

A REVIEW ON APPLICATION OF HYPERSPECTRAL IMAGING TO FOREST RESOURCES IN MALAYSIA

MOHD HASMADI ISMAIL^{1*}, KAMARUZAMAN JUSOFF², ALIAS MOHD SOOD¹,
PAKHRIZAD HASSAN ZAKI¹ AND MANOHAR MARIAPAN¹

¹Centre for Tropical Forest Airborne Observatory (TropAir), Faculty of Forestry, Universiti Putra Malaysia, 43400 UPM, Selangor, Malaysia and ²Yale University, School of Forestry and Environmental Studies, 205 Prospect St, New Haven, CT 06511, USA.

* Corresponding author email address: mhasmadi@putra.upm.edu.my

Abstract: Remote sensing application of hyperspectral imaging is relatively new to Malaysian forestry. Through a wide range of wavelengths of hyperspectral data, precise and narrow bands of spectra are captured. Airborne sensors typically offer greatly enhanced spatial and spectral resolution compared to their satellite counterparts, and are able to control experimental design closely during image acquisition. Hyperspectral imaging for forest inventory in Malaysia was first conducted by The Centre for Precision Agriculture and Bioresource Remote Sensing of Institute of Bioscience, Universiti Putra Malaysia (UPM). This study which was conducted in 2001 used the ISA sensor manufactured in Finland. The main objective was develop methods that are directly suited for practical tropical forestry application at high level of accuracy. Forest inventory and tree classification including development of single spectral signatures of important interest. Studies have shown that retrieval of timber volume and tree discrimination using this system is successful and some is often better than other remote sensing methods. This article reviews the research and application of airborne hyperspectral remote sensing for forest survey and assessment in Malaysia.

KEYWORDS: Hyperspectral imaging, forest resources, research and application

Introduction

Forest land covers a large area of the earth surface and significantly influenced economic, social and environments needs. In 2000, the total area of tropical rain forest in Malaysia was only 58.7% of the total land area of 32,855,000 ha (FAO, 2005). However, they remain as a large proportion of tropical biodiversity in the world. In tropical forest management, information on tree composition, species richness and forest structure are greatly hindered by the lack of intensive information either spatially and temporally. Most of the available data were collected from small field plots with infrequent re-sampling interval. Forest covers were derived by foresters using field and aerial surveys where the area measured reflect the extent of national forest covers. It is difficult to understand the process of forest landscape at regional and global scale generated based on such field data (Foody, 2003). To overcome the inconsistency in the survey of forest cover information, DeFries and Belward, (2000) emphasized the need for a more consistent use of remote sensing technology to adjust and update forest cover estimates.

Existing literature on the application of satellite remote sensing to Malaysian tropical forests are principally focused on the change detection in land cover such as deforestation, monitoring changes, whereas in other objectives are to improve land cover maps that may serve a basic to further specific applications (Kamaruzaman and Souza 1997; Mohd. Hasmadi and Kamaruzaman, 1999). LANDSAT and SPOT imageries have been the most commonly applied.

These imageries generally provide a clear boundary between forest and non forest cover types and allow manual and semi automated interpretation (Achard et al., 2002). In addition with a moderate cost, a rational globally data acquisition policy (Arvidsen et al., 2001) and a spatial resolution of 30 meter for six optical bands can be used to detect changes in canopy condition. However they still produce images with a few relatively broad wavelength bands. On the other hand hyperspectral remotely sensed images are generate data by collecting simultaneously in dozen or hundreds of narrow and adjacent spectral band. The complete reflectance wavelengths make it possible to derive continuous spectra for each cell in the region viewed by the devices.

The development of remote sensing in Malaysia has changed from the panchromatic and multispectral satellite system to the airborne hyperspectral sensing technology. Similarly to other remote sensing system, hyperspectral is better than the conventional multi-spectral data as data can be acquired anywhere and anytime on daylight prior to user request. Data can also be provided year round temporal data or near real time, and data available with unique capabilities as well as potential to discriminate physical and chemical properties of land surface features which is not possible using current broad band multispectral data. Thus, new technology provided by the hyperspectral imaging system can improve the quality of Malaysia forest information especially for use in precision forestry and environmental monitoring and assessment. This article reviews the application of airborne hyperspectral remote sensing for forest survey and assessment in Malaysia.

