Going
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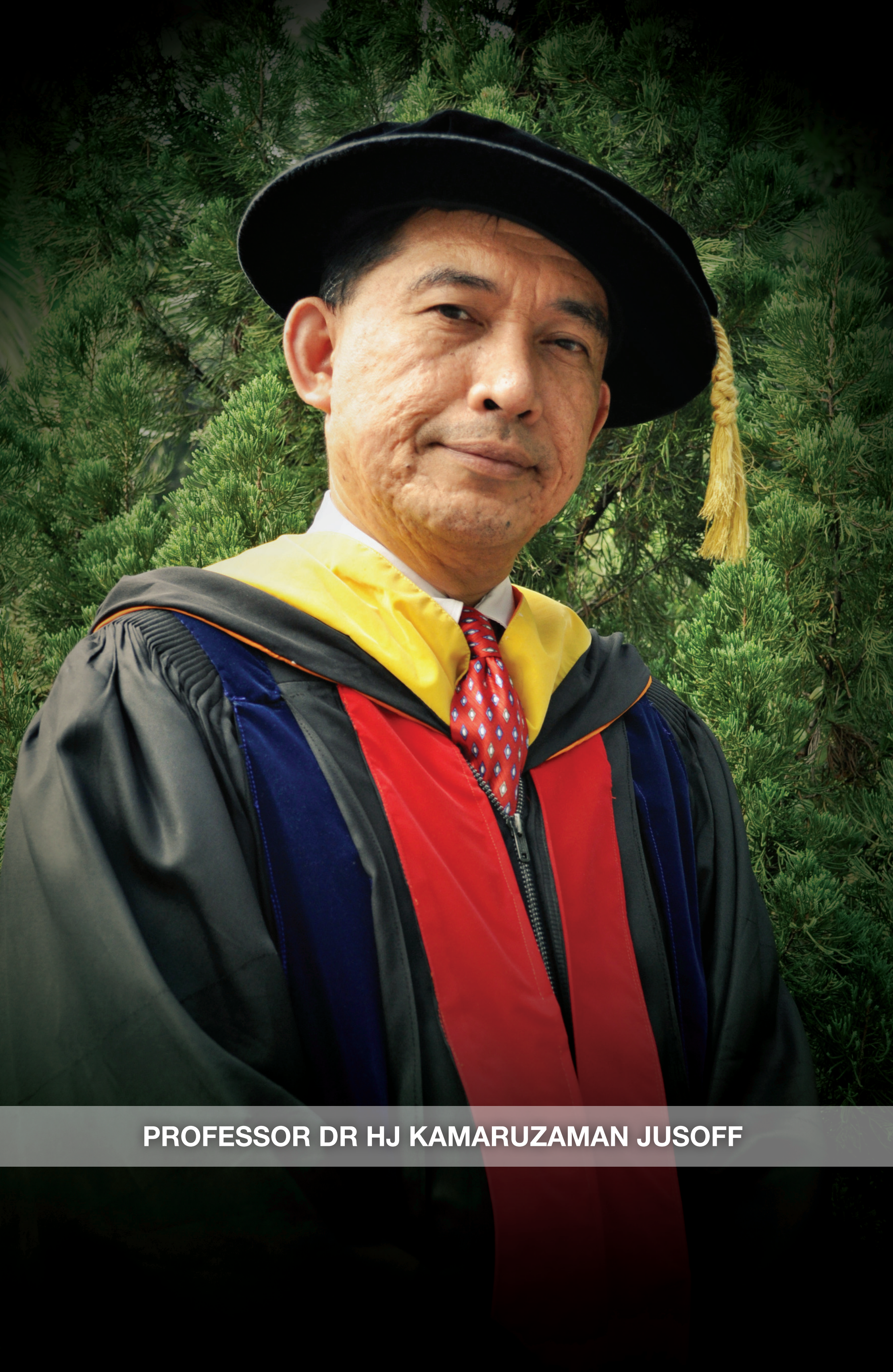
The 'UNSEEN' Captured?



PROFESSOR DR HJ KAMARUZAMAN JUSOFF

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ABSTRACT

All objects, name them soil, water, trees, vegetation, structures, metals, paints or fabrics, create a unique spectral fingerprint. A sensor determines these fingerprints by measuring reflected light, most of which registers in wavelengths, or bands, invisible to humans. This is what the crime scene investigation (CSI) television programs have popularized how DNA or fingerprints can be used to solve crimes. Similarly, forest CSI of "seeing" the trees in the deep high mountain tropical forest is now a major focus in the air and spaceborne hyperspectral sensing technology and in other different applications such as agriculture, environment, geology, transportation, security, and several others. The availability of sub-meter resolution colour imagery from satellites coupled with internet based services like Google Earth and Microsoft Virtual Earth have resulted in an enormous interest in remote sensing among the general public. The ability to see one's home or familiar landmarks in an image taken from hundreds of kilometers above the earth elicits wonder and awe. Deciding where, when, what and how to sense or measure the DNA of individual trees from the air or space is a crucial question in the sustainable development and management of our Malaysian tropical forest ecosystems. However, to monitor, quantify, map and understand the content and nature of our forest, one would ideally like to monitor it everywhere and all the time too. This is impossible, and consequently, forest engineers must select relatively very high to high near to real time resolution sensors with the ability to transcend boundaries, capabilities, features and interfacing realms for such measurement. The dynamic interplay of these elements is precisely coordinated by signaling networks that orchestrate their interactions. High-throughput experimental and analytical techniques now provide forest engineers with incredibly rich and potentially revealing datasets from both

air and spaceborne hyperspectral sensors (also known as imaging spectrometers). However, it is impossible to exhaustively explore the full experimental and operational hyperspectral sensors available in the market out there and so forest engineers must judiciously choose which one is the best to perform and fulfill their project objectives and missions. The complexity and high-dimensionality of these systems makes it incredibly difficult for forest engineers and other users alone to manage and optimize sensing processes. In order to add or derive value from a hyperspectral remotely sensed image several factors such as resolution, swath, and signal to noise ratio, amongst others need to be considered. A grand challenge for the forest engineer's scientific discovery in the 21st Century is therefore, to devise very high real-time ultra-spatial and spectral air and space borne sensors that automatically measure and adapt sensing operations in large-scale and economical systems with the unseen captured. This lecture therefore focuses on the emerging theory, origin of the hyperspectral sensors, research, practice, limitations and identifies future challenge and outlook of hyperspectral sensing systems in the quest towards a sustainable Malaysian forestry context and other different applications to capture the "unseen". It is quite certain that advances in hyperspectral remote sensing and more sophisticated analytical methods will resolve any "unseen" issues in time with the best approach of transcending boundaries and interfacing remote sensing data with precise information from the field plots. Unfortunately, as a relatively new analytical technique, the full potential of air and spaceborne hyperspectral imaging has not yet been realized in Malaysia.

INTRODUCTION

A new way to look at and capture the unseen world - a stretch of highway, an expanse of the blue ocean, a blanket of evergreen forest, a checkerboard of plantation crops, familiar vistas: scenic, but nothing out of the ordinary, if you know how to look. With the right tool, a hyperspectral imager, the unseen or hidden detailed pictures may emerge: a military vehicle hidden in the thick jungle by camouflage, a sea teeming with phytoplankton fish food, tropical evergreen individual trees growing at different rates, nutrient deficiency infertile land under-utilized. By seeing what is unseen by the human eye, a hyperspectral imaging system gives forest engineers and surveyors, foresters, resources managers, front-line commanders, farmers, urban planners, environmental analysts a powerful tool to help classify features, measure productivity, yield and identify trends.

The crime scene investigation (CSI) television programs have popularized how DNA or fingerprints can be used to solve crimes. As for a surgeon, the place is an operating room where a patient undergoes surgery to remove a malignant tumor, and the surgeon tries to locate the remaining few tissue cells into which the cancer has spread. These are the most difficult to spot. A camera-like device is pointed at the exposed flesh. An image appears on a large overhead monitor, and certain areas are delineated and highlighted with false colors that correspond to a probability level of a local malignancy. The technician zooms in and the surgeon decides whether to remove additional tissues. This is one of the newest applications for ground-hyperspectral imaging is non- or minimally-invasive photo-diagnosis. Conventional spectroscopy is, of course, not a new tool in pathology, and the idea of using spectroscopic techniques in real time and in-vivo, is a natural extension. The problem may be that whereas the pathologist is trained in the interpretation of spectra, very few physicians and surgeons would call themselves experts in this field. The computerized pathologist does the job.

Locating a few malignant cells in a benign background is not unlike finding an individual tree species in the deep high tropical mountain forests or a camouflaged military tank in the deep virgin protected jungle in Malaysia. The forest landscape background has its own spectral signature, and so does the target, say a single individual tree. The background exhibits a spatially non-stationary clutter, and the target signature is masked by the adjacent cells. Furthermore, early stage detection is critical, and at that stage the target may still be classified as “sub-pixel” in size, meaning that the signature is composed of contributions from both the target and background; and if the malignant cell is covered under a layer of benign cells (camouflage), than the spectral mixing is non-linear. Unlike conventional spectroscopy, which deals with all these problems as well, imaging spectroscopy provides simultaneous spatial and spectral data. The mathematical algorithms should be able to take advantage of the spatial data to develop image statistics and other parameters which aid in the detection, improving on the capabilities of conventional spectroscopy.

Much as a doctor can use a CAT scan to detect and diagnose myriad ailments in the human body, a hyperspectral sensor, either it is on the air or spaceborne platform is designed to ferret out a variety of our mother earth’s environmental threats. All objects such as soil, water, trees, vegetation, structures, metals, paints, fabrics-create a unique spectral fingerprint. A sensor determines these fingerprints by measuring reflected light, most of which registered in wavelengths, or bands, invisible to humans. Looking to the skies has long been popular in both science fiction movies and military doctrine. The ability to see one’s home or familiar landmarks in an image taken from hundreds of kilometers above the earth elicits wonder and awe. However, technological advances now allow for the development of unmanned aerial systems, fixed-wing aircraft, and cruise missiles that are small enough and fly low enough to elude conventional radar detection. Such aircraft could carry out chemical, biological, or nuclear attacks, or they could be employed to smuggle drugs or illegal immigrants across the border. The skies over Universiti Putra Malaysia (UPM) were once buzzed with the propellers of a fixed wing aircraft with a small opening underneath that bristles with a sensor. This unassuming vessel has helped forest engineers and researchers probe deeper into the inventory, structure and soon, the chemistry of the Malaysian forest ecosystems than ever before. The UPM Institute of Bioscience's Center for Precision Agriculture and Bio-resource Remote Sensing (later, Faculty of Forestry's Forest Geospatial Information and Survey Laboratory at Lebuh Silikon and finally Tropical Forest Airborne Observatory (TropAIR) once wields some of the most powerful airborne hyperspectral remote sensing instruments available today. On a typical flight, the instruments gather gigabytes of data that can reveal patterns in individual species diversity, inventory, forest growth rates, and overall ecosystem health and for other applications. It is as if the information is written in invisible ink, and all we have to do is to figure out how to read it. When we fly overhead, we see the tops of trees. But an airborne hyperspectral sensor cannot see physical structures down below the canopy, and probably can hardly pick up on the volumetric and biochemical information that is invisible to the naked eye. This poses a great challenge to the forest engineers on how best such valuable information can be derived from the hyperspectral remote sensing technology.

Fortunately, the hyperspectral remote sensing industry has its own technology to detect and discriminate unique characteristics of the forest parameters, materials and features, either it be indirect or directly. Airborne hyperspectral imaging provides the capability to detect and discriminate unique characteristics of materials and features much like DNAs is used in CSI. Satellite multi- and hyper-spectral sensors have evolved over the past three decades into powerful monitoring tools for the tropical forest ecosystem and other earth observation processes. Research in tropical forest environments, however, has tended to keep pace with new remote sensing technologies more so than in temperate environments. Hyperspectral sensing can provide mapping of forest species, forest inventory, and above-ground biomass. Assessment and monitoring of the environment have become increasingly reliant on hyperspectral sensing technologies, especially given the availability of historical data as well as the ability to provide precise data covering large spatial extents. These hyperspectral sensors typically are defined in terms of their specifications related to resolution. Spectral resolution has recently received immense attention as research has proven the capability of sensors with narrow contiguous channels (bandwidths of less than 2 nm) to detect subtle variations in surface features that might otherwise be masked by broader bands of multi-spectral scanner systems. Research has shown that subtle variations in features such as individual timber tree species (Mohd Hasmadi et. al., 2010; Kamaruzaman et. al., 2009; Kamaruzaman, 2009a, 2009b), oil palm, rubber and rice paddies precision agriculture (Kamaruzaman and Malek, 2009a; 2009b and Kamaruzaman and Mubeena, 2009; Kamaruzaman, 2006), coastal zone, marine and islands mapping (Kamaruzaman, 2009f) and search-and-rescue of missing aircrafts (Kamaruzaman, 2010c; 2008a), highways and transmission lines mapping (Kamaruzaman Jusoff and Norsuzila, 2008a; 2008b) can be detected and mapped using hyperspectral resolution sensors. In this regard, a review and illustration of the developments of hyperspectral and spatial resolution technology is critical for a better understanding of its application in forestry and non-forestry fields.

The main objective of this lecture is therefore to describe the science, techniques, analysis, and the broad air and spaceborne hyperspectral imaging spectroscopy landscape with a particular emphasis in the context of Malaysian forestry. Air and spaceborne sensing can both together provide a broad to precise forest engineering function which is an important component of an integrated sustainable forest management system. This lecture also briefly reviews both selected air and spaceborne hyperspectral imaging spectrometers available, the utility of imaging spectroscopy in forest analysis and its potential in non-forestry applications, with reference to the upcoming available commercial space borne imaging spectrometers.

HYPERSPECTRAL QUEST FOR SUSTAINABLE MANAGEMENT OF FOREST

Monitoring 21 million hectare of forest or 63.6% of land area in Malaysia is needed to ensure the sustainable development of these forests (http://rainforests.mongabay.com/20malaysia.htm). The nature of heterogeneity that exists in the tropical mixed hill dipterocarp and mountain Malaysian forest poses many challenges to the remote-sensing techniques that are applied in characterising forest variables, e.g. species identification, biochemical concentration, stress and biomass in Malaysia (Kamaruzaman and Kasawani, 2009). The use of a computer based remote sensing and GIS for urban forestry has been well recognized by Hasmadi et al. (2006). Sensing or imaging the heavily dense tropical mountain biological resources has been a fundamental issue in the management of their use for a sustainable balance of production and environmental health (Kamaruzaman and Dahlan, 2006). As the human eye sees basically three bands of light, all trees are seen as green. On the other hand, the hyperpsectral sensor sees more than 50 colours and can differentiate things that are anomalous in the vegetation such as metal or something from aircraft wreckage. Forest sensing includes the establishment of precise baselines as well as temporal assessment in ways that lead to effective geo-spatial information for forest operations, production, management and sustainable development (Kamaruzaman and Skidmore, 2009).

Forest management should encompass the many functions related to forest recourses. It requires detailed data to execute current operations, to build-up records of past activities and to predict the long-term impacts of management decisions. In support of this, Mohd Hasmadi et al. (2009) reported that the airborne hyperspectral remote sensing data may provide foresters with detailed spatial explicit information on forest vitality, species composition, canopy closure, just to name a few. Due to the complex nature of hyperspectral remote sensing data sets, a complete imagery pre-processing chain must be set up to perform standard corrections for radiometric, geometric and atmospheric effects which might corrupt the data. Moreover, bidirectional effects caused by the heterogeneous character of terrestrial targets are influencing the captured (airborne) hyperspectral signal. Forests are such heterogeneous surfaces and might have pronounced vegetation structure which will also affect the accuracy of hyperspectral derived thematic products, useful in forest management practices (Kamaruzaman and Skidmore, 2009). It is to my hope that the upcoming state-of-the-art hyperspectral imaging systems operate across up to 220 wavelengths to paint precise portraits of this unseen or hidden world of forests for future sustainability of our Mother Earth. Where a standard sensor with fewer than 10 bands is capable only of differentiating between gross classes of forest types, a hyperspectral imager should be able to discriminate a Chengal from a Nyatoh tree, Meranti tembaga from a Meranti sarang punai, rice paddies from weed paddies, and is sensitive enough to separate healthy from unhealthy growth and a crashed aircraft wreckage hidden and tucked in a virgin jungle reserve (VJR).

GETTING TO KNOW HYPERSPECTRAL SENSING

All objects reflect or emit energy. Receiving this energy for interpretation is called sensing. If instruments located at a considerable distance from the subject being measured do the sensing, it is called “remote” sensing. Thus, hyperspectral sensing, as defined here, is the acquisition of information from afar about the chemical composition of an object or its environment based on the energy that is emitted or reflected from the object or its environment. In hyperspectral imaging, the electromagnetic spectrum is partitioned into hundreds of narrow, contiguous spectral bands, sufficient to read the spectral signatures of the materials in the image. Hence, performing hyperspectral imaging of the scene from a space-based, airborne, or ground remote sensor can accomplish identification of objects in the scene. The result is a three-dimensional spatial-spectral data set with two axes of spatial information and one axis of spectral information, termed as image cube as shown in Figure 1.

