evaluate the most sensitive wavebands to identify different tropical timber and non-timber species in addition to the sub-pixel classifications from airborne and satellite images.

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