Early Studies and Development

Hyperspectral imagery is as a single image dataset with a continuous spectrum of radiance (or reflectance) values associated with each image pixel (Bateson and Curtiss, 1996). Research and development of hyperspectral imaging has been actively carried out in the European during the past decade. The advancement in sensor development, hyperspectral imaging offers a wealth of data, but it demand a better understanding of the characteristic and in interpretation and digital processing technique. On the other hand, interpreting the imageries need an exact knowledge of what object and properties under investigation are being measured, and how the recorded properties relates to the measurement by the hyperspectral instruments.

At the early stage hyperspectral images are only available to researchers. Currently, commercial airborne hyperspectral imaging system is commonly used by the remote sensing communities. In resources management it plays an important role and is widely used in a large number of application such as forestry, agriculture, mineral exploitation and environmental monitoring although the advanced device technology of hyperspectral imaging contain a wealth of data, it requires a better understanding of the characteristic and its limitation of the images, and effective strategies in digital processing and interpretation technique.

The increased need and demand for accurate data in forestry survey and management especially in species classification was encouraged the development of the hyperspectral sensor in Malaysia. The high spectral and spatial resolution of sensor like AISA offers precision classification of tree species within a forest which enable user to identify record and up date a vast forest resource (Mohd. Hasmadi et al., 2007). In Malaysia, the pioneer study and user of the AISA sensor technology is Centre for Precision Agriculture and Bioresource Remote Sensing of Institute of Bioscience, Universiti Putra Malaysia (UPM) in 2001. Later on in 2002 collaborative research and business has been set up with private company and then the centre was known as Aeroscan Precision (M) Sdn. Bhd (UPM-APSB). UPM-APSB'S AISA airborne hyperspectral system is a commercial hyperspectral sensor product that was manufactured by

Finnish Company Specim Ltd. and is operated by the Forest Geospatial Information & Survey Laboratory-Aeroscan Precision (M) Sdn. Bhd. in Universiti Putra Malaysia. The next step is the establishment of Centre for Tropical Forest Airborne (TropAir) by UPM in June 2008. The centre is operated by The Faculty of Forestry, UPM. The mission of TropAir is to provide a physical and intellectual focus for interdisciplinary research on the development and application of airborne hyperspectral remote sensing in tropical forest, natural resource management and environmental monitoring.

In brief, this sensor consists four main parts including a hyperspectral sensor front-end head, an integrated miniature of GPS with Inertial Navigation Systems (INS), data acquisition unit and post-processing (Caligeo software). With the integrated GPS-INS, the emitted energy from the ground to the airborne sensor can be most determined with an accuracy less than 1m or better. The uniqueness of the sensor is 'on demand' data collection, high spatial and spectral resolutions, near real-time processing of images, airborne Differential Global Positioning System (DGPS) navigation of imagery (no ground control points required), first generation geo-referenced images, radiometrically and geometrically corrected data and "GIS data ready" (Kamaruzaman, 2004). The some typical technical characteristics of the UPM-APSB'S AISA sensor are as follows:

Name	: AISA
Spectral Range(μm)	: 430 to 900
Number of Band	: 288
Spectral Interval (nm)	: 2.9
FOV (degree)	: 200
Manufacturer	: SPECIM, Finland
Application Developer	: UPM-Aeroscan Precision (M) Sdn Bhd (APSB)
Weight	: 15 kg
Available Date	: 2001

Current operational collection configurations range from 10 to 70 spectral bands where largely depends on the aircraft speed, altitude and mission goal. High spatial-resolution hyperspectral images were acquired with the AISA sensor at altitude of approximately 1000 meters, with spatial resolution was 1 m. Image processing improved the image quality. Mounted in a small airplane the sensor can be flown over and 'capture' specific land parcel at varying altitudes to produce spatial and temporal resolution. With unlimited data capture, users now can conduct hyperspectral image processing by selecting band combination from hundreds spectral regions to their specific application.