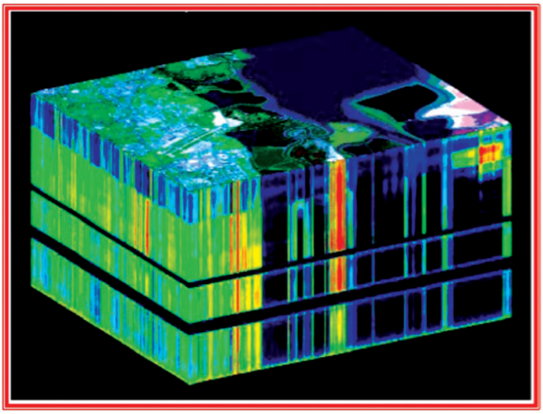


Figure 1 AVIRIS hyperspectral data cube over Moffett Field, CA
(Source: http://www.csr.utexas.edu/projects/rs/hrs/hyper.html)

Hyperspectral data source usually includes 10 or more contiguous bands of spectral data and the bandwidth of the data collected is typically in the range from 1-15 nm with the aim of allowing for spectral analysis of measured objects. Hyperspectral sensing or imaging is very closely associated with the term spectroscopy and spectrometer. However, imaging spectroscopy is defined as the art and science of analysing hyperspectral data whereas imaging spectrometry is the engineering task and science of making the hyperspectral data available, for example, defining and building the instrument and acquiring the data in a meaningful way. In contrast, multispectral data typically consist of three to seven bands of data, with bandwidths ranging from 50-120 nm. This higher hyperspectral resolution enables quantification and analysis of the interaction of surface materials and features with light and radiant (heat) energy, and is based on concepts of energy reflectance, absorption and emissivity resulting from feature composition and atmospheric condition. Hyperspectral sensors collect reflected and radiant energy data from the ultraviolet (UV) and infrared (IR), as well as the familiar visible (VIS) portions of the electromagnetic spectrum where a variety of statistical and mathematical algorithms are applied to automate the image interpretation and feature identification process.

Hyperspectral imaging sensors measure many narrow-wavelength adjacent spectral bands to create the spectrum for each pixel on the ground. Hyperspectral remote sensing, especially airborne in Malaysia was first initiated and operated in Forest Geospatial Information & Survey Lab, Lebuh Silikon, Universiti Putra Malaysia about seven years ago with the introduction of the classical AISA from SPECIM Ltd, Finland. The trend in the development of hyperspectral sensing has been since then, with the increase of the spatial and spectral resolutions, to move from the panchromatic multispectral to the hyperspectral, superspectral and then to the ultraspectral. During the last 10 years, research on hyperspectral sensing has been carried out intensively in Malaysia. In the Malaysian hyperspectral remote sensing system, the airborne hyperspectral sensor pioneered by Center for Precision Agriculture & Bioresource Remote Sensing, Institute of Bioscience (later Faculty of Forestry), Universiti Putra Malaysia is already in place as one of the basic systems. Due to the sufficient spectral features such as spectral reflectance with wavelength it provides, hyperspectral data plays an important role in forestry and other different fields. So, it is a rush now to develop some special algorithms and models for hyperspectral data processing, information extraction and classification. Many surface materials, for instance have unique absorption and reflectance characteristics that are only 10 - 20 nm wide; the detailed reflectance spectrum acquired by hyperspectral remote sensing makes it possible to identify and distinguish material and conditions on the ground in ways that are impossible even with very high resolution multispectral imagery. Figure 2 demonstrates the difference in detail between hyperspectral and multispectral land cover signatures for a typical suburban/rural scene. In the example shown below, the hyperspectral image contains 64 bands. Just as with multispectral data, no more than three bands can be displayed simultaneously. The user must choose a subset of bands for display purposes; however, if all bands can be simultaneously loaded into the software, mathematical analyses can use all of the spectral information. This requires more sophisticated digital image processing software than the commonly used commercial packages such as ENVI (produced by ITT Visual Information Solutions which was formerly Research Systems, Inc.), ERDAS Imagine (produced by Leica Geosystems Geospatial Imaging) or IDRISI (produced by Clark Labs at Clark University).

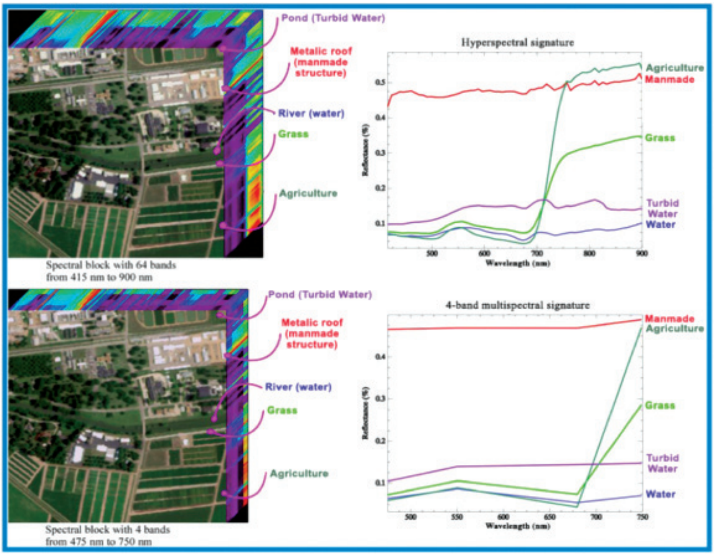


Figure 2 Spectral signatures from hyperspectral and multispectral sensors

(Source: ITRES Research Ltd. http://www.itres.com/Sensor_Products. Accessed on 24 th. June 2010)

While there are many advantages to using hyperspectral data, there are also significant challenges. A typical 3-band, 8-bit radiometric resolution (8 bits, or 1 byte, per pixel per band) image chip of 5,000 x 5,000 pixels would comprise a 75 MB (5,000 * 5,000 * 1 * 3) data file while a 64-band image of the same scene at the same radiometric resolution would yield 1.5 GB (Schuckman and Dutton, 2010). As radiometric information is of key importance for spectral analysis, hyperspectral instruments generally have a 12 to 16-bit dynamic range, which further increases the volume of data by a factor of 1.5 to 2, respectively. A spaceborne sensor usually operates in broad spectral bands in order to achieve an adequate signal-to-noise ratio at high spatial resolution. This physical limitation makes true hyperspectral remote sensing from space a difficult proposition. Hyperspectral sensors are mostly based on the pushbroom linear arrays such as the airborne AISA Classic, Eagle and Hawk from SPECIM or whiskbroom scanner designs.

HYPERSPECTRAL TECHNOLOGY IN CAPTURING THE "UNSEEN”?

Do forest engineers or other general user always need very high resolution imagery to capture the "unseen" of the forest and other required objects of interest? How long can an illegal logging activity, for example be captured when the raw remote sensing data from airborne or satellite images being received? Simillarly, how quick can the search-and-rescue team locate a missing aircraft wreckage in the open see or thick jungle mountainuous reserves? These images can be full of distortions like lines, blurring or even cloud cover. They have to be cleaned and aligned to the scales and coordinate and then passed over to the GIS experts who must verify the data soonest possible as it has to compare the images with the most current Forestry or other departments base maps. The verification part is to see if there is over exploitation or unpermitted logging that may has taken place. What is on the imagery must be confirmed and ascertained with what is on the ground. The target is to ensure that everything is completed within less than an hour for the “unseen” to be captured. This is where near to real-time hyperspectral data sets, particularly airborne can extend remote sensing and image processing beyond the traditional capabilities of multispectral satellite remote sensing. In fact, both space and airborne imagers are powerful diagnostic tools for forestry sensing since as earlier mentioned, hyperspectral sensors measure the intensity of reflected solar energy across a continuous span of wavelengths–from shortwave infrared light to visible light and visible near-infrared light resulting in a complete spectrum for each pixel. The spectral resolution derived from an airborne hyperspectral sensed data when looking at the forest, provides the ability to determine whether such forest cover is dominated by one dominant species (homogeneous) or many intermixed species; the morphology of the feature (e.g. size, growth form); timber types (e.g. *damar* or *non-damar* species group), and number of features (e.g. tree stand density/volume) as shown in Figure 3 and Table 1 for Block 53, Berangkat P.F.R.

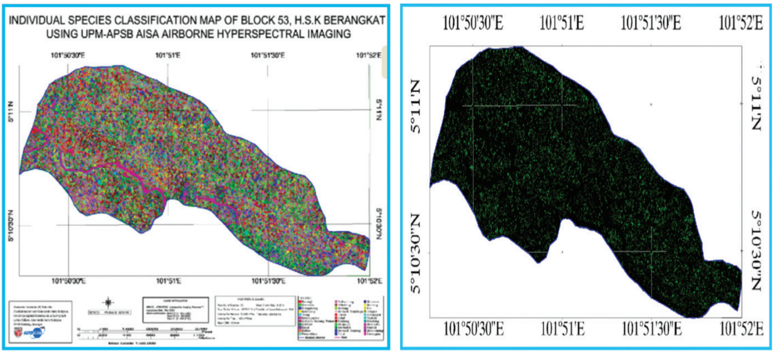


Figure 3 A timber species classification map (left) showing Kedondong individual species (right) in green pixels for Block 53, Gunung Berangkat P.F.R as derived from UPM-AISA Classic airborne hyperspectral image data

Remote sensing often provides proxy measurements for the parameters we are really interested in. They will play an increasing worldwide role in forest engineering survey, operations, harvesting, management, conservation, protection, recreation, eco-tourism, biodiversity, ecology, etc. If we would like to know about precise changes in forest cover, particularly the change in area from one form of species to another, hyperspectral remote sensing does a good job of providing this precise information. If we are interested in changes in carbon density of a specific forest ecosystem, say a rubber plantation or an agroforestry project, an airborne hyperspectral imaging can trace carbon-monoxide emissions, which is a proxy for a number of greenhouse gases. Merging this kind of hyperspectral data in a GIS can provide a very powerful analytical tool as being suggested by Kamaruzaman (2009e) in his cabbage estimation market intellegence research in Cameron Highlands.

Table 1 Feature characterization of a timber harvesting block as derived from UPM-AISA airborne hyperspectral sensing, modeling and ground measurements

No.	Parameters Derived from UPM-ASIA Airborne Classic Hyperspectral Sensor & Ground Measurements	Values of Measure
1	Total No. of Species	33
2	No. of Damar Species Group	5 (Merawan, Meranti tembaga, Mersawa, Meranti kepong, Meranti sarang punai)
3	No. of Non-Damar Species Group	28 (Keranji, Mempisang, Kekatong, Terap, Kelempayan, Merbau, Kasai, Kulim, Penarahan, Kedondong, Keladang, Medang, Perah, Kelat, Tualang, Merpauh, Sesenduk, Pulai, Mahang, Ara, Rengas, Bintangor, Nyatoh, Jelutong, Merbatu, Sepetir, Mempening, Berangan)
4	Total Timber Volume (m^3)	15,071.11
5	Timber Volume Per Ha (m^3/ha)	55.91
6	Mean Volume Per Tree (m^3/tree)	1.63
7	Mean Diameter at Breast Height (cm)	43.90
8	Mean Crown Diameter (m^2)	9.23
9	Total No. of Crowns/Canopies Delineated	9,241
10	Total Area of Interest (ha)	269.58

Geospatial analysis, the study of forest features and the relationships that exist between them can be applied to many areas of the forest industry. By better understanding how features within the forest landscape interact, forest engineers can optimize operational efficiency and improve economic returns. Regardless of scale-whether at the compartmental level analyzing timber yield information or across the entire logging concessionaires, hyperspectral sensing is becoming fully integrated and widely accepted for assisting forestry department and forest related agencies to manage programs that support foresters and protect the environment. Integrated hyperspectral remote sensing data with GIS offers forest engineers various data management opportunities to analyze ways to increase timber production, reduce input costs and manage forest efficiently. From handheld computer mapping in the field to the scientific analysis of timber production data at the compartmental level, integrated hyperspectral sensing/GIS plays a part by tying together disparate data that has previously never brought into one computing environment for analysis.

Recently, hyperspectral remote sensing has stepped into a new stage in Malaysia where an AISA Eagle was flown on a calibration and test bed flights in the Malaysian airspace by private and state government agencies. There are several advanced hyperspectral imaging systems developed in the US, Canada, and the EU, especially NASA that has been playing a very important role in such high-technology application development and research activities. Aiming to caputre the "unseen" for different research and applications, the spectral wavelength and resolution of an airborne hyperspectral sensor can be easily changed by selecting different interference filters. According to these airborne hyperspectral sensors, some data processing and info-extraction models have also been developed in Malaysia (Kamaruzaman, 2007b). These models have been widely used in many remote sensing projects, such as timber inventory, precision agriculture, highway transportation, urban and town planning and so on (Kamaruzaman, 2010a; 2010b; 2009a, 2009b, 2009c; 2008b).

However, the development of a Malaysian market in hyperspectral remotely sensed data for forest engineering survey or other applications is affected and limited by the access to information on the availability, parameters and quality of hyperspectral remotely sensed data for specific application areas. There is also no guarantee that high resolution hyperspectral images of a specific area from The National Remote Sensing Agency or Space Agency (ANGKASA) will be obtained. In addition, the quality of the Malaysian remotely sensed data as a commercial product (standardization of formats supplying meta-data, complete characterization of remote sensing conditions and techniques) is still low. We are aware that hyperspectral remote sensing has never been conducted by any Malaysian agency space-based platforms and the production of new satellite sensors does not reflect specific user requirements for hyperspectral technology. Generally, the potential users have still insufficient knowledge of relevant applications of hyperpspectral sensing methods and their analysis on top of the security requirements for using airborne hyperspectral remotely sensed data and maps is unnecessarily strict. Furthermore, the domestic hyperspectral remotely sensed data is still expensive and not in real time.

For forest ecosystem monitoring, and for the observation of short-term processes and phenomena in Malaysian forestry, it is necessary to obtain and process hyperspectral sensing information in close to real time. In this case, data from the technique of operational space observation are of high importance. Information is transferred from the spacecraft by radio channels, received by ground antennas, undergoes preliminary processing, and is provided to the customer in digital form and in near-real time. Scanner images have a lower resolution than photographic images, but they are more available and are thus of primary importance for the monitoring of forest fires, the detection and evaluation of degraded forest and the estimation of phonological condition of forests (by calculating the vegetation index).

THE ORIGIN AND DEVELOPMENT OF SELECTED HYPERSPECTRAL AIR AND SPACEBORNE SENSORS

The hyperspectral era began with airborne mineral mapping in the late 1970s and early 1980s. The invention of the charge-coupled device in 1969 was a key factor in moving hyperspectral technology forward. The idea behind hyperspectral imaging, also known as imaging spectroscopy is simple. In the 1970s, multispectral remote sensors produced images with relatively few broad wavelength bands that have allowed us to understand our environment better. If acquiring images in just a few spectral bands afforded this, then to a few hundred narrower spectral bands would theoretically offer even more rooms to capture the unseen of interest. This thinking led to the birth of hyperspectral imaging in the early 1980s with the Airborne Visible-Infra Red Imaging Spectrometer (AVIRIS) developed at the NASA Jet Propulsion Laboratory in California. Before AVIRIS, technological limitations prevented spectrometers from being used on moving platforms. Only two such sensors are in orbit – Hyperion on NASA’s Earth Observing-1 satellite and CHRIS on ESA’s Proba-1 – and none that enables the global capturing and mapping the unseen of our Mother Earth. CHRIS is Europe’s only flying imaging spectrometer, with a spatial resolution of 17 m in up to 62 bands. Despite being designed for a one-year life, it is now operating in its ninth year and is serving more than

300 scientific groups in more than 50 countries. Its data support a wide range of applications, such as land surface, coastal zone and aerosol monitoring. After several decades of research and development into hyperspectral imaging, which greatly enhances our ability to characterize the state of the Earth, the technique has been embraced by the Earth-observation community and has entered the mainstream of remote sensing. This section therefore provides an overview of a selection of available high-profile airborne and spaceborne imaging spectrometers and their resolutions (Table 2).

Table 2 Spatial and spectral resolutions of hyperspectral sensors (Source: Adopted from Mutangga et al., 2009)

Sensor	Spatial Resolution	Spectral Resolution	Altitude/Platform
MSM176	14.5 m	200 bands	Spaceborne
	hyperspectral	(400-2, 350 nm)	(660 km)
		4 bands	
	4.6 m	(visible region)	Spaceborne
Hyperion	multi-spectral	220 bands	(660 km)
		(356-2,577 nm)	
	30 m		Spaceborne
			(705 km)
HyMap	2-10 m	128 bands	Airborne
		(440 nm-2,500 nm)	(2,000-5,000 m)
AVIRIS	20 m	224 bands	
		(400-2, 500 nm)	Airborne (20 km)

Airborne

AVIRIS (Airborne Visible/Infrared Imaging Spectrometer)

The Airborne Visible InfraRed Imaging Spectrometer (AVIRIS) was designed and built by the NASA Jet Propulsion Laboratory

(JPL). It is a whiskbroom scanner, and it flies on several airborne platforms. The swath and spatial resolution depend on the flying height and over-ground speed of the aircraft. On the NASA ER-2 jet at 20 km above MSL, AVIRIS covers an 11 km swath at 20 m GSD. On a DeHaviland Twin Otter turboprop at 4 km AGL, AVIRIS covers a 2 km swath at 4 m GSD. The sensor records radiance levels at 12-bit radiometric resolution for 224 10-nm bands between 400 nm (blue) – 2,500 nm (mid-IR). The duration of an airborne remote sensing mission varies with weather and lighting conditions; however, under optimal conditions, AVIRIS can yield up to 75 GB of data per mission (Boardman, 1993; Boardman et al., 1995). This tremendous amount of data must be evaluated in the field to ensure that all the data passes an initial quality assessment before the aircraft and crew leave the project area.