Since July 2004 to December 2006, UPM-APSB has conducted research and development by specializing in the use of airborne hyperspectral sensor in developing precision forest management. With the pixel size of 1 m by 1 m at a flight altitude of 1000 m above the sea level, the images generated can be used as a source of geospatial data and information for rapid forest resources inventory and management. Several field trials were conducted in the lowland hill dipterocarp, mountain mixed dipterocarp as well as mangrove forest. Airborne hyperspectral digital data were captured, processed and analysed. A handheld field Spectroradiometer was used to "scan" spectral reflectance measurement of timber tree species to verify the airborne digital data signatures.

Hyperspectral Discrimination on Tropical Tree Species

Detailed forest parameters such as species type, quantity, density, age, height, site index, and canopy closure, were obtained from ground forest survey. These data were measured from temporary and permanent sample plots. The accuracies of the forest inventory database can be improved by using accurate forest species maps produced by classifications of hyperspectral remote sensing data (Goodenough et al., 2002). By using a large number of contiguous bands, hyperspectral data characterize important diagnostic signatures in reflectance, establishing a basis for plant species identification (Hirano et al., 2003).

The two initial studies conducted in 2004 motivated further investigations based on the idea that airborne hyperspectral data could be used to survey large areas and improve forest tree species discrimination. The first research was conducted at the Berangkat Forest Reserve in Kelantan, Peninsular Malaysia. The study produced the first detailed individual tree mapping of tropical forest in Malaysia. A spectral library data base developed from this work was used as primary references to species identification for another related projects (Kamaruzaman, 2006). Spectral angle mapper (SAM) technique was used for classification approach. SAM is a spectral matching technique (Kruse et al., 1993). The individual tropical tree species is possible and enough to resolve the early stage of research by UPM-APSB to measure pertinent discrimination spectral features from 500 to 600 nm through this project with mapping accuracy more than 90%.

The selected dominant family spectral curve of ten species in block 53 of Berangkat Forest Reserve generating from the image is shown in Figure 1. The species were Jelutong, Kedondong, Kelat, Medang Daun Besar, Rengas, Penarahan, Kedondong Kangkong, Meranti Tembaga dan Minyak Beruk. This result depicts the hyperspectral data exhibit minimum spectra of tree in term of magnitude in the visible wavelength, especially the band between 500nm and 600 nm. It should be noted that the minimal variability in a spectra curve is relative to the mean and may indicate much differentiation in infrared wavelength between 759 nm and 850 nm due to internal structure of the crown (Stone et al., 2001).

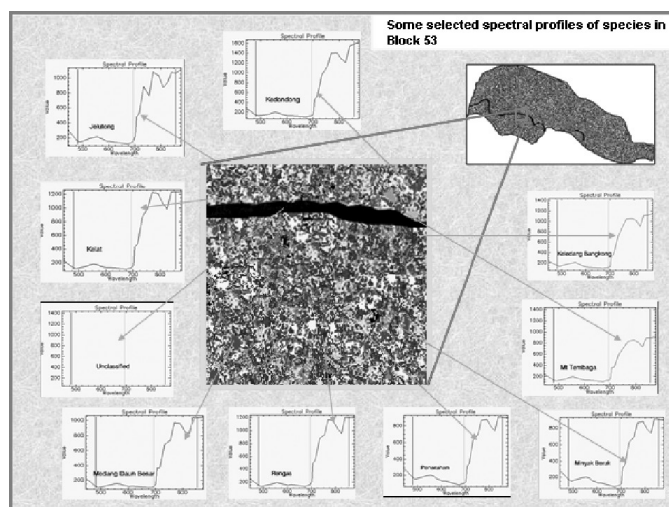


Figure 1. Spectral curves of some individual dominant tropical tree from UPM-APSB AISA hyperspectral sensor (source: Kamaruzaman, 2006)

In 2005 a pilot study was carried out at the 2 ha Bukit Bujang old growth forest plot area at the Forest Research Institute Malaysia (FRIM). The forest was confined with a mixed species plot comprising 16 tree species from dipterocarps and non-dipterocarps. An airborne hyperspectral data covering 430nm to 900nm with 1 m spatial resolution was obtained in May 2005. The main objective of the study was to evaluate the discriminative capabilities in terms of the spectral separability among tropical tree species (Affendi et al., 2005). The first derivative transformation was used to calculate numerical derivation of the original spectrum with respect to the wavelength and use them to detect the absorption band positions of the spectrum. Figure 2 shows a false color composite (FCC) image from the spectrally enhanced first derivative data set using band 13,11,9 (R,G,B) in the mixed forest plot. However, for overall accuracy this study indicated that only 70% accuracy was achieved which is not as expected from the hyperspectral imaging. The first derivative transformation is not enough to identify individual tree species in this study.

Another study was conducted by Wafiah (2007), on the distribution of the tree species in Gunung Stong Forest Reserve, Kelantan. The study was able to identify, map and tag individual trees in Gunung Stong Forest Reserve. Fifteen (15) tree species were identified and mapped in the 1 ha study area with an accuracy of 89.66%.

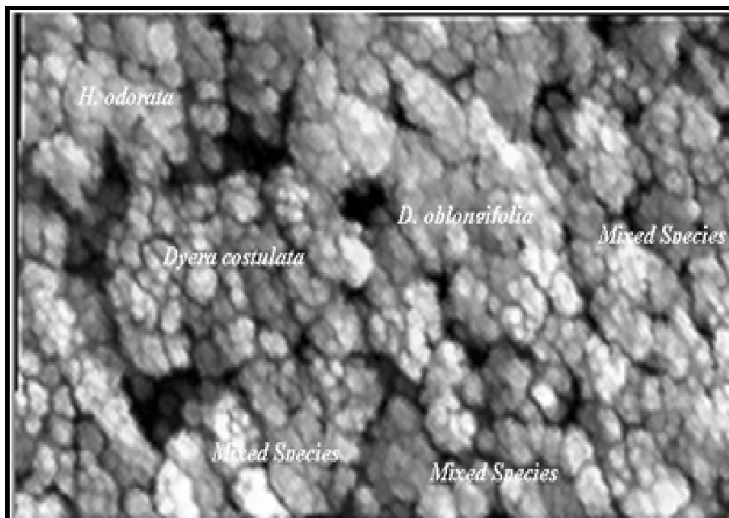


Figure 2. FCC image Band 13-11-9 (R-G-B) over the old growth forest plot
(source: Affendi et al., 2005)

Generally, the estimation of standing timber volume is difficult as ground survey is expensive due to time involved in data collection. However, Kamaruzaman (2008) stated that the use of airborne remote sensing could change the way on how tree mapping and standing timber volume estimation are done. He conducted a pilot study to estimate *Acacia mangium* plantation's standing timber volume on 0.8 ha. in Lebu Silikon UPM. The total standing timber volume mapped and quantified by the sensor was about 20.73 m³ with a mapping accuracy of 80%. In practice, users of airborne hyperspectral data can now predict the timber volume by measuring tree crown size using remote sensing software and apply the appropriate equation developed from linear regression as an indirect method of timber volume estimation.

Mangrove Species Identification and Mapping

Spectral features of vegetation are closely related to physical properties of leaves and stems of trees. Those features give strong spectral reflectance and absorption in VNIR and SWIR regions. Some researchers have reported the possibilities of mangrove mapping using those spectral features derived from satellite data (Kotera, 1997). A tremendous effort has been made in the last few decades to manage wetland and coastal area by using satellite imageries. Satellite imagery has been used to map and assess vast coastal areas such as mangroves (Aschbacher et al., 1995; Ravan and Roy, 1997 and Ramachandran et al., 1998). However, the coarse resolution of these data sources rarely allows identification at the species or generic level, or the typology of assemblages necessary to detect changes within a mangrove forest (Mohd Norisham, 2003).