AVIRIS is flown primarily for NASA-funded scientists and researchers but graduate students can obtain small amounts of existing AVIRIS data at no cost. A few sample data sets can be downloaded for free from the AVIRIS data products web page. AVIRIS data is normally radiometrically and geometrically corrected by a JPL team before it is distributed to the user (Boardman and Huntington, 1996); however, raw data can be made available. For example, a researcher working on the science of radiometric calibration would most likely want to work with raw data. Figure 4 illustrates the comparison of a true color image composed of AVIRIS bands 646.7 nm (red display channel), 547.6 nm (green display channel), and 449.1 nm (blue display channel). Meanwhile, a false color IR image composed of AVIRIS bands 841 nm (red display channel), 1,225 nm (green display channel), 1,690 nm (blue display channel); and Grayscale image from AVIRIS band 15 (509.3) nm.

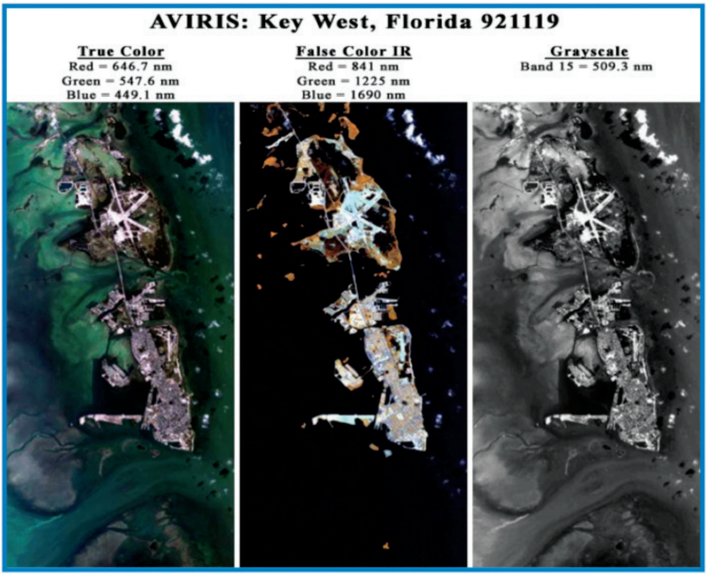


Figure 4 Comparison of three AVIRIS images
(Source: NASA http://aviris.jpl.nasa.gov/. Accessed on 20th. June 2010)

HYMAP (Hyperspectral Mapper)

HyMap is a state-of-the-art aircraft-mounted commercial hyperspectral 128-band whiskbroom hyperspectral scanner developed by Integrated Spectronics, Sydney, Australia, and operated by HyVista Corporation (Figure 5). It operates in the familiar spectral range of 400 – 2,500 nm, but with a bandwidth of 15-20 nm rather than 10 as for AVIRIS and Hyperion. It records data in 12 - 16 bit format. It is designed to be flown on a small twin-engine aircraft at fairly low altitudes. Spatial resolution depends on flying height, but ranges from 3 - 10 m under typical conditions. HyVista uses the HyMap sensor to provide mapping and analysis services to a broad range of clients world-wide.

Figure 5 HyMap Airborne Hyperspectral Sensor
(Source: HyMAP http://www.hyvista.com/technology/sensors. Accessed on 20th. June 2010)

CASI (Compact Airborne Spectrographic Imager)

The Compact Airborne Imaging Spectrometer (CASI) is built by ITRES Research Ltd., of Canada. ITRES has sold a number of CASI sensors to commercial and government clients throughout the world. They also provide data acquisition, processing, and analysis services. The the CASI 1500, is a pushbroom with very high spectral resolution. It can collect data in 14-bit format for 288 bands at 2.5 nm nominal intervals. However, the overall spectral range is limited to 650 nm, which is adjustable anywhere between 400 nm (blue) and 1050 nm (near-IR). Flown on a standard cessna fixed-wing aircraft configured for forest aerial surveys (Figure 6), the CASI 1 can achieve a GSD in the range of 25 cm - 1.5 m. Figure 7 showed a timber volume estimate map for one of the flight strips flown over Gunung Rara-Kalabakan F.R, Sabah during a joint collaborative first airborne hyperspectral remote sensing research project campaign between UPM and THEMAP-CSIRO, Australia.

Figure 6 The first airborne CASI-1 sensor mounted in an Australian Cessna flown over Gunung Rara-Kalabakan, Sabah and Amanah Saham Sarawak (ASSAR) forest sites, Sarawak

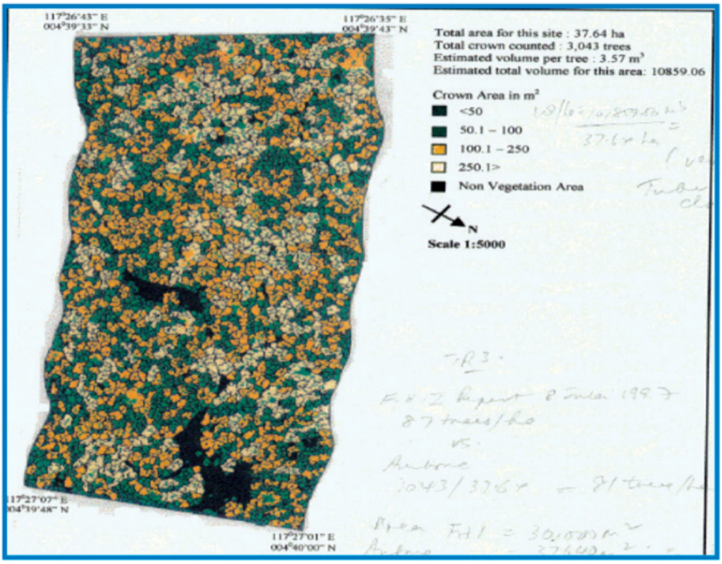


Figure 7 A tree volume thematic map product strip generated from an airborne CASI 1 datasets in Gunung Rara-Kalabakan

Besides tree individual species mapping application for timber inventory, CASI has been extended into several other systems aimed at hyperspectral remote sensing of the shortwave infra-red and thermal portions of the spectrum as shown in the Shortwave IR Airborne Spectrographic Imager (SASI) products (Figure 8). The SASI is a 160-band system with 10-nm bandwidth that operates in the 950 nm – 2,450 nm range.

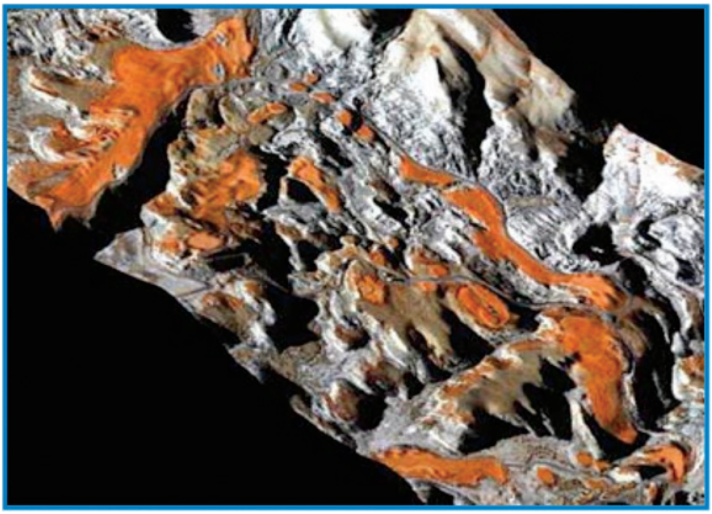


Figure 8 SASI short-wave infrared image of mineral deposits. (Source: ITRES Research Ltd. http://www.itres.com/Sensor_Products. Accessed on 24th. June 2010)

AISA (Airborne Imagine System for Different Applications)

AISA is a solid-state, pushbroom instrument developed by a Finnish engineering firm Spectral Imaging, Ltd. and NASA. The small size of its complete system makes it quite portable for use in any fixed wing aircrafts (Figure 9) or even modified helicopters. The instrument such as the AISA Classic can be mounted on a plate that is compatible with a standard aerial camera mount, available in any fixed wing aircrafts such as the Cessna 402B (Figure 10). Another advantage of AISA over other hyperspectral instruments is the flexibility in selecting the sensors' spatial and spectral resolution characteristics. Simple ASCII text configuration files that can be written and loaded at any time control the sensor settings, bandwidth selections, and integration time. Multiple configuration files are loaded on the controlling computer and used interchangeably throughout the flight depending on the image targets or mission goals. Reflected light from the target below the aircraft is transmitted through a camera lens and directed to a prism-grating-prism optical system, which splits the light into its component wavelength spectra. The refractive properties of the two opposing prisms allow for a linear projection of light onto the charged coupled device (CCD) array. The two-dimensional array consists of a spatial axis of 364 detectors, and a spectral axis of 286 detectors.

Figure 9 The UPM-AISA Classic mounting and installation on-board a RMAF Cessna C402B aircraft

Figure 10 The close-up of the UPM-AISA classic mounted on an aluminum metal plate on-board a RMAF Cessna C402B aircraft

AISA Classic is capable of collecting data within a spectral range of 430-900 nm. Although it is capable of collecting up to 286 spectral channels within this range, the data rate associated with the short integration times (sampling rates) required of the sensor in most operational/flight modes, limits the number of channels. The full spectral mode, however, is useful for acquiring 286 band spectral signatures of specific targets that can be used to generate pure endmembers as well as for band selection purposes. Current operational collection configurations range from 10 to 70 spectral bands depending on the aircraft speed, altitude and mission goals.

Meanwhile, the AISA Eagle sensor (Figure 11) with a spectral range from 400 to 1,000 nm has the highest achievable spectral resolution of 2.4 nm, and spatial resolution between 0.4 m and 6.0 m. Its pushbroom system consists of similar compact hyperspectral sensor head, data acquisition unit (rugged PC), GPS/INS unit, and downwelling irradiance sensor (FODIS). The system is working in visible and near infrared part of spectra (VNIR). This assembly, complemented by the supporting pre-processing software, is capable to deliver in almost real time the orthorectified hyperspectral images in at surface and/or at sensor level reflectance values. Nevertheless, quality of the radiometric, geometric, and atmospheric corrections of the airborne hyperspectral images must always be validated. Therefore, the ground spectral and spatial reference data are measured simultaneously with the AISA Eagle over-flights using a portable field spectroradiometer ASD FieldSpec-3 and the geodetic Topcon GNSS system. Monitoring of the aircraft position and attitude is performed by three-axial inertial navigation GPS/INS unit. The spectral bands are during acquisition split by the slit prism and pixel-wise progressively recorded by the CCD matrix into the 12 bit digital numbers (http://www.specim.fi/products-aisa.html).

Figure 11 An AISA Eagle VNIR airborne hyperspectral system mounted in an aircraft
(Source: http: //www. specim.fi/products-asia.html)

DAIS (Digital Airborne Imaging Spectrometer)

The European Union and German Aerospace Center funded the 79-channel Digital Airborne Imaging Spectrometer (DAIS 7915), which was built by the Geophysical Environmental Research Corporation (GER). This sensor covers the spectral range from the VIS to TIR wavelengths at variable spatial resolution from 3-20 m depending on the carrier aircraft flight altitude. The DAIS 7915 has been used since spring 1995 for remote sensing applications such as environmental monitoring of land and marine ecosystems, vegetation status and stress investigations, agriculture and forestry resource mapping, geological mapping, mineral exploration as well as for the supply of data for geographic information systems (GIS). Six spectral channels in the 8,000 – 12,000 nm regions could be used for the retrieval of temperature and emissivity of land surface objects. These and 72 narrow band channels in the atmospheric windows between 450 and 2,450 nm allow to investigate land surface processes with a special emphasis on vegetation/soil interactions. DAIS 7915 has a wavelength range of 400 nm - 12.6 µm, 4 spectrometers and 79 spectral bands (http://www.dlr.de/DAIS/dais-scr.htm)

APEX (Airborne Prism Experiment-Simulator for PRISM)

APEX is an airborne imaging spectrometer specifically built to simulate, calibrate and validate the PRISM instrument. The key characteristics of APEX are a swath width of 1,000 pixels across track and 300 spectral channels. The spectral resolution in the visible part of the spectrum is 5 nm (400-1,100nm) and 10 nm in the SWIR (1,100-2,500 nm). The instrument is flown in an aircraft. The system also consists of a laboratory calibration facility and its Processing and Archiving Facility (PAF). The planning for APEX started in 1993 with a European Space Agency (ESA) funding. It was then designed and developed under ESA-PRODEX (Programme pour le dévelopement des éxperiments) and co-funded by Switzerland and Belgium for general applications in development and research. APEX is a flexible airborne hyperspectral mission simulator and calibrator for existing and upcoming or future space missions. It is operating between 380 and 2,500 nm in 313 freely configurable bands, up to 534 bands in full spectral mode. One of the main features of APEX is providing spatial synchronization of the VNIR and SWIR images, otherwise offered separately from other sensors. This characteristic led to design the instrument with very stringent requirements in order to offer low data uncertainty. Therefore the scanner has been optimized for non-uniformities, mainly caused by the intrinsic nature of the acquisition mechanism and by the non-linear nature of the light. In order to allow users implementing hyperspectral-based applications with a satisfactory radiometric resolution, the APEX bands provide a high Signal-To-Noise-Ratio (SNR), usually higher than 100 (http://www.apex-esa.org/).

MAIS (Modular Airborne Imaging Spectrometer)

The Modular Airborne Imaging Spectrometer (MAIS) developed by Shanghai Institute of Technical Physics (SITP) has 32 channels in visible/near-infrared band and 32 channels in short-wave infrared band. The spectral resolution is 20 nm and 30 nm, respectively. There are 7 channels in thermo-infrared band with spectral resolution of 0.4 - 0.8 nm. The modularized instrument is compact, small, light and sensitive. It can be easily installed on different kind of planes to form 64-Channel V/NIR and SWIR Imaging Spectrometer, 32-Channel V/NIR or 32-Channel SWIR Imaging Spectrometer, 7-Channel TIR Multi-Spectral Scanner. Its spatial resolution is 3.0 -4.5 mrad, while the noise equivalent reflectance difference is 0.2-0.4% (V/NIR), 0.5-1.0% (SWIR), temperature resolution 0.2-1.0K (TIR). The instrument system was tested by the Chinese Academy of Science in 1991 for its experimental type. In 1993 the improved practical type was put in use. Since 1991 the instrument has been applied in many remote sensing projects for different purposes in the areas of Shanghai, Xinjiang, Hebei and Shandong in China, also in the areas of north and west of Australia, acquiring a great deal of valuable imaging spectral data and results (http://ltpwww.gsfc.nasa.gov/ISSSR-95/modulara.htm)

ARCHER (Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance)

The Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance (ARCHER) is an aerial imaging system that produces ground images far more detailed than plain sight or ordinary aerial photography can. It is the most sophisticated unclassified hyperspectral imaging system available Woollard (2007). ARCHER can automatically scan detailed imaging for a given signature of the object being sought (such as a missing aircraft) (Florino, 2009) and for abnormalities in the surrounding area, or for changes from previous recorded spectral signatures (Goodlin, 2007). It has direct applications for search and rescue, counterdrug, disaster relief and impact assessment, and homeland security, and has been deployed by the Civil Air Patrol (CAP) in the United States on the Australian built Gippsland GA8 Airvan fixed-wing aircraft. CAP, the civilian auxiliary of the United States Air Force, is a volunteer education and public service non-profit organization that conducts aircraft search and rescue in the U.S. ARCHER is a daytime non-invasive technology, which works by analyzing an object's reflected light. It cannot detect objects at night, underwater, under dense cover, underground, under snow or inside buildings (Alexa, 2008). The system uses a special camera facing down through a quartz glass portal in the belly of the aircraft, which is typically flown at a standard mission altitude of 800 m and 50 m/sec ground speed. The system software was developed by Space Computer Corporation of Los Angeles, California and the system hardware is supplied by NovaSol Corporation of Honolulu, Hawaii.

The major ARCHER subsystem components include an advanced hyperspectral imaging (HSI) system with a resolution of one square meter per pixel, panchromatic high-resolution imaging (HRI) camera with a resolution of 8 cm x 8 cm per pixel, and global positioning system (GPS) integrated with an inertial navigation system (INS). The passive hyperspectral imaging spectroscopy remote sensor observes a target in multi-spectral bands. The HSI camera separates the image spectra into 52 "bins" from 500 nanometers (nm) wavelength at the blue end of the visible spectrum to 1,100 nm in the infrared, giving the camera a spectral resolution of 11.5 nm. Although ARCHER records data in all 52 bands, the computational algorithms only use the first 40 bands, from 500 nm to 960 nm because the bands above 960 nm are too noisy to be useful. As mentioned earlier and for comparison, the normal human eye only responds to wavelengths from approximately 400-700 nm and is trichromatic, meaning the eye's cone cells only sense light in three spectral bands.