A study using hyperspectral data on mangrove has been conducted in Port Klang in Malaysia, specifically at Klang River and Northport of Klang (Kamaruzaman, 2006). The area lies between latitudes 2°59'24" N-2°59'12" N and longitudes 101°22'36" E-101°23'12" E. The mangrove area comprises of three major families of mangrove species (*Avicenniaceae*, *Rhizophoraceae*, and *Sonneratiaceae*). The study identified species group of mangrove and the wavelength regions that defines the inherent spectral curve between each mangrove species of the mangroves.

A total of 19 samples of mangrove trees were randomly selected for this study. The mangrove species randomly selected comprised of *Rhizophora mucronata* (Bakau Kurap), *R. stylosa* (Bakau), *R. apiculata* (Bakau Minyak), *Bruguiera parviflora* (Lenggadai), *B. gymnorrhiza* (Tumu), *B. cylindrical* (Bakau Putih), *Sonneratia caseolaris* (Berembang), *S. alba* (Perepat), *Lumnitzera littorea* (Teruntum Merah) and *Avicennia officinalis* (Api-api Ludat). The hyperspectral data were acquired by Forest Geospatial Information & Survey Lab./Aeroscan Precision (M) Sdn. Bhd. from 18-19 February 2004. The UPM-APSB's AISA hyperspectral data presented here are only from five flight lines covered from an overall total of 20 including the UPM-APSB's AISA data for mangrove forests in Port Klang (Kamaruzaman, 2006).

The spectral libraries for the 19 randomly selected mangrove species at Port Klang were developed from image using the ENVI software and also from the field with an aid of a handheld spectroradiometer. From the 19 samples that were randomly selected, mangrove species can easily be identified and divided into nine species and some of the species are as shown in Figure 3. Through the VIS light region (650-680 nm), the mangroves have very low spectral reflectance in the blue and red, with the exception of small rise in the green band. The spectral profiles for nine species from 19 selected trees showed different spectral profile and wavelength absorption because each tree species emitted or radiated varying VIS and NIR light at different wavelength range.

In this study, we found that each mangrove species were characterized by a unique spectral signature which differs from one species to another. Therefore, varying spectral patterns were observed from the nine different mangrove species identified and mapped in Port Klang. A total of 10 of tree species were registered in the NIR region approximately at 700-900 nm wavelengths region. These include families from *Rhizophora*, *Avicennia* and *Sonneratia*. In the electromagnetic spectrum of 450-700 nm, the spectral profiles appeared similar which implied that the mangroves are difficult to be separated and identified in the VIS range of the spectrum. However, in the NIR region of the spectrum, the spectral profiles can be separated from each other. Simillar trend for 15 different urban tree species were recorded in the UPM Arboretum and Wetland Park, Putrajaya (Holmgren and Thuresson, 1998; Mohd Norisham, 2003).

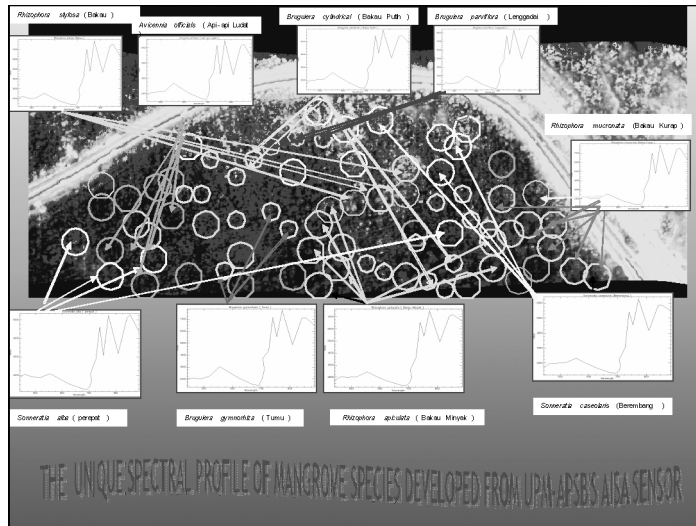


Figure 3. Image spectral of individual mangrove species in Port Klang area using hyperspectral data (source: Kamaruzaman, 2006)