A monitor in the cockpit displays detailed images in real time, and the system also logs the image and Global Positioning System data at a rate of 30 Gigabytes (GB) per hour for later analysis. The on-board data processing system performs numerous real-time processing functions including data acquisition and recording, raw data correction, target detection, cueing and chipping, precision image geo-registration, and display and dissemination of image products and target cue information. ARCHER has three methods for locating targets, namely signature matching where reflected light is matched to spectral signatures, anomaly detection using a statistical model of the pixels in the image to determine the probability that a pixel does not match the profile, and change detection which executes a pixel-by-pixel comparison of the current image against ground conditions that were obtained in a previous mission over the same area.

In change detection, scene changes are identified, and new, moved or departed targets are highlighted for evaluation. In spectral signature matching, the system can be programmed with the parameters of a missing aircraft, such as paint colors, to alert the operators of possible wreckage. It can also be used to look for specific materials, such as petroleum products or other chemicals released into the environment, or even ordinary items like commonly available blue polyethylene tarpaulins. In an impact assessment role, information on the location of blue tarps used to temporarily repair buildings damaged in a storm can help direct disaster relief efforts; in a counterdrug role, a blue tarp located in a remote area could be associated with illegal activity.

Airborne Imaging Spectrometer (AIS-1, AIS-2)

The Airborne Imaging System (AIS-1, AIS-2) designed and built in the early '80s as part of a NASA Jet Propulsion Laboratory (JPL) imaging spectrometry program was a testbed for higher resolution imaging spectrometers. It yielded a number of advances in detector technology and data analysis. Rather than using a system of filters and discrete detectors, AIS-1 used a grating spectrometer to separate the signal into 128 contiguous bands in the spectral region from 1.2 to 2.4 um. The spectral resolution of AIS-1 was 9.3 nm, allowing it to clearly detect most surface material absorption features. AIS-1 used a 32x32 element mercury cadmium telluride area detector array. This design permitted a pushbroom-style scan in which the image of each cross track pixel was detected by a specific line of detectors in the area array, eliminating the need for cross track mechanical scanning. The surface pixel size, or spatial resolution, was approximately 8 m from the design altitude of 6 km. The swath size, or region-scanned perpendicular to flight path, was 365 m. AIS-1 became operational in 1984, providing information not only about the earth, but also about the technology of imaging spectrometry. No analysis of the data was performed during collection, but an on site data analysis system was developed for assessment of data quality immediately upon landing. A second generation instrument, AIS-2, imaged over the spectral region from 0.8-2.4 um, with a spectral resolution of 10.6 nm, a larger array, and a significantly higher signal-to-noise ratio (http://www.spie.org/web/oer/november/image_spectro.html).

Spaceborne

Hyperion

Hyperion, NASA's first hyperspectral imager to become operational on-orbit, was launched in November, 2000. Built and delivered by Northrop Grumman, the 220-band instrument sets the standard for orbiting imagers, providing a more than thirty-fold increase over multispectral capability. Spaceborne hyperspectral sensors provide pre-planned overflights for large-scale sensing operations. The Hyperion hyperspectral imaging sensor (Figure 12) flies on the NASA Earth Observing-1 (EO-1) spacecraft launched in late 2000. Pushbroom technology gives Hyperion a longer target look time than a scanning radiometer, which helps to overcome the signal-to-noise problem described in the section above. The EO-1 platform is in a 705 km sun-synchronous orbit following 1 min. behind LANDSAT 7, essentially viewing the same atmospheric conditions. The Hyperion sensor detects 220 10-nm hyperspectral bands between 400 nm (blue) and 2,500 nm (mid-IR) and records reflectance in 12-bit format. The 30 m x 30 m GSD of Hyperion mimics Landsat's spatial resolution; however, the 7.5 km hyperspectral swath is only a fraction of a 185-km wide Landsat scene. Another hyperspectral sensor aboard EO-1, called LEISA, with a 185-km swath at 250 m x 250 m GSD, collects 246 bands in the mid-IR portion of the spectrum where water vapor absorption is significant. This data is used to derive atmospheric correction information for the other sensor datasets.

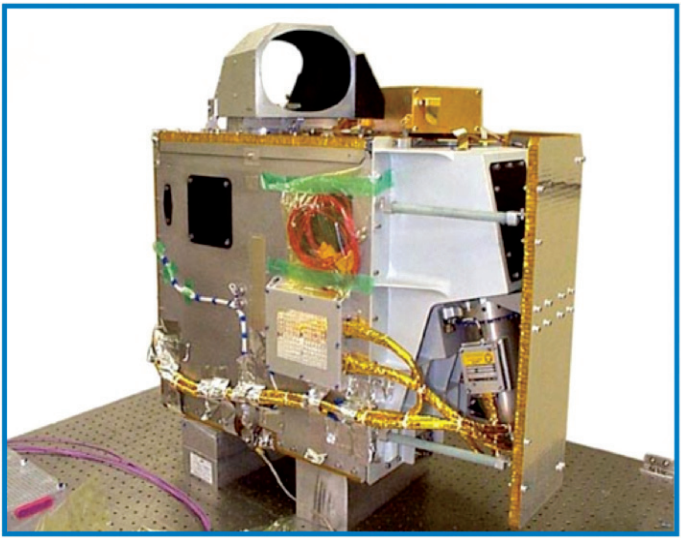


Figure 12 Hyperion spaceborne hyperspectral sensor
(Source: NASA http://eo1.gsfc.nasa.gov/Technology/Hyperion.html. Accessed on 20th. June 2010)

MODIS (NASA's Moderate Resolution Imaging Spectroradiometers)

MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. These data will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. MODIS is playing a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment.

The MODIS Rapid Response System was developed to provide daily satellite images of the Earth's landmasses in near real time. True-color, photo-like imagery and false-color imagery are available within a few hours of being collected, making the system a valuable resource for organizations like the U.S. Forest Service and the international fire monitoring community, who use the images to track fires; the United States Department of Agriculture Foreign Agricultural Service, who monitors crops and growing conditions; and the United States Environmental Protection Agency and the United States Air Force Weather Agency, who track dust and ash in the atmosphere. The science community also uses the system in projects like the Aerosol Robotic Network (AERONET), which studies particles like smoke, pollution, or dust in the atmosphere. More information about science and application partners, including links, is provided on the applications page (http://rapidfire.sci.gsfc.

nasa.gov/apps/). Captioned interpreted images for educators, the media, and the public are available through the Earth Observatory. The system is freely available to everyone–scientists, operational users, educators, and the general public. The Moderate Resolution Imaging Spectroradiometer (MODIS) flies onboard NASA's Aqua and Terra satellites as part of the NASA-centered international Earth Observing System. Both satellites orbit the Earth from pole to pole, seeing most of the globe every day. Onboard Terra, MODIS sees the Earth during the morning, while Aqua MODIS orbits the Earth in the afternoon. Figure 13 shows a sample image of aerosol detection using Terra-1 MODIS.

Figure 13 Aerosol detection using Terra-1MODIS image
(Source: Itten and Nieke, 2007)

Proba's CHRIS (Compact High Resolution Imaging Spectrometer)

The CHRIS (Compact High Resolution Imaging Spectrometer) is a new physically compact payload imaging spectrometer, carried on board a new space platform called PROBA (Project for On Board Autonomy). The satellite was successfully launched in late October, 2001. CHRIS has the additional advantage of being relatively cheap and easy to manufacture since it has no moving parts. Its main applications have been in environmental monitoring, forestry inventory and precision farming. From a 600 km orbit, CHRIS can image the Earth in a 14 km swath with a spatial resolution of 18 m. This is somewhat variable as the altitude varies around the orbit. Using PROBA's agile steering capabilities in along and across track directions enables observation of selectable targets well outside the nominal field of view of 1.3^{o}. Images can generally be acquired in sets of five, these being taken at along track angles of +/- 55^{o}, +/- 36^{o}, and as close to nadir as possible. CHRIS operates over the visible/near infrared band from 400 nm to 1,050 nm and can operate in 63 spectral bands at a spatial resolution of 36 m, or with 18 bands at full spatial resolution. Spectral sampling varies from 2-3 nm at the blue end of the spectrum, to about 12 nm at 1,050 nm. Sampling is about 7 nm near the red edge (approx. 690-740 nm). The instrument is very flexible and different sets of bands can for different applications.

Australian Resource Information and Environment Satellite (ARIES-1)

The Australian Resource Information and Environment Satellite (ARIES) hyperspectral remote sensing system would provide users with the next generation of data and information services for mineral exploration, resource mapping and environmental monitoring. It would enable nationally and internationally focused organizations to map key areas of interest more effectively than is possible with existing satellite systems. ARIES would identify a suite of specific minerals and will provide an unprecedented capability to target the surface expressions of potential mineralization and to map geology in greater detail than at present. Combined with other data sets, ARIES-1 data would allow the creation of valuable, new, field-ready mineral maps, anywhere in the world. ARIES would measure variations in green and dry vegetation, bringing an improved capability to map vegetation species and condition leading to new applications in agriculture, vegetation mapping, forestry and environmental monitoring. Calibrated, hyperspectral sensors would permit, for the first time, quantitative extrapolation of biophysical and mineralogical properties between scenes, regions and times. Sophisticated new algorithms would allow more precise identification of sub-pixel components leading to more accurate estimates of ground cover or end-member abundances which would allow the generation of a whole new range of theme specific maps (http://www.auspace.com.au/projects/aries.htm)

China High Resolution Imaging Spectrometer (C-HRIS)

The satellite is a solar synchronous polar orbit satellite. Its altitude is 800 km and the inclination angle is 99°. The local time of crossing point is 10:30. The circle time is 101 minutes and the ground velocity is 6.6 km/s. Every 16 days, the satellites will pass over the same swath of ground. C-HRIS uses two area array detectors and operates in pushbroom mode. Two slits are used at the focal plane of the telescope to separate the spectral waveband into VNIR and SWIR. The 128 waveband imaging spectral data ranging from 0.43 mm is obtained through two flat field spectrometers and CCD and InSb area array detectors. Its MTF reaches 0.6, the spectral transmittance is very high over the whole spectral range, and spectral resolution meets the design requirement. The purpose of developing C-HRIS is to probe the methods to develop the next airborne engineering prototype, and master the critical techniques (http://www.gisdevelopment.net/aars/acrs/1999/ts10/ts10210pf.htm)

The Future Hyperspectral Sensors

Prisma

Italy's ASI space agency plans to launch Prisma, a medium-resolution hyperspectral imaging mission, in 2012. Prisma's hyperspectral camera will be able to acquire images in about 235 channels in the visible and near-infrared and short-wave infrared. Prisma is an Earth-observation system with innovative electro-optical instrumentation that combines a hyperspectral sensor with a panchromatic, medium-resolution camera. The advantages of this combination are that, in addition to the capabilities offered by hyperspectral sensors, which can determine the chemical-physical composition of the target, the panchromatic adds a higher spatial resolution and the recognition of the geometrical characteristics of the scene. This offers the scientific community and users many applications in the field of environmental monitoring, resource management, crop classification, pollution control, etc. Further applications are possible even in the field of national security.

EnMAP (**En***vironmental* **M***apping and* **A***nalysis* **P***rogram)*

EnMAP is a German hyperspectral satellite mission providing high quality hyperspectral image data on a timely and frequent basis. The German Aerospace Center (DLR) and the German Research Centre for Geosciences (GFZ) are planning to launch the EnMAP hyperspectral satellite in 2014 to map Earth's surface in over 200 narrow color channels at the same time. The primary goal of EnMAP is to offer accurate, diagnostic information on the state and evolution of terrestrial ecosystems on a timely and frequent basis, and to allow for a detailed analysis of surface parameters encompassing agriculture, forestry, soil and geological environments, coastal zones and inland waters with regard to the characterization of vegetation canopies, rock/soil targets and coastal waters on a global scale. EnMAP is designed to record bio-physical, biochemical and geo-chemical variables to increase the understanding of biospheric/geospheric processes and to ensure the sustainability of our vital resources. EnMAP is a dedicated imaging pushbroom hyperspectral sensor mainly based on modified existing or pre-developed technology. It has broad spectral range from 420 nm to 1,000 nm (VNIR) and from 900 nm to 2,450 nm (SWIR) with high radiometric resolution and stability in both spectral ranges. The swath width is 30km at high spatial resolution of 30 m x 30 m and off-nadir (30°) pointing feature for fast target revisit (4 days) with a sufficient on-board memory to acquire 1,000 km swath length per orbit and a total of 5,000 km per day.

HysprIRI (Hyperspectral Infrared Imager)

NASA plans to launch the HyspIRI mission in 2015, which will acquire images with 210 spectral bands (http://cce.nasa.gov/pdfs/HYSPIRI.pdf). The HyspIRI mission includes two instruments mounted on a satellite in Low Earth Orbit (LEO). There is an imaging spectrometer measuring from the visible to short wave infrared (VSWIR) and a multispectral thermal infrared (TIR) imager. The VSWIR and TIR instruments will both have a spatial resolution of 60 m at nadir. The VSWIR will have a temporal revisit of approximately three weeks and the TIR will have a temporal revisit of approximately one week. These data will be used for a wide variety of studies primarily in the Carbon Cycle and Ecosystem and Earth Surface and Interior focus areas. The mission is currently at the study stage and this includes the processes of volcanic eruption, analyzing the nutrients and water status of vegetation, deforestation and provides early warning of droughts among others.

METHODS FOR PROCESSING HYPERSPECTRAL SENSED DATA

In order to understand and design a hyperspectral imaging system completely and efficiently, the primary goal of the system must be firstly defined and detailed. The design of a hyperspectral image processing system is a challenge because it is such a software system which incorporates a number of special algorithms and features designed to allow remote sensing scientist to take advantage of the wealth of information contained in large scale imaging spectrometer data easily and efficiently. Processing techniques generally identify the presence of materials through measurement of spectral absorption features. Often the hyperspectral data are post-processed to derive surface reflectance through the use of atmospheric radiative transfer models. Various spectral matching or band rationing techniques are then used to extract the presence and amount of the materials.

According to Zhang et al (2000), the design criteria for the new generation of imaging spectrometer software are as follows: (a) the system should not be related to any software and hardware platform. This means the software is dependent on ENVI/IDL (the Interactive Data Language) no more and compatible for other platforms (Unix, Linux) with little modification, (b) it should be independent of specific image display hardware, (c) the system should allow routine analysis of the available imaging spectrometer data sets in the market. It should support the following data format straight: BSQ (band sequential), BIL (band interleaved by line) and BIP (band interleaved by pixel), (d) the flexible and powerful utilities should be provided for data input, data formatting, data calibration and other common image processing tasks. Data visualization for rapid, exploratory spectra and image analysis should be established especially, (e) the fundamental function of GIS (Geographic Information System) should be included. The analysis result can be exported via standard vector format to exchange with other common GIS software, and (f) the system should be easy-to-use and easy-to-understand.

The first relates to research and applications that require the full width of spectral response to derive indicators e.g. curve derivatives, slopes anpd integrals. These types of spectral curve characteristics have been used by many researchers to describe natural system properties. Application-specific research, on the other hand, requires that only those spectral indicators that apply to a specific question be identified from the hyperspectral curve. The goal in this case is to identify, from this oversampled imaging spectroscopy data source, exactly which spectral features are required to address an application of interest. The research question thus becomes an issue of moving from a situation of ‘more data than we need’, to ‘exactly the data we need’. This effectively allows the development of operational sensors that are hyperspectral in design, cheaper and tailor- made for a specific set of applications.

Since much of the work in the hyperspectral imaging area has been done in the research and academic realms, there are very few commercial sources of hyperspectral data and, more importantly, the capability to perform the processing and interpretation of hyperspectral data. For instance, Spectrum Mapping, Denver, Colorado, is unique in the remote sensing/mapping industry in that they have their own hyperspectral sensor, planes and other instruments such as multi spectral and LiDAR sensors (http://www.specmap.com). Spectrum has the ability to acquire geospatial information with multiple sensors, fusing data from these sources and extracting meaningful "Intelligent Data." Spectrum is integrating high resolution HSI, digital orthophotos and airborne LiDAR data to derive thematic data layers and structural features in urban and natural environments. By collecting all three datasets simultaneously with their own plane, multispectral digital camera, LiDAR, and Hyperspectral sensors, they use a data fusion approach for the development of Intelligent 3-D Urban/Natural Geospatial Databases for GIS, mapping and simulation purposes. The hyperspectral imagery is used for feature attribution using automated spectral analysis techniques. All hyperspectral pixels are geo-located to their corresponding LiDAR point data, giving each point an identifiable material class to be used in the visualization construction process. The hyperspectral data is also used to generate an overall land cover map, which provides feature class names and material class attributes for all surface features contained within the project area. Extracted features include: roof and building composition; road composition; tree species and health; wetlands; and agricultural classes. The future trend in the remote sensing industry is the fusion of geospatial data from hyperspectral and other sensors which allows the creation of thematic data layers and structural features for urban and natural environments that can be critical elements of any geospatial database, providing a powerful toolkit that may not solve crimes, but enable intelligent data analysis.

Geo-Referencing Hyperspectral Data

Geo-referencing has been covered extensively in most remote sensing digital analysis; therefore, there is not a lot new to say about it here. Because all of the airborne sensors described above are either pushbroom or whiskbroom scanners, they all require a direct geo-referencing system in order to reconstruct a coherent, geometrically-correct, two-dimensional image. Only then can rigorous orthorectification be performed using an existing DEM of appropriate resolution and vertical accuracy. As an example, as a first step in UPM-AISA airborne hyperspectral data processing, SPECIM's software Caligeo was used to convert the raw hyperspectral data into radiance and later geo-rectify the image to a map. The geo-rectified strip over an oil palm plantation was first visualized in true colors and later a palm tree detection algorithm needs to be applied to remove the background and create a palm tree map. This optimized detection algorithm utilizes sensitive spectral information particularly in the red edge region where it shows the tree map after the diseased/pest infested/soil nutrient deficiency detection algorithm has been applied. Infected trees are visualized in range of grey color, and healthy trees in black (Figure 14) which will make it easy for the plantation field workers to identify and locate the infected individual oil palm trees (Kamaruzaman 2008d: 2009b).

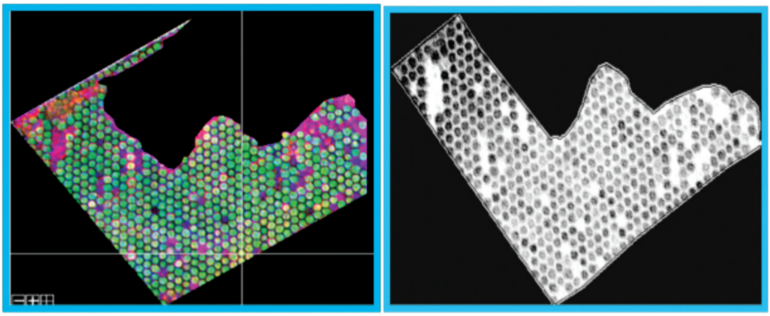


Figure 14 A UPM-AISA airborne hyperspectral thematic precision product image in true colour (left) and grey scale map (right) indicating the number of healthy (green/black), stressed (yellow/grey) and dead palms/barren areas (pink/white)

It has been a well known fact that DEM accuracy also affects the horizontal accuracy of the end hyperspectral product. When attempting to correlate hyperspectral pixels to distinct phenomena observed on the ground, it is critical to have as accurate an XY location for each pixel as possible. Removal of relief displacement and sensor tilt from the raw images is also critical to temporal change detection using images. It is imperative to note that the success of hyperspectral data for characterising vegetation biophysical parameters is also dependent on the analytical techniques followed. These analytical techniques can be broadly divided into physically-based models and empirical methods. While most physically-based radiative transfer models, such as the PROSPECT and SAIL, have been developed and widely applied in homogenous vegetation, their application in Malaysia is not that common. This is partly due to the difficulties related to model parameterisation and also because of the heterogeneous nature of the tropical forest. Owing to the heterogeneous nature our tropical forest, which is rather site specific, most hyperspectral remote sensing studies have followed the empirical approach using statistical tools, such as multiple regression, discriminant analysis, transforms (e.g. principal component analysis) and support vector machines. Research in the physical modeling approach is now moving towards the 3D radiative transfer models that can cater for the heterogeneous nature of our tropical forest.

Furthermore, analysis of imaging spectroscopy data presents various challenges, especially in terms of ensuring statistical validity of an approach, given on the large number of potential independent variables in a modeling scenario. This is referred to as ‘reduction of data dimensionality’ and hints at the types of applications that imaging spectroscopy data and analysis are suited for. Many hyperspectral applications, e.g. mineral mapping, require a contiguous set of wavelengths to define a spectral feature that differentiates between minerals, while other applications, e.g. foliar chemistry assessment, require a defined selection or combination of wavelengths. In the first instance, the hyperspectral data curve can be subset to include only that spectral range of interest. However, in the second case, robust methods for sub-selecting only those wavelengths that are pertinent to the application need to be developed.

Competitive Hyperspectral Detection Software and Algorithm

MicroMSI, Opticks and ENVI are three remote sensing applications that support the processing and analysis of hyperspectral data. The acquisition and processing of hyperspectral images is also referred to as imaging spectroscopy. It has been mentioned earlier that hyperspectral imaging sensors measure the spectrum of each pixel in a 2D image in hundreds of very narrow spectral wavelength (color) bands, resulting in a 3D data cube (hypercube) with one spectral and two spatial dimensions (Figure 15). This high-resolution spectral data can be used to detect and identify spatially resolved or unresolved objects on the basis of their spectral signatures. If each material had a unique spectrum, the solution of detection and identification problems would be straightforward. Unfortunately, variability in material composition and atmospheric propagation, in addition to sensor noise, introduce random spectral variations. Also, for pixels containing unresolved objects, the measured spectrum includes a mixture of object and background contributions. Thus, every detection algorithm has to overcome two major obstacles, which are spectral variability and background interference.

The measured spectra corresponding to the pixels with the same surface type exhibit an inherent variability that prevents characterization of homogeneous surface materials with unique spectral signatures. Radiance from all materials within a ground resolution cell is seen by the sensor as a single image pixel. Therefore, the result is a hyperspectral data cube of pure and mixed pixels, where a pure pixel contains a single surface material and a mixed pixel includes multiple materials. A large number of hyperspectral detection algorithms has been developed and used in the past two decades. A partial list includes classical, finite-target, and mixture-tuned matched filters; Reed-Xiaoli (RX) anomaly detector; orthogonal-subspace projector; adaptive-cosine estimator; and subspace, kernel-matched subspace, and joint subspace detectors. In addition, different methods for dimensionality reduction, background-clutter modeling, end-member selection, and radiance-versus-reflectance domain processing multiply the number of detection algorithms yet further. New algorithms, new variants of existing algorithms, and new implementations of existing methods appear all the time. Furthermore, a large number of papers have been published in attempts to establish the relative superiority of these algorithms such as the one at 1st. IEEE GRSS Workshop on Hyperspectral Image and Signal Processing (WHISPERS 2009) in

Grenoble, France (http://www.ieee-whispers.com/). In this context, it is both time consuming and difficult for designers of hyperspectral imaging systems to navigate through the existing literature to choose a detector or decide if a certain level of performance can be expected.

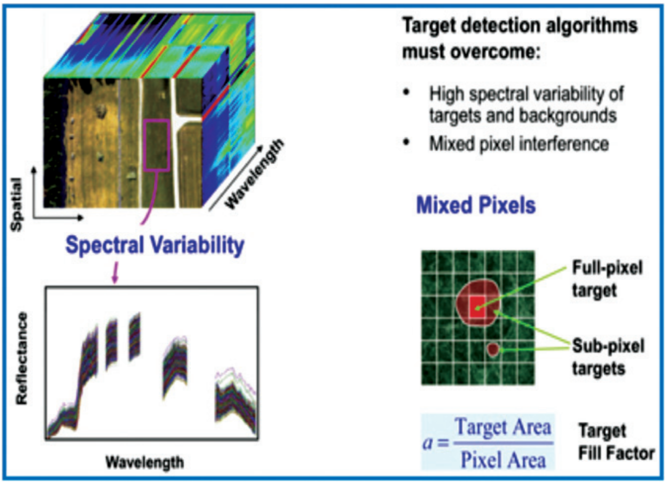


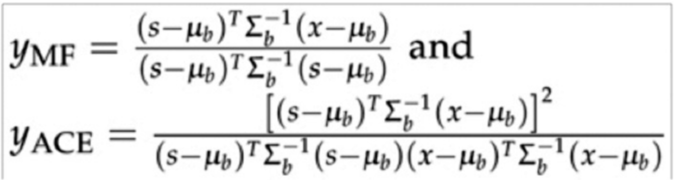
Figure 15 Data-cube structure, spectral variability, and sub-pixel interference in hyperspectral imaging
(Source: http://spie.org/x35496.xml?ArticleID=x35496. SPIE Newsroom 17 June 2009. Accessed on 26th. June, 2010)

The key to the understanding, design, and evaluation of detection algorithms is the use of sufficiently accurate and mathematically tractable models of spectral variability. Each spectrum in the hypercube can be interpreted as a vector (x) in a p-dimensional space, where p is the number of spectral channels. Statistical models of spectral variability consist of multivariate probability distributions. Subspace models are essentially break linear vector spaces defined by $q<p$ basis vectors. If these vectors are spectra of pure constituents (end members), we have the well-known linear

mixing model. Estimating the number of end members and their spectra from a hyperspectral cube is difficult. Thus, the use of the linear mixing model in practical detection algorithms is very limited. Most widely-used detection algorithms assume that spectral variability can be modeled by a multivariate normal (Gaussian) distribution with mean vector μ and covariance matrix Σ. This model requires estimation of $p+p(p+1)/2$ parameters.

Natural backgrounds have multimodal distributions and can be better modeled by Gaussian mixture models. However, estimating their parameters is complicated, and the results are often inaccurate. For a given data cube, it seems preferable to use all data to estimate one covariance matrix, rather than split the data to estimate several matrices (bias-variance tradeoff).

Based on Manolakis et al. (2009), the two robust and easy-to-use detection algorithms that model background variability using a mean vector μ_b and a covariance matrix Σ_b, and represent the target signature as a known spectrum *(s)* are recommended in this lecture. These algorithms are the classical matched filter and the adaptive-cosine estimator, defined by:



$$y_{\mathrm{MF}} = \frac{(s-\mu_b)^T\Sigma_b^{-1}(x-\mu_b)}{(s-\mu_b)^T\Sigma_b^{-1}(s-\mu_b)} \text{ and}$$

$$y_{\mathrm{ACE}} = \frac{\left[(s-\mu_b)^T\Sigma_b^{-1}(x-\mu_b)\right]^2}{(s-\mu_b)^T\Sigma_b^{-1}(s-\mu_b)(x-\mu_b)^T\Sigma_b^{-1}(x-\mu_b)}$$

where, the superscript *T* refers to a transverse matrix operation.

A simple geometrical interpretation is provided in Figure 16 by Manolakis and Shaw (2002) and Manolakis et al. (2003). The mean and covariance of the background are estimated from the data cube. The target signature is obtained from a spectral library. To our knowledge, despite all assumptions regarding the background and target signal models being violated, both algorithms (if properly implemented) compete favorably with any other detector. The key is to estimate Σ_b without using target-like pixels, and its inverse using 'dominant-mode rejection' combined with 'diagonal loading.' The resulting algorithms are numerically stable and robust to target mismatch, target variability, and corruption of background covariance by target spectra. Furthermore, the formula for the inverse covariance matrix provides a link between covariance- and subspace-based algorithms. These can be applied in both the reflectance and radiance domains.

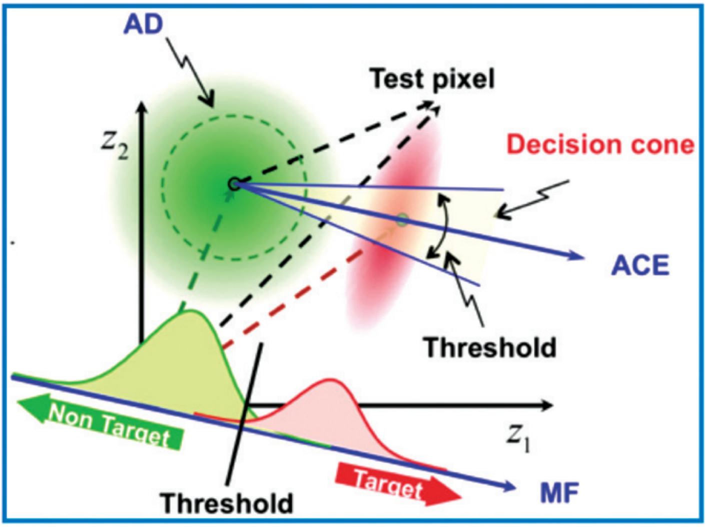


Figure 16 Geometrical interpretation of detection algorithms (Source: Manolakis and Shaw, 2002 and Manolakis et al. 2003).

Practical applications of hyperspectral detection algorithms have to consider many issues that are often overlooked. For example, selecting a threshold to maintain a constant false-alarm rate is challenging. Additional practical limitations, like sensor calibration, sensor noise, atmospheric compensation, small number of pixels compared to the number of spectral channels, background variability, and target mismatch, suggest that any small performance gains attained by more sophisticated detectors may be irrelevant in practical applications, where the goal is to provide the best performance for the greatest number of target-background combinations with the least amount of a priori knowledge required or assumed. Finally, because it is very difficult to acquire data with a variety of targets and a sufficient number of pixels per target, detection algorithms are often evaluated with simulated targets or a single data set with a limited number of target pixels. Although such evaluations are useful, they are not conclusive and they cannot be used to demonstrate the superiority of one algorithm over another. So, is the best hyperspectral detection algorithm available? If the important aspects of real-world hyperspectral imaging problems are taken into account, proper use of simple detectors, like the matched filter and adaptive-cosine estimators, may provide acceptable performance for practically relevant applications. An undiscovered optimal detector probably does not exist. However, even if such a detector has been found, there is insufficient data available now to prove its superiority.

Supportive Ground Measurement and Observations during Hyperspectral Image Acquisition

Through previous research initiatives conducted at the Faculty of Forestry's Tropical Forest Airborne Observatory (TropAIR) UPM, a network of high quality ground reference forest and agricultural plots, environmental and search-and-rescue data has been established. This ground reference dataset was augmented by a detailed GIS database which, included forest inventory data provided by Forestry Department HQ, Peninsular Malaysia. Classifications were performed using training data to create maps of major timber species including the mangroves. These species classifications will be used with spectral unmixing for subsequent potential chemistry analysis and the mapping of canopy chlorophyll, and nitrogen. Geomorphological effects on canopy chemistry will be examined. The long term goal is operational mapping of National Forest Inventory (NFI) for global forest climate change, carbon sequestration and forest health as inferred from canopy chemistry. Hyperspectral forestry applications ready for large scale monitoring are forest area, forest type, biomass, disturbance, chlorophyll, nitrogen, lignin, moisture, foliage age grouping, foliar damage, forest health, above ground carbon, afforestation, reforestation, and deforestation. The supportive ground measurements need to be acquired simultaneously (under the same illumination conditions) with hyperspectral flights or satellite repeated passes. They are essential for calibration and validation of the image data pre-processing procedures. They are used for atmospheric and geometric corrections of airborne/satellite hyperspectral images and assessment of geo-referencing accuracy and quality of at-surface reflectance values. Each flight/ground campaign is specific and therefore main parameters of remote sensing data (e.g., targeting spatial resolution) needs to be based on user demands.

There is a need to prepare a strategized and carefully planned field campaign which consists of the following steps, namely: (a) basic survey of a study site from maps and aerial photographs, (b) detailed in-situ ground survey of the study site, (c) selection of reference targets for at surface reflectance verification, i.e.

spatially homogenous natural or artificial ground surfaces of near Lambertian surfaces (e.g. bare soil, clay, concrete, etc.), (d) measurement of targets coordinates by means of GNSS receiver, (e) selection of ground control points (GCP) for verification of geo-referencing accuracy, i.e. natural (i.e., regular objects with high contrasts between an object and its surrounding) or artificial (i.e., bright square-shaped targets) and (f) measurement of GCPs coordinates. The optical properties of reference targets are measured during image acquisition by field portable spectroradiometer, e.g. Ocean Optic spectrometers or ASD FieldSpec 3. Measured field spectral profiles are used to verify the image data at surface reflectance and also for additional calibration purposes (Figure 17). For post-processing of data from GPS/INS unit are necessary GPS observations. GPS measurements need to be performed at the study site by the GNSS receiver TOPCON or can be taken from any nearest reference station.

Figure 17 An ocean optic hand held spectroradiometer (left) being used to measure spectral signatures of a one-seater RMAF fighter jet that crashed into Mersing coast

Hyperspectral Data Processing

Raw hyperspectral data, either air or spaceborne needs basic pre-processing in order to be useable by the end-users. High quality pre-processing of hyperspectral airborne remote sensing data is important in order to produce the accurate thematic map products. Only then the airborne imaging spectroscopy can be operationally used for development of various applications in forestry, agriculture, ecology, geology, limnology, and other scientific and public domains. Several software tools and packages have been developed for radiometric, geometric and atmospheric corrections of hyperpspectral remote sensing data. One example is the CaliGeo (Spectral Imaging Ltd.) which is a software package specifically developed by SPECIM Ltd. in Finland which carries out the radiometric corrections and orthogeorectification over the raw AISA image data. The PARGE software (Schläpfer, 2006), produced by ReSe Applications Schläpfer and Remote Sensing Laboratories (RSL) of the University of Zurich, is specialized in orthorectification and geo-referencing of remote sensing images. Meanwhile, ATCOR-4 (Richter, 2007) was developed by ReSe and Deutsches Zentrum fuer Luft- und Raumfahrt e. V. (DLR). ATCOR-4 is the software package designed for atmospheric, topographic and BRDF corrections of airborne spectroscopy image data. Atmospheric corrections implemented in ATCOR-4 are based on physical model of atmosphere MODTRAN4 (Schläpfer and Odermatt, 2006). PARGE and ATCOR-4 were developed as a complete package for georectification and atmospheric correction of airborne hyperspectral data and they were adjusted to perform atmospheric corrections even for non-georeferenced data.