Specifically spectral reflectance curves of the nine mangrove species can be separated at the NIR range covering from 450-900 nm wavelength bands with a spectrum range of 1,625-8,250 nm. Those group were easily identified and mapped with the spectrum values of 700-900 nm wavelength, eg. 1,750-6,000 nm (*Bruguiera cylindrica*), 2,000-7,750 nm (*B. gymnorhiza*), 1,875-8,250 nm (*B. parviflora*), 875-5,500 nm (*Avicennia officinalis*), 1,625-6,250 nm (*Sonneratia caseolaris*), 1,875-5,250 nm (*S. alba*), 1,750-7,500 nm (*Rhizophora apiculata*), 2,200-7,000 nm (*R. stylosa*) and 1,875-7,750 nm (*R. mucronata*). These results encourage further studies on the different mangrove species available in other areas in Malaysia in order to develop more profiles for the other species. This will help in building inventory of mangroves in Malaysia.

Non wood forest product

Malaysia is a heavily forested country. Non forest product such as bamboo is ranked as the second important source of income after rattan. Malaysian bamboos grow wild in the natural forest and is also cultivated by villagers in rural areas (Roslind, 2004). Azmy and Abd Razak (1991) noted that, there are 12 bamboo species commonly used for commercial purposes. The most common species are *Gigantochloa scortechinii*, *G. levis*, *G. ligulata*, *Dendrocalamus asper*, *Bambusa blumeana*, *Scizostachyum grande* and *S. zollingeri*.

The assessment and mapping of bamboo distribution is necessary for the development of bamboo product. Hyperspectral also been used in investigating non wood forest product such as bamboo mapping. Identification of bamboo in natural forest has been carried out in Kelantan, Peninsular Malaysia (Koh, 2006). Using False Color Composite 25-14-2 (R-G-B) image was enhance using Sobel filter (3 x 3 of size) and then bamboo was identified and classified using SAM technique. The SAM algorithm determines the spectral similarity between two spectra by calculating the angle between the spectra, then treating them as vectors in space with dimensionality equal to the number of bands. The end-member of bamboo spectra come from spectral library, which was taken from ground sampling.

Figure 4 shows the location of bamboo identified in the study area using SAM technique. The post classification was carried out to group the cluster into clump. Clump classes and morphological operator was used to group adjacent classified pixel. Figure 4 (bottom) shows the result of the post classification after using clumping and sieving process. The bamboo species identified from this study is *Gigantochloa scortechinii*. The estimate area of bamboo coverage was 2.12 hectare, with the culms was 4009 and mapping accuracy of 60%.

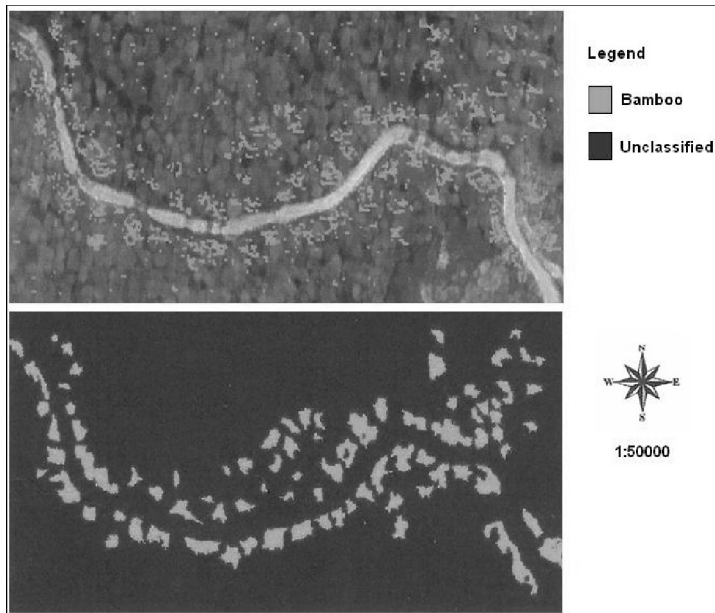


Figure 4. Bamboo identified using SAM technique (top) and bamboo clustered after post classification process (bottom) (source: Koh 2006)