Radiometric correction is the first step within all corrections. The acquired raw digital numbers (DN) are transformed into the physical radiometric values (radiance). Direct image georeferencing could be performed in PARGE or CaliGeo software. Data from the GPS/INS unit (geographic coordinates, altitude and attitude angles of the plane during image acquisition) and digital elevation model (DEM) are compulsory for georeferencing in both software packages. Airborne data are mostly affected by geometric distortions caused by variations of the flight path and the attitude of the plane (roll, pitch, heading angle). Direct georectification is performed in two successive steps. First of all, the centre coordinates of all acquired pixels are calculated, and in the second step image data are resampled into a grid of the selected coordinate system. The process of georeferencing includes geometric corrections, orthorectification and image location into a desired map projection. Currently data from almost all hyperspectral system are mostly geo-referenced into a specific coordinate system required in such country. Atmospheric correction is applied in order to remove effect of atmosphere (absorption by atmospherical gasses and aerosols, etc.) and to produce at-surface reflectance from acquired airborne images. Several approaches to atmospheric correction can be employed, namely the Empirical Method where the acquired image spectra is forced to match reflectance spectra of reference collected at the field during supportive ground measurement by means of empirical statistical relationship. At least one reference target is required for calculation of linear regression for each band but more reference targets result in higher accuracy of reflectance values. On the other hand, in the FODIS Ratio technique, the whole image cube is divided by data acquired by FODIS sensor, which measure the incoming solar irradiance at the aircraft level per acquired band. The result is at-sensor reflectance (atmospheric effects caused by atmosphere between the aircraft and ground remain uncorrected). Meanwhile, the Radiative Transfer Models is the most common and universal approach which uses one of the atmospheric radiative transfer models, e.g. ATCOR-4 coupled with MODTRAN4 atmospheric model. The ATCOR-4 software package is offering also other additional corrections of hyperspectral data like topographic correction, BRDF correction, etc.

All hyperspectral remote sensing thematic map products must indicate some forms of accuracy level with ground truthings or verification support. Classification accuracy depends on a number of factors, of which the nature of the training samples, the number of bands used the number of classes to be identified relative to the spatial resolution of the image and the properties of the classifier are the most important. For example, the methodology for water constituents - chlorophyll detection will evolve the correction for atmosphere effects, correction for air-water interface effects, and inversion of the sub-surface radiation for the determination of the quality parameters such as chlorophyll a or suspended matter. High spectral and spatial resolution data were used to compare the performance of four classification procedures (maximum likelihood, neural network, support vector machines and decision tree). There was no evidence to support the view that classification accuracy inevitably declines as the data dimensionality increases. The support vector machine classifier performed well with all test data sets. The use of the orthogonal MNF transform resulted in a decline in classification accuracy. However, the decision-tree approach to feature selection worked well. Small increases in classifier accuracy may be obtained using more sophisticated techniques, but it is suggested here that greater attention should be given to the collection of training and test data that represent the range of land surface variability at the spatial scale of the image (Pal and Mather, 2006)

CAN THE "UNSEEN" BE CAPTURED BY HYPERSPECTRAL TECHNOLOGY?

Hyperspectral is the key to forest remote sensing technology and the wide range of products possible for forest resources inventory surveying, mapping and other applications (Kamaruzaman, 2009i, Kamaruzaman, 2008d). Although the Malaysian forest types have been described and mapped, detailed features such as species mapping, distribution and finer physiognomic and biochemical characteristics are still outstanding. Variations in leaf structure and orientation due to the different forest types, tree composition and phenology, different soil background effects, as well as the highly variable effects of standing litter, which often dominates the total fraction of aboveground biomass, complicate the forest CSI variables such as biochemicals and species identification, mapping and distribution in such heterogeneous environments. Bamboo, (Kamaruzaman, 2007a), timber (Kamaruzaman, 2007b) and mangrove (Kamaruzaman and Kasawani, 2007; Kamaruzaman, 2006c) species discrimination, biomass assessment, leaf area index (LAI) estimation, foliar water content measurement, crop growth modeling and net primary productivity estimation are areas where imaging spectroscopy has been applied effectively in Malaysia and elsewhere.

The DNA imaging spectroscopy of the tropical forest *CSI* is a relatively new field of study in Malaysia, yet research has revealed that the approach is critical in characterizing various properties of the tropical forest vegetation. Conveying remote sensing data as a complement to ground-based inventory and management presents a significant challenge. Indeed, airborne hyperspectral imagery services offer to forest manager's current and potential tools to retrieve both qualitative and quantitative information at appropriate level on forest health status and its changes such as forest cover detection and characterization (tree crowns delineation, tree trunks location, tree diameter), discrimination of dominating and rare species, common tree species differentiation and classification and early detection of disease, health status identification. A brief overview of the application of imaging spectroscopy for forest *CSI* analysis is presented with particular reference to Malaysia.

Forestry

Individual Tree Species and Timber Volume

There is a need of ways to definitively identify any unseen and hidden objects on the ground, name it a tree or plant species from the air or space in order to study species diversity and patterns of invasion. In theory, each species should have its own unique fingerprint based on the chemicals in its leaves and stems, which will reflect slightly different wavelengths of light. To develop a key to these fingerprints, leaf samples need to be collected in the old-fashioned way-on foot-and matching each species and their biochemistry with the spectra of light they reflect. With this information in hand, it is testing the sensor's ability to accurately detect plant "DNAs" or fingerprints from the air. As it refines the system, it is my hope to eventually be able to identify the entire tropical timber tree and plant species in a study area with just one pass. The task of distinguishing between spectrally similar materials clearly illustrates the benefits of hyperspectral remote sensing. Figure 18 shows the image spectra of three timber tree species from Gunong Stong F.R., south of Kelantan as measured by UPM-AISA's hyperspectral airborne sensor. All three species have almost a subtle different absorption features and dip displays in the VIS light feature with several narrow contiguous bands. This airborne hyperspectral sensor collects enough spectral detail to see the individual species double dip, distinguishing between the three very similar species. Analogous work using hyperspectral imagery has also been performed to distinguish vegetation species, vegetation condition, construction materials, types of camouflage, and other spectrally similar materials

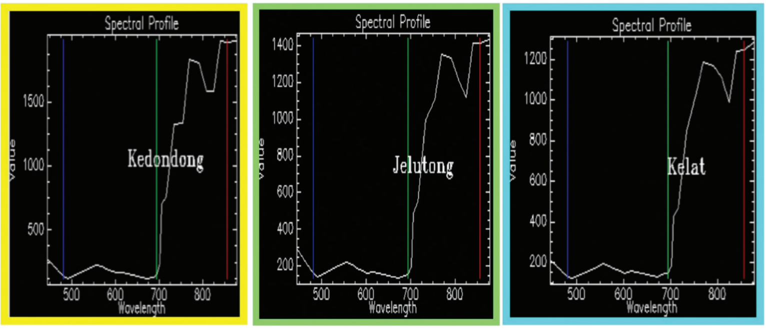


Figure 18 Image pixel spectra from a UPM-AISA Classic airborne hyperspectral image. The left spectrum is from a pixel filled Kedondong, middle with Jelutong and the right spectrum is from a pixel filled with Kelat species

By now, the question should have crossed our mind as to how well individual tree species (and the individual trees themselves) can be identified by various hyperspectral sensors and data processing techniques (Kamaruzaman, 2007c). Generally, if complete spectra over VIS, NIR, and SWIR regions of the electro-magnetic spectrum are available, the discrimination of species can be accomplished with acceptable accuracy. Figure 19 demonstrated how the individual species were easily identified, delineated and mapped at 1.5 m spatial resolution using a UPM-AISA Classic hyperspectral sensor through their individual tree crowns in one of the compartments in Gunong Stong F.R, Ulu Kelantan. Meanwhile, similar supporting work in Sg. Buloh F.R showed that individual species mapping and timber volume estimate using a UPM-AISA hyperspectral is possible when four similar species indicated four significant differences in their spectral signatures despite only subtle differences were observed (Figure 20). In another study at Bukit Lagong F.R., Kepong, the UPM-AISA Classic hyperspectral sensor was able to quantify five dominant species (Seraya, Meranti tembaga, Keladan, Keruing gombang and Kapur) with a total timber volume estimate of 351.45 m^3 over a 7.5 ha forest block. A tree stand density of 46.9 m^3/ha was recorded with a mean volume of 0.99 m^3/tree and a mean diameter at breast height of 69.5 cm and tree crown diameter of 12.19 m. *Shorea curtisii* seemed to be very distinctive (white colour) from the other species due to their high reflectance over the other species (Figure 21).

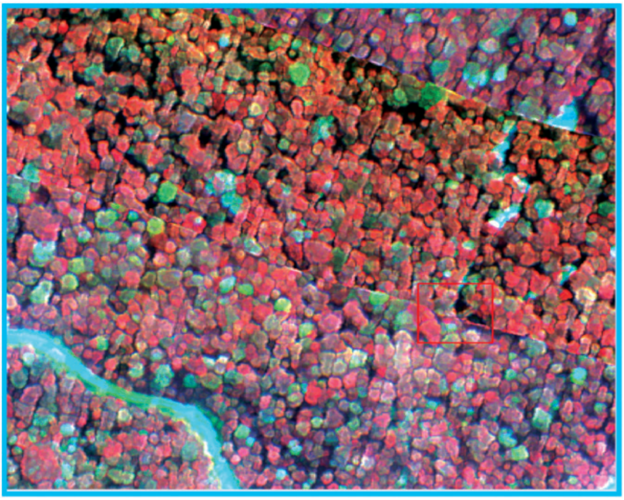


Figure 19 A 1.5 m spatial resolution image of individual tree crown over Gunong Stong, Kelantan acquired from a UPM-AISA Classic airborne hyperspectral sensor

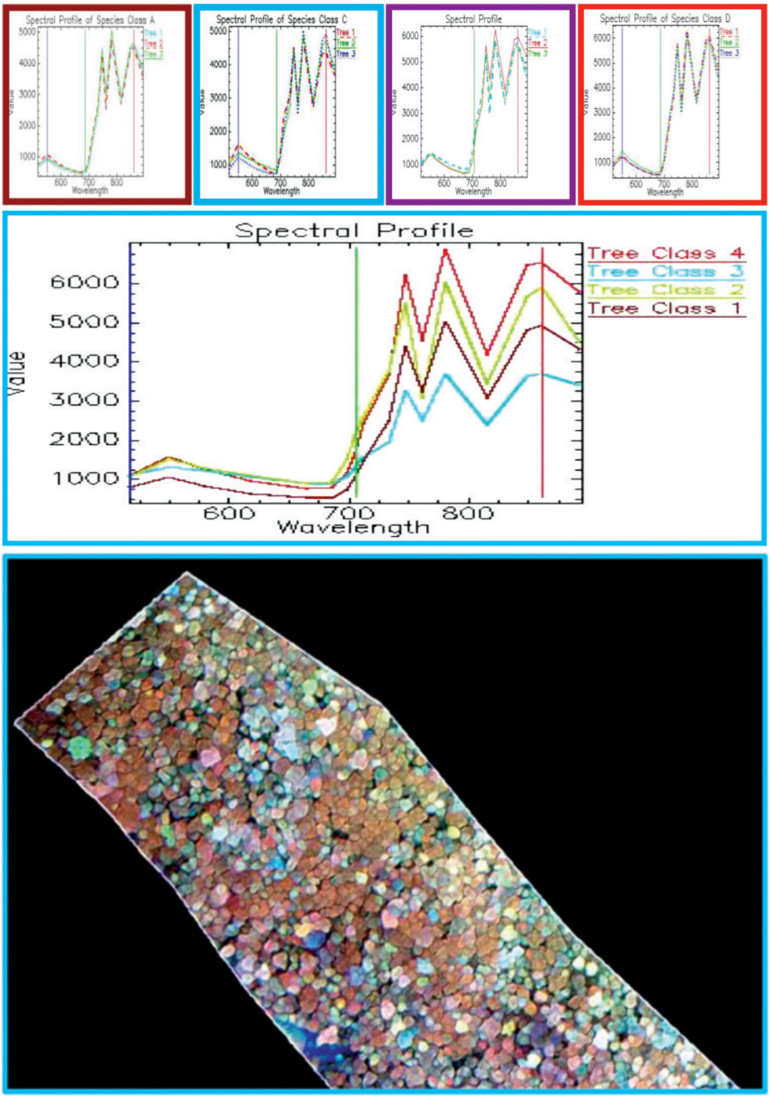


Figure 20 Assessment of four spectral signatures (DNAs) in a flight strip over Sg. Buloh

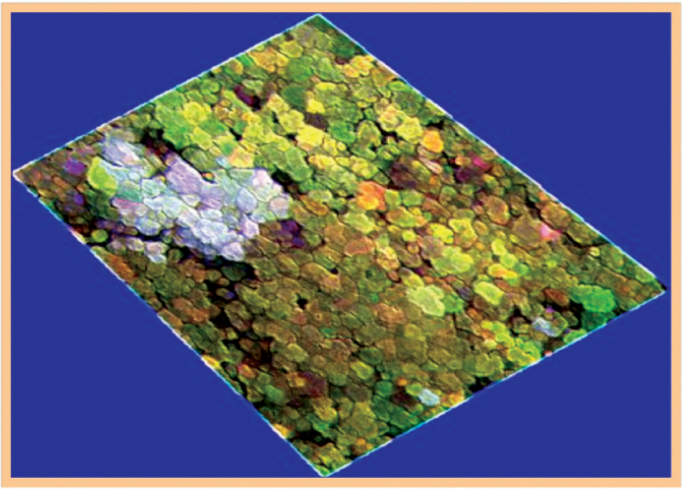


Figure 21 A tree species map of one of the flight strips in Bukit Lagong F.R, Kepong

Another study in UPM showed that UPM-AISA images (Figure 22) coupled with adequate ground truth, can be effective in classifying, quantifying and mapping individual trees down to the species level. This study of urban tree classification in UPM Serdang Campus surrounding the Faculty of Forestry supports well the discrimination of species can be accomplished with a high acceptable accuracy of 90%. The UPM-AISA Classic airborne hyperspectral data sets can easily counted 67 trees before enhancement and 184 trees after enhancement with the help of ground verifications.

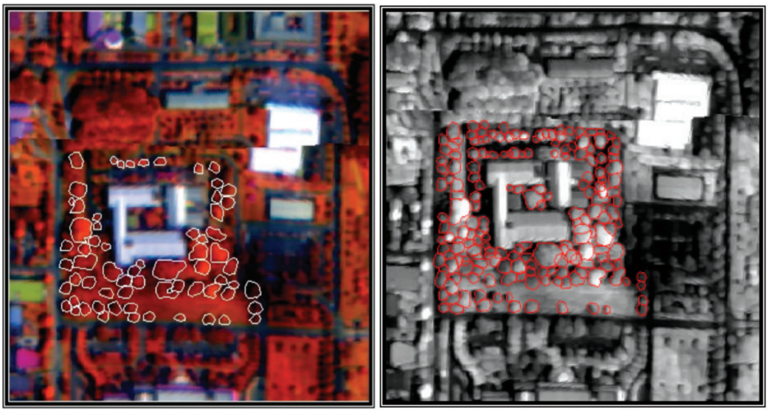


Figure 22 A UPM-AISA tree species product map surrounding the Faculty of Forestry, UPM

Unpermitted Logging and Deforestation

The issue of unpermitted logging or illegal logging has never been resolved in Malaysia. There has been a collaborative work between Peninsular Malaysia Forestry Departments HQ and the Malaysian Remote Sensing Agency to monitor the Malaysian forest with a satellite-based computerised system which monitors both licensed concession areas to detect compliance with regulations as well as high potential areas for illegal land clearing. Certainly, by identifying and tracking down logging machines or skid trails used by illegal loggers in a shorter and precise manner with hyperspectral sensors, we can detect illegal loggers faster by going down to the field to check. The construction of skid trails and skid roads outside the logging concession area as well as logging of prohibited trees can be easily prohibited if licensed logging areas as well as sensitive areas are being imaged with airborne hyperspectral sensor as shown Figure 23, say twice a week. This proposed hyperspectral system has all the required and relevant data incorporated into it, including the template for licensed land boundaries, so it is immediately known that a crime is being committed with the hope that such hyperspectral images can be used as evidence in court for fines and penalties.

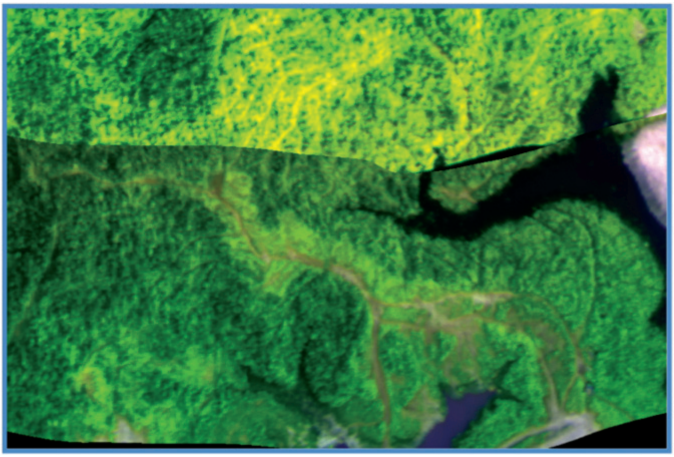


Figure 23 Detection of foot path/tracks (in yellow) and unpermitted forest trails (in grey) leading to Sg Rasau in Ayer Hitam F.R as mapped by UPM-AISA airborne sensor

Deforestation is likely to increase and historical deforestation rates will not help Malaysia to predict how fast this change will be. Baselines for current emission rates are deeply controversial. Near real-time hyperspectral datasets can monitor the range of official processes relating to forest management for example, of the initial allocation of logging concession permits, the management of these concessions and related logging activities, as well as the subsequent processing and trade in forest products in relation to deforestation. To date, the focus will be on observing official oversight and control of logging concessions and giving support to State or Peninsular Malaysia Forestry Department HQ law enforcement agencies to help them develop strategies and procedures. The aim is to ensure the elimination of illegal logging and related corrupt practices, not the elimination of companies operating within the law. Using a hyperspectral sensing approach, the protected area effectiveness in reducing tropical deforestation can be easily assessed. Hyperspectral remote sensing is crucial to get the measure of forest loss. In order to calculate the extra carbon released when a forest is chopped down or degraded, we must know precisely what area is affected and must estimate how much carbon that forest stores. The quality of these data could make or break Reducing and Emissions from Deforestation and Forest Degradation (REDD) initiatives. Hyperspectral remote sensing satellites should be in a position to monitor forest cover at global, national and regional levels, providing data for forest cover maps. For example, large-scale deforestation, i.e. in patches extended by more than 25 ha-is easily spotted using satellite images from sensors such as the U.S. National Aeronautics and Space Administration (NASA)'s Moderate Resolution Imaging Spectroradiometers (MODIS). Smaller patches can be detected using satellites offering higher resolution imagery, such as those used by Brazil's Amazon Deforestation Monitoring Project, PRODES. Deforestation hotspots, once identified, can then be examined more carefully using ground or airborne observations. Better still, if this technology can be made accessible to non-forestry hyperspectral remote sensing experts who are working on the applications of forest cover and deforestation.

Monitoring deforestation and/or illegal logging in Malaysia yearly with hyperspectral sensing will help, but it takes time and money. Countries like Malaysia has made some attempts and efforts to do this systematically with some political will, but very often there is insufficient funds, infrastructure and human capacity. Countries differ widely in their capacity to monitor and measure emissions from their forests. Perhaps, Malaysia should follow the footsteps of Brazil, the country with the largest tropical forest and the single largest emitter of greenhouse gases from tropical forest loss-30% of global emissions from deforestation. Brazil is also one of only two developing countries with a long-running forest monitoring programme using high resolution satellites.

Biomass in the Trees and Forest Carbon Stocks

Hyperspectral remote sensing should be able to satisfy one of the program requirements of Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD) which is estimating just how much carbon is locked up in a particular forest (Kamaruzaman, 2009i). Typically, about half of a tree's biomass is carbon. Besides the direct measure of carbon by cutting the tree down, dry it out and weigh it, we can also map and measure indirectly the carbon by hyperspectral sensing of the individual tree and apply some modeling work. Traditionally, forestry researchers do this and then devise ways of scaling up the measurements. For example, the biome-average method synthesises a few rough numbers for different categories of forests, some broad numbers for each type of forest's carbon stocks, and paints the summary onto land cover maps. The results are globally consistent but highly uncertain. Another, more precise method is a forest inventory that uses the diameters of the trees and their heights to estimate biomass. The UN FAO compiles such inventories for countries around the world but these are slow to produce and can be spotty and inconsistent. How could then hyperspectral remote sensing help?

Radar sensors on satellites and airborne laser sensors show promising results, but it remains expensive and technically demanding. In a decade's time, it is expected that increased investment and research may fell these technical obstacles. For now, combining existing hyperspectral remote sensing techniques with field measurements should give Malaysia reasonably good estimates of the carbon lost from her forests. Field measurements have always been vital to collect the information on carbon stocks.

Foliar Chemistry

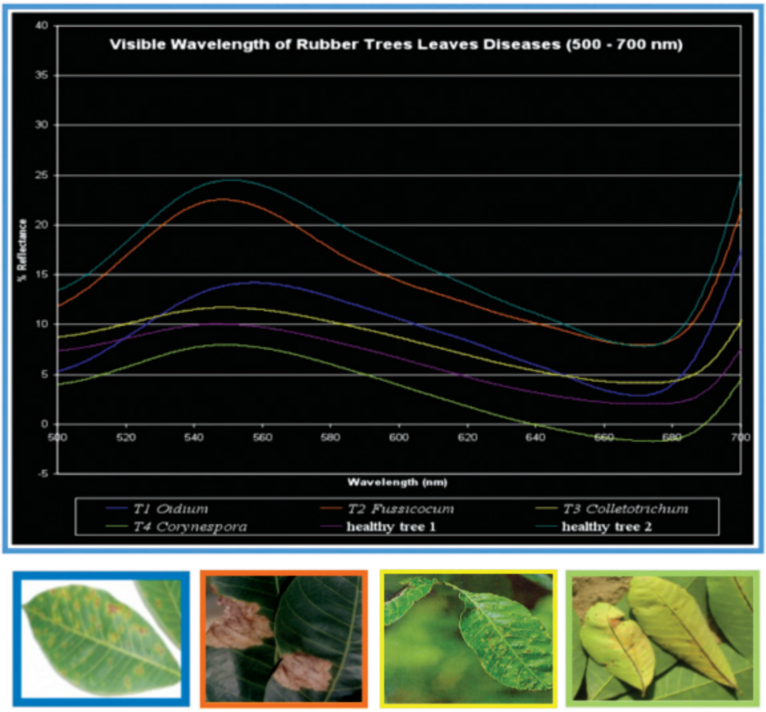
Laboratory near-infrared spectroscopy methods triggered the hyperspectral remote sensing of foliar chemistry, mainly predicting protein, amino acids, lignin and cellulose concentrations contained in dried, ground forage. This technique has replaced wet chemistry as the standard analytical procedure for assessing plant biochemicals in many laboratories. The premise behind the hyperspectral detection and mapping of foliar biochemicals is that plants absorb electromagnetic radiation through the molecular vibration (rotation, bending and stretching) of bonds (C-H, N-H, O-H, C-N and C-C) which form the primary constituents of organic compounds. Therefore, the amount and composition of biochemicals in plants determine the amount of energy reflected per wavelength. A list of absorption features that is related to particular plant compounds has been produced by many researchers comprising 45 absorption features that are related to particular biochemical compounds between 400 nm and 2,500 nm.

Techniques to estimate foliar biochemical using hyperspectral imaging have gradually developed over the years. Overseas, attempts were made during the late 1980s to estimate forest biochemical composition using first difference-at-sensor radiance measured by the Airborne Imaging Spectrometer (AIS). Strong correlations were found between AIS data and total canopy lignin and nitrogen content in deciduous and coniferous forests. Biochemical concentrations have also been estimated using AVIRIS spectra in mixed species forest canopies using first derivative reflectance and stepwise linear regression. Attempts to estimate foliar chemistry in sparsely vegetated canopies have been made using wavelengths related to known biochemical absorption features, a data reduction technique that minimizes over-fitting and the effect of spectral variability that is independent of the biochemical concentration. Key wavelengths located in the shortwave infrared region as well as the red edge position, have been linked to the concentration of foliar nitrogen and tannins. The technique can be successfully scaled to canopy level for the estimation of foliar biochemicals using air or spaceborne imagery with an artificial neural network.

Forest Plantation Tree Stress and Damage

Pests and diseases cause mortality in plantation forests and natural vegetation. Advances in imaging spectroscopy have offered opportunities to timely assess and delineate a range of forest health conditions. Leaf reflectance and shifts in the red edge position have been associated with insect infestation through damage of the waxy cuticle, destruction of cell walls and reduction in plant moisture. Zhang et al. (2000) investigated the utility of imaging spectroscopy for crop disease detection using tomatoes infected by *P. infestans* (late blight) as an example. A minimum noise fraction (MNF) transformation was applied to AVIRIS imaging spectroscopy data (224 bands; 400-2,500 nm), which reduced the dimensions to 28 MNF components. The MNF components were subjected to end-member spectra selection and Spectral Angle Mapper (SAM) classification. Results indicated that the blight-diseased tomatoes could be effectively separated from the healthy plants. Similarly, a series of spectral indices was computed from airborne UPM-AISA imaging spectroscopy data to detect the severity of *Hevea brasiliensis* foliage damage caused by leaf fall diseases (Kamaruzaman et al., 2010). Results from independent validation data showed that hyperspectral data could discriminate between the different levels of blight infection with accuracies above 70% using a four-band combination comprising bands located in the visible and red edge portions of the electromagnetic spectrum.

Spectral signatures from diseased infested rubber plantation trees can be also collected and archived as shown in Figure 24. Once every individual rubber tree has been captured using both the field and image spectras, the rubberwood plantation's volume can easily be calculated with the help of some ground work and standing timber volume models. The correlations between the different crown area of rubber trees and the diameter at breast height with the ancillary data were obtained. It shows that the rubberwood volume of an old matured unmanaged rubber plantation can easily be predicted with high accuracy obtained through this approach (Kamaruzaman and Malek, 20009a; Kamaruzaman et al., 2010). A total of 20 rubber tree samples was identified, quantified and mapped representing a standing rubberwood volume of 91.44 m^3/ha and a mapping accuracy of 89.84%. Similar work was repeated by Kamaruzaman (2008c) on old growth plots of wild unmanaged *Acacia mangium* plantation in UPM Serdang. Results indicated the presence of 29 canopies of *A. mangium* trees over a 0.8 ha plot. A single crown or canopy represented a single tree. A set of simple linear regression model for predicting volume from the crown area was developed using the 29 samples of tree crown. The value for R^2 was 0.801 for this fit of the model, which showed 80.1% erratum data could be evaded. The equation developed in this study was $V = 0.1045 + 0.0111(CA)$ where it provides a mean for predicting volume from the crown size measurement using the airborne sensor. The total standing timber volume mapped and quantified by the UPM-AISA Classic sensor for the study site of 0.8 ha *A. mangium* plantation was about 20.73 m^3 with a mapping accuracy of 80.45%. In practice, users of airborne hyperspectral data can now predict the timber volume by measuring tree crown size using ENVI software and apply the appropriate equation developed from linear regression as the indirect method of timber volume estimation.



Oidium Fussicum Collectotrichum Corynespora

Figure 24 The image spectral signatures (*DNAs*) of a rubber tree leave diseases in the VIS electromagnetic spectrum as obtained from the handheld spectroradiometer

Leaf Chlorophyll Content

Hyperspectral remote sensing, especially airborne imaging has great potential for accurate retrieval of forest biochemical parameters with a suitable hyperspectral remote sensing algorithm to retrieve the total leaf chlorophyll content. Studies by Blackburn (1998) and Staenz (1992) with an airborne CASI sensor have shown that the estimated canopy reflectance agrees well with the CASI measured reflectance in the chlorophyll absorption sensitive regions, with discrepancies of 0.06% – 1.07% and 0.36% – 1.63%, respectively, in the average reflectance of the red and red-edge region. An empirical relationship of simple ratio derived from the CASI imagery to the ground-measured leaf area index can be developed to map leaf area index. Canopy chlorophyll content per unit ground surface area can then estimated, based on the spatial distributions of leaf chlorophyll content per unit leaf area and the leaf area index.

Besides airborne hyperspectral data, Serrano et al. (2000) used AVIRIS data to estimate water content in Chaparral vegetation. In South Africa, Hyperion imagery was used to estimate LAI of *Eucalyptus* in the coastal Zululand of KwaZulu-Natal Province. A LI-COR 2000 was used to measure LAI on seven plots in the study area. Reflectance measurements and indices from Hyperion Level 1R data were regressed against LAI measurements. Results indicated that all relationships between LAI and the computed vegetation indices were significant ($P < 0.05$) with relatively high R^2 values ($R^2 > 0.80$). Another study by Mutanga and Kumar (2009) assessed the utility of hyperspectral remote sensing to discriminate between site qualities in *E. grandis* plantation in KwaZulu-Natal, South Africa. The relationships between physiology-based hyperspectral indicators and site quality, as defined by total available water (TAW), were assessed for *E. grandis* using one-way analysis of variance (ANOVA). These results show that differences in site quality, based on total available water, could be detected using imaging spectroscopy of canopy water or chlorophyll content.

Non-Forestry

Besides forestry, hyperspectral imaging can be an extremely powerful tool in a wide variety of other applications, due to the ability of producing scientific quality spectroscopic data with high spatial resolution at high speeds. Land applications include vegetation studies (species identification, plant stress, productivity, leaf water content, and canopy chemistry), soil science (type mapping and erosion status), geology (mineral identification and mapping) and hydrology (snow grain size, liquid/solid water differentiation). Lake, river and ocean applications include biochemical studies (photoplankton mapping, activity), water quality (particulate and sediment mapping) and bathymetry. Atmospheric applications include parameter measurement (water vapor, ozone, and aerosols) and cloud characteristics (optical thickness, cirrus detection, particle size). Quite a number of recent symposia and a journal special issue provide a sampling of the various potential real world applications and techniques that benefit from hyperspectral data, such as materials mapping (sand, clay, gravel, asphalt, vegetation, and water), land use/cover classification, pervious/impervious surface mapping, identification of geologic materials, detecting and identifying indicators of water quality (turbidity, chlorophyll, organic and inorganic pollutants), vegetation type mapping for both terrestrial and aquatic, vegetation health and vigor and insect pest infestations of forests and crops, amongst others (Kamaruzaman, 2009h and Itten, 2010). Some of the main selected non-forestry application areas are highlighted.

Coral Reef

Coastal managers can use hyperspectral remote sensing data to determine the effects of tide restriction on marsh habitat and help prepare for future restoration and preservation projects. Scientists from the Meadowlands Environmental Research Institute and Rutgers University compared habitat heterogeneity in tide-restricted areas and tide open areas using hyperspectral remote sensing. Hyperspectral imagery from the Airborne Imaging Spectroradiometer for Applications (AISA) instrument was used to create a thematic map of marsh surface types in the New Jersey Meadowlands. They found a significant difference in landscape heterogeneity between tide-open and tide restricted marsh areas. Tide-open sites displayed a greater number of patch types and a more even distribution than tide-restricted sites. Results from this project revealed the potential for using hyperspectral imagery on its own to identify marsh features that are ecologically significant. More hyperspectral mapping work of coral reef benthic substrates using hyperspectral space-borne images and spectral libraries in the coral reef of Australia with Hyperion and Malaysia with UPM-AISA were reported by Kutser et al (2006) and Kamaruzaman (2009f), respectively. Figure 25 illustrated the hyperspectral power of the Bohey Island Map which was derived and created from a UPM-AISA airborne sensor campaigns in Sabah.

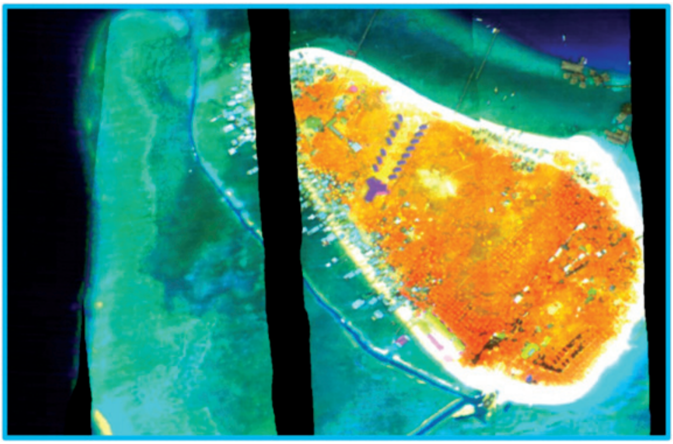


Figure 25 A UPM-AISA's sample image of the rich corals surrounding Bohey Island, Sabah

Oil Palm Tree Health and Plantation Age

In the field of tropical agriculture especially for precise farming, some successful progresses have already been achieved with hyperspectral sensing. They are the works of Kamaruzaman (2006a, 2006b), Kamaruzaman (2007d), Kamaruzaman (2009a; 2009b; 2009c; 2009d) and Kamaruzaman and Malek (2008; 2009b) and Kamaruzaman and Mubeena (2009) amongst others. Various methods are investigated for in-vivo photodiagnosis that could be made amenable to hyperspectral analyses, by producing spatio-spectral signatures. The Forest Geospatial Information and Survey Laboratory at Lebuh Silikon, UPM first pioneered the precision oil palm plantation mapping using a UPM-AISA Classic airborne hyperspectral sensor to monitor the growth development and age status (Kamaruzaman and Malek, 2009b; Kamaruzaman, 2009g). More recently, one of the state governments has experimented the RT3052 Inertial and GPS navigation systems in combination with an AISA Eagle hyperspectral sensor to determine the condition of oil palm's basal stem and root rot from the air http://www.oxts.com/client/images/500_Platform.jpg). As this common infection can have a negative impact on palm oil production, airborne hyperspectral imaging was used to assess the scope of the damage where the RT3052 system onboard the hired aircraft provides accurate position, roll, pitch and true heading measurements. It is expected that the sensor system could detect and map the distribution of infected oil palm trees due to pest and diseases. With a map showing the health condition of individual palm trees, the plantation agencies may now operationalized similar systems to treat the oil palm trees in specific locations which have been identified by the hyperspectral survey. On the other hand, spectrally continuous UPM-AISA hyperspectral remote sensing data can also provide information on the different ages of oil palm and replanted areas, which are important for oil palm stress studies, nutrient cycling, productivity and post harvest planning. Figure 26 clearly pin-pointed the different ages of oil palm and the newly replanted areas of the plantation. Using such geo-referenced hyperspectral technology brings many benefits in precision oil palm sustainable plantation management. Once the individual single oil palm locations have been mapped, the amount of fertilizer and fungicide needed is properly managed and drastically reduced, saving money and reducing the damage on the environment. The time taken to treat the infected tree growth process can be also reduced. Early treatment and management to individual trees prevents any diseases or pest infestation from spreading, further reducing costs.