Conclusion

Hyperspectral data in Malaysia is in its infancy but there are numerous opportunities for adoption. The bigger picture for the full operationalised will take some time due to some problem especially high cost and lack of human expertise. Therefore, support from the governments and the private sector during the initial stages of adoption are vital. The adoption of the technology also depends on product reliability and ability to show the benefits. Based on the little experience in Malaysian, there seem to be a significant contribution of airborne hyperspectral for forest survey and assessment. The early benefit of the data is the procedure based on hyperspectral data with less ground sampling but high in mapping accuracy. However, further development, improvement, testing and refinement are needed although the preliminary work presented here indicate superior precision to that of conventional sensing data. It is also important to assess systematically the effects of the varying flying altitude and sampling density to the accuracy, especially when dealing with large area.

This paper has shown that the airborne hyperspectral data has a potential to be implemented in Malaysia. Despite promising result obtained on species identification, ground sampling is needed to provide precise single tree discrimination in tropical forest due to multispecies stand and multi storey structures. Moreover, the tree communities are

characterized by high diversity and relative rarity of individual species at closest space. Thus, large image extents are needed to find representative training sample to use as reference subject. Species discrimination by hyperspectral data enables researchers to improve the quality of image classification or data extraction in which would improve sustainable forest management. Hyperspectral remote sensing has also enhanced the demand of its applications in resources inventory and environmental monitoring. In the near future research and application development could be extended to new fields of importance to forest–ecosystem management such as biodiversity and bioresource assessment and accounting.

References

- Aschbacher, J., Ofren, R., Delsol, J-P., Suselo, T.B., Vibulstresh, S. and Charrupatt, T. (1995). An Integrated Comparative Approach to Mangrove Vegetation Mapping Using Advanced Remote Sensing and GIS Technologies; Preliminary Results. *Hydrobiologia*, 295: 285-294.
- Achard, F., Hugh, D and Hans, J.S. (2002). Determination of Deforestation Rates of the World's Humid Tropical Forest. *Science*, 297: 999-1002.
- Affendi, S., Ainuddin, N.A, Awang Noor, A.G, and Faridah Hanum, I. (2005). Optimized Selection of Hyperspectral Bandsets for Mapping of Tropical Timber Trees using Hyperspectral Imaging Sensors. 14th Malaysian Forestry Conference, Kota Kinabalu, Sabah, 12-16 Sept., Malaysia 2005.
- Arvidsen, T., Johd, G. And Samule, G. (2001). Landsat 7's long term acquisition plan-An innovative approach to building a global imagery archive. *Remote Sensing of Environment*, 78: 13-26. 16.
- Azmy, H. M and Abd Razak, O. (1991). Field Identification of 12 Commercial Malaysian Bamboos. FRIM Technical Information, no.25, Kuala Lumpur.
- Bateson, A. and Curtiss, B. (1996). A Method for Manual Endmember Selection and Spectral Unmixing. *Remote Sensing of the Environment*, 55:229-243.
- DeFries, R.S. Belward, A. S. (2000). Global and Regional Land Cover Characterization from Satellite Data: An Introduction to the Special Issue. *Int. Journal of Remote Sensing*, 21: 1083–1092.
- FAO (2005). State of the World's Forests 2005. FAO, Rome, Italy.
- Foody, G. M. (2003). Remote Sensing of Tropical Forest Environments: Towards the Monitoring of Environmental Resources for Sustainable Development. *Int. Journal of Remote Sensing*, 24(20): 4035–4046.
- Goodenough, D. G., Andrew Dyk, K, Sarah McDonald and Greg, W. (2002). Monitoring Forests with Hyperion and ALI. Proceeding IGARSS 2002, Toronto, Canada.
- Hirano, A., Marguerite, M and Roy, W. (2003). Hyperspectral Image Data for Mapping Wetland Vegetation. *Wetlands*, 23: 436-448.
- Holmgren, P. K. and Thuresson, T. T. (1998). Satellite Remote Sensing for Forestry Planning. *Journal of Forestry Research*, 13: 90-110.
- Kamaruzaman, J. (2004). The Potential of Utilizing Remotely Sensed Data for Integrated Coastal Management with Special Emphasis on Airborne Imaging Spectrometry. Paper Presented at KUSTEM 3rd Annual Seminar on Sustainability Science and Management, 4-5 May, Malaysia.
- Kamaruzaman, J. (2006). Individual Mangrove Species Identification and Mapping in Port Klang using Airborne Hyperspectral Imaging. *J. of Sustainability Science and Management*, 1(2): 27-36.

- Kamaruzaman, J. (2008). Estimating Acacia mangium Plantation's Standing Timber volume using an Airborne Hyperspectral Imaging System, *The Open Forest Science Journal*, 1: 61-67.
- Kamaruzaman, J. and Souza, G. D. (1997). Use of Satellite Remote Sensing in Malaysia Forestry and its Potential. *Int. Journal of Remote Sensing*, 18(1): 57-70.
- Koh, W. A. (2006). Bamboo Mapping in Berangkat Forest Reserve, Kelantan using Airborne Hyperspectral Imaging. B.Sc. Project Report, Faculty of Forestry, Universiti Putra Malaysia, Serdang, Selangor. 61pp.
- Kotera, T. K. (1997). Mutual Regularity of Spring Phenology of Some Boreal Tree Species: Predicting with Other Spe and Phenological Models. *Canadian Journal of Forest Research*, 30:667-67.
- Kruse, F. A., Brian, H. C, Richard, C. O. and John, H. (1993). The Spectral Image Processing System (SIPS). Interactive Visualization and Analysis of Imaging Spectrometer Data. *Remote Sensing of Environment*, 44(2): 145-163.
- Mohd Norisham, M., (2003). Spectral Reflectance of 15 tree Species at Universiti Putra Malaysia's Arboretum, Serdang, Selangor. B.Sc. Project Report, Faculty of Forestry, Universiti Putra Malaysia, Serdang, Selangor. 61pp.
- Mohd. Hasmadi, I. and Kamaruzaman, J. (1999). Use of Satellite Remote Sensing in Forest Resource Management in Malaysia. *Proceeding of the Second Malaysian Remote Sensing and GIS Conference*, 16-18 March, Malaysia.
- Mohd. Hasmadi, I., Kamaruzaman Jusoff, Pakhriazad Hassan Zaki and Frisco Nobilly. (2007). Geoinformatics for Better Forest Management. *Proceeding of the National Conference on the Management & Conservation of Forest Biodiversity in Malaysia*, 20-21 March 2007, Putrajaya Marriot Hotel, Malaysia.
- Mohd Norisham, M. (2003). Spectral Reflectance of 15 tree Species at Universiti Putra Malaysia's Arboretum, Serdang, Selangor. B.Sc. Thesis, Faculty of Forestry, Universiti Putra Malaysia, Serdang, Selangor, 61p.
- Ramachandran, S., Anitha, S, Balamurugan, V and Dharanirajam, K., (1998). Application of Remote Sensing and GIS to Coastal Wetland Ecology of Tamil Nadu and Andaman and Nicobar Group of Islands with special Reference to Mangroves. *Journal Society of India*, 75(3): 236-244, 1998.
- Ravan , S. A. and Roy, P. S. (1997). Satellites Remote Sensing for Ecological Analysis of Forested Landscape. *Plant Ecology*, 131: 129-141.
- Roslind, H. (2004). Detection of Forest Tree Stress in Taman Wetland Putrajaya with a Spectoradiometer. B.Sc. Project Report, Faculty of Forestry, Universiti Putra Malaysia, Serdang, Selangor. 96pp.
- Stone, C., Chisholm, L. and Coops, N. (2001). Spectral reflectance characteristics of eucalypt foliage damaged by insects. *Australian Journal of Botany*, 49: 678-698.
- Wafiah, M. W. (2007). Tree Tagging in Gunung Stong Forest Reserve using UPM-APSB's Hyperspectral Imaging System. B.Sc. Project Report, Faculty of Forestry, Universiti Putra Malaysia, Serdang, Selangor. 70pp.