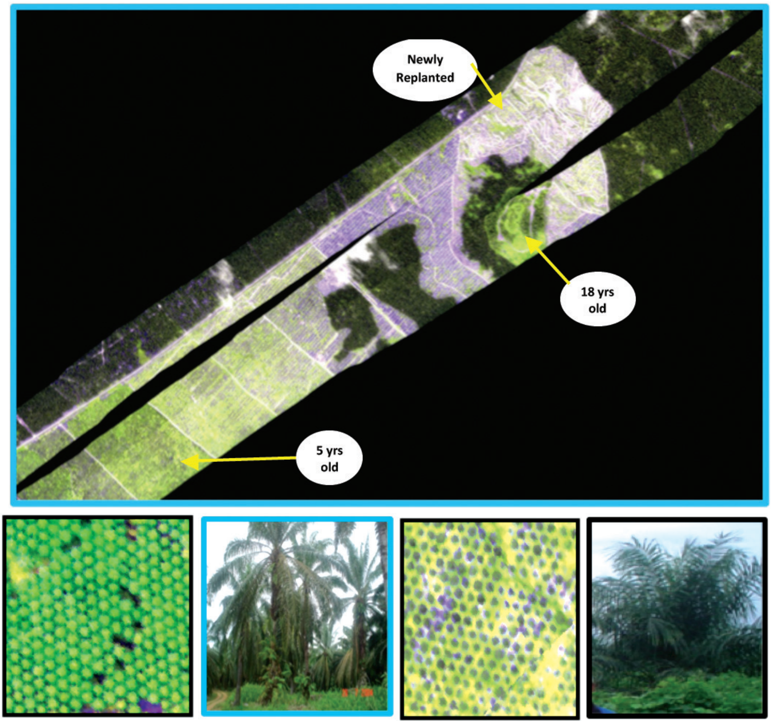


Figure 26 Oil palm plantation age map (above) with UPM-AISA sensor showing 18 years (bottom left) and 5 years old (bottom right) oil palm individual trees

Rice Paddies Land Use/Cover

Quantifying and mapping rice paddies parameters has met with mixed success through the use of hyperspectral remote sensing in UPM's former Center for Precision Agriculture & Bioresource Remote Sensing, Institute of Bioscience in Lebuh Silikon. However, with the recent advances in a locally developed and operated airborne hyperspectral imaging technology incorporating a global positioning system (GPS) and "ready-made" geographic information system (GIS), have provided a cheap and powerful analysis tool for precision agriculture.

Commercial estates of rice paddies are major and economically important land use in Malaysia and other South East Asian countries. Commercial rice paddies estates are high input agricultural systems. Standard practice is to apply fertilizer, herbicide and pesticide to whole blocks of trees and rice fields several times each year. Being able to target areas needing treatments would remove the need to treat the whole block, so reducing costs and input of agro-chemicals into the environment. Further, if growth problems can be identified at an early stage or between ground checks, then preventive or remedial measures have a greater chance of success. Airborne hyperspectral imaging offers a great potential to survey large areas as per user or client demand in near real time and the early detection of growth anomalies.

Hyperspectral remotely sensed images taken from a fixed wing aircraft has provided a means to assess rice paddies field conditions in near real-time over KADA's Ladang Merdeka in Bachok, Kelantan. The remote view of the hyperspectral sensor and its "ready-made GIS" data ability to store, analyze, and display the sensed data on field maps are what make airborne hyperspectral remote sensing a potentially important tool for agricultural producers. Remotely airborne hyperspectral sensed images can be used to identify, map and quantify the different growth stages of rice paddies namely plough, ripening, vegetative (Figure 27) in addition to the idle land, harvestable areas and infrastructural facilities (Kamaruzaman, 2006; 2009g). It is expected that future hyperspectral sensors should be able to map out areas with nutrient deficiency, diseases, water deficiency or surplus, weed infestations, insect, wind, herbicide damage, and plant populations of rice paddies.

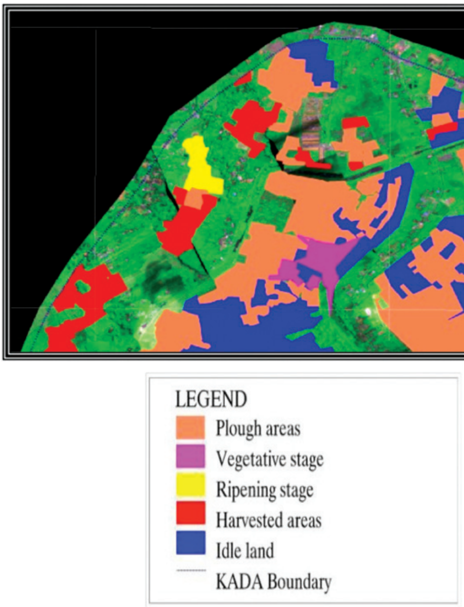


Figure 27 A geospatial map of KADA's Ladang Merdeka rice paddies characteristics as seen from a UPM-AISA Classic airborne hyperspectral sensor

Plant Water (Moisture) Content

An accurate estimate of plant water content is significant in making management decisions for irrigation, wildfire risk, and drought assessment. Variations in reflectance related to OH bonding of water may provide a method of nondestructively estimating plant water content in certain plant species. Quite a number of researchers including (Danson et. al., 1992: Riggs and Running, 1991) have investigated different spectral bands and for water sensitivity. The spectral bands at 950-970, 1,150-1,260, 1,450, 1,950, and 2,250 nm have shown promise in estimating water content in certain species (Sims and Gamon, 2003). With this note of known optimum spectral band combinations, hyperspectral sensing is certainly the best tool to determine plant water content of various plantation crops as indicated in Figure 28.

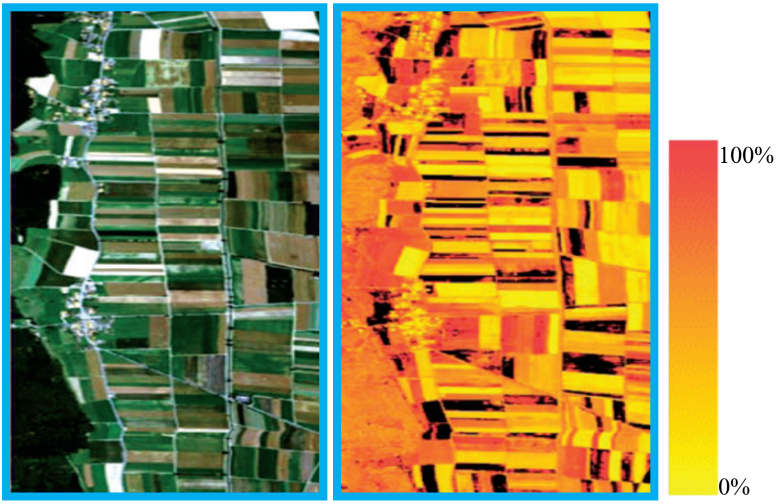


Figure 28 HyMAP data set (right) for determination of plant water content
(Source: Sims and Gamon, 2003)

Highway Transmission Lines

Power transmission lines routes mapping is an important technique for locating power transmission line routes and towers on mountain/ hilltops to assist viewing of their impacts on the environment, operations and allocation of public utilities. Power transmission lines are electrical lines that typically carry high voltage and have to traverse the length and breadth of the country, for evacuation of power from generating stations to load centers and beneficiary states, the topographical and geographical nature of the terrains play significant influence in the project cost and implementation time. Hence, it is important to determine power transmission lines routes spotting using hyperspectral sensor. Unmonitored power transmission lines such as when tree grow too close to power lines are potential threat to electrical system reliability and safety, resulting in unnecessary power outages and interruptions in electrical service to customers or may cause forest fires when the bamboo tops hit the wire lines. The potential environmental impacts from the construction and operation of transmission lines can be minimized once precise location of power transmission lines tower footings can be determined as shown in Figure 29. Many of the issues relating to changes in land use or bamboo growth rejecting into the power lines can be dealt with easily once the lines are recorded and monitored in the GIS spatial database. For instance, sites with cultural or historical importance might fall in the transmission line route. From the study carried out on mapping of power transmission lines routing and spotting using UPM-AISA sensor in Bukit Lanjan PLUS highway by Kamaruzaman and Norsuzila (2008a), it was discovered that airborne hyperspectral imaging can locate and map the power transmission lines. Image enhancement filtering using convolution technique with band 3 that produced gray scale image was found to be the best technique for power transmission lines routing and mapping.

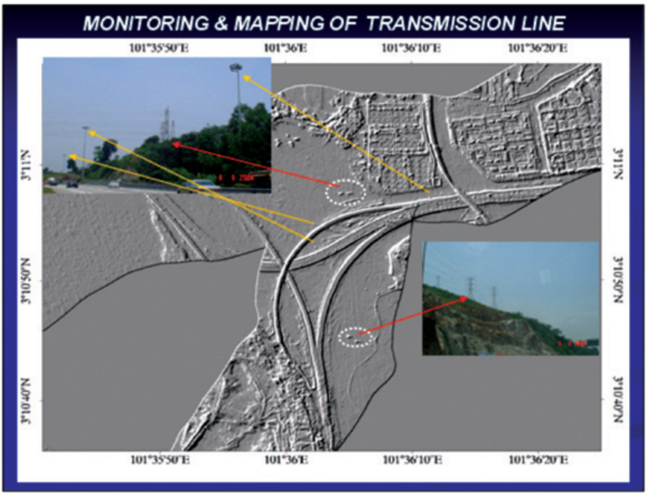


Figure 29 Monitoring and mapping of PLUS highway transmission lines

Turf Grass of Golf Courses

The use of UPM-AISA Classic airborne hyperspectral sensing to aid in the management of large turf grass fields (e.g. IOI Marriot Golf Course) has been attempted as shown in Figure 30. A turf grass field of interest was surveyed from 1200-1400H in the direct sunlight by use of an airborne hyperspectral imaging system, and then the raw observational data was pre-processed into hyperspectral reflectance image data. These data was further processed to identify turf grass stresses, to determine the spatial distributions of those stresses, and to generate maps showing the spatial distributions. This is critical in golf course management since until now, chemicals and water have often been applied indiscriminately to the entire turf grass field without regard to localization of specific stresses or to visible and possibly localized signs of stress-for example, browning, damage from traffic, or conspicuous growth of weeds. Indiscriminate application is uneconomical and environmentally unsound; the amounts of water and chemicals consumed could be insufficient in some areas and excessive in most areas, and excess chemicals can leak into the environment. In cases in which developing stresses do not show visible signs at first, it could be more economical and effective to take corrective action before visible signs appear. By enabling early identification of specific stresses and their locations, the airborne hyperspectral method would provide guidance for planning more effective, more economical, and more environmentally sound turf grass management practices, including application of chemicals and water, aeration, and mowing.

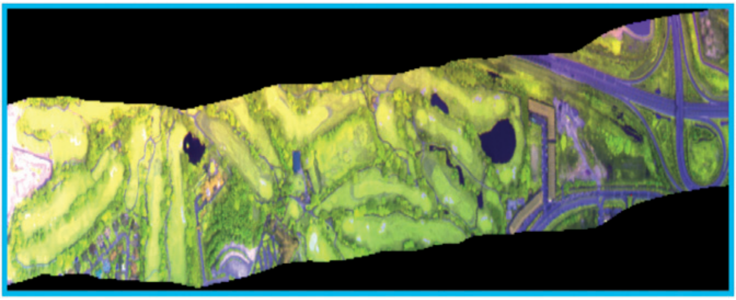


Figure 30 A sample strip of UPM-AISA airborne hyperspectral image over IOI Marriot Golf course

The underlying concept of using hyperspectral imagery to generate stress maps as guides to efficient management of vegetation in large fields is not new; it has been applied in the growth of crops to be harvested. What is new here is the effort to develop an algorithm that processes hyperspectral reflectance data into spectral indices specific to stresses in turf grass. The development effort has included a study in which small turf grass plots that were, variously, healthy or subjected to a variety of controlled stresses were observed by use of a hand-held spectroradiometer. The spectroradiometer readings in the wavelength range from 350 to 1,000 nm were processed to extract hyperspectral reflectance data, which, in turn, were analyzed to find correlations with the controlled stresses. Several indices were found to be correlated with drought stress and to be potentially useful for identifying drought stress before visible symptoms appear.

Green Townships

Towns and cities are centers of human activity. The intensive use of land in urban areas by housing, traffic or industrial areas leads to ecological impacts on the environment and on man's living quality as well. To reduce these impacts, municipalities attach great importance on ecological urban planning. Green spaces, for example, can serve several purposes. They are not only habitats for fauna, but can also be used as bio-indicators for pollution and do act as regulators of micro-and meso-climate.

Urban biotope maps are an important information source for ecological urban planning. They document the current state and quality of urban biotopes and are considered in landscape and town planning. The area-wide urban and town maps such as that of Tuaran, Sabah (Figure 31) and Seri Serdang, Selangor (Figure 32) were produced through digital analysis of UPM-AISA airborne hyperspectral imageries in combination with field verifications. Automated differentiation of urban surfaced based on airborne hyperspectral imagery has also been reported by Roessner et al. (2001). As this procedure is very time-and-money consuming many municipalities do not update their existing town and urban maps regularly. Thus, there is a need for a near real time- and cost-efficient update hyperspectral system that takes into account the rapid changes in urban areas and municipalities to ensure an adequate monitoring of urban thematic maps.

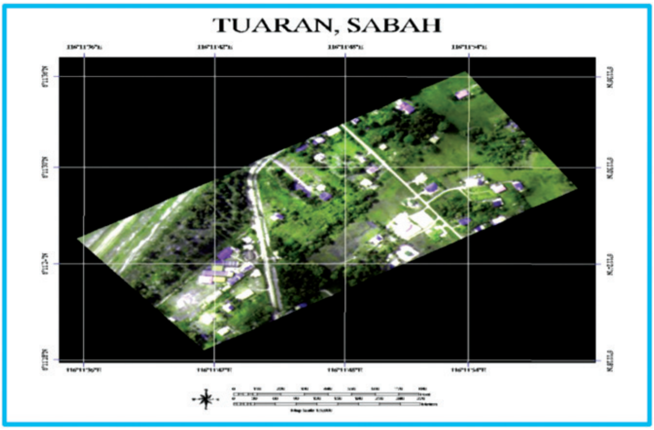


Figure 31 A portion of the town and urban regional planning map for Tuaran Sabah derived from UPM-AISA Classic airborne hyperspectral sensor

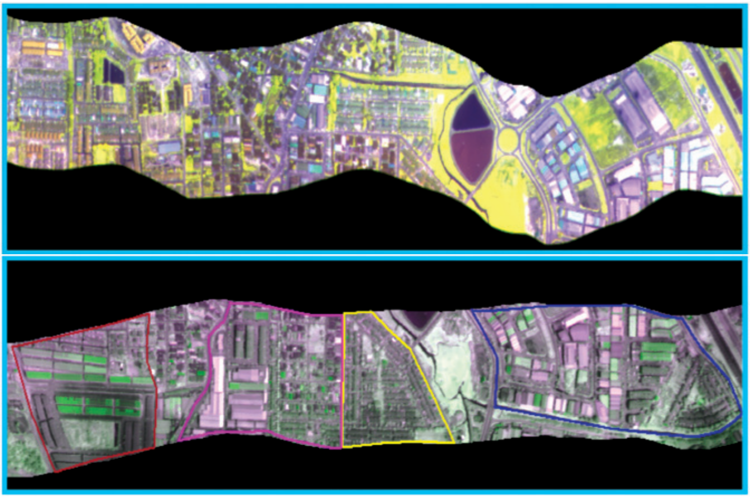


Figure 32 Two sample flight strips flown over Seri Serdang showing the two big sewerage ponds in bluish- purple close to the circle (top) and delineated zones of the housing blocks (bottom) derived from UPM-AISA Classic image

Environmental Pollution

Eutrophication diminishes water quality by promoting the excessive growth of algae, and increasing suspended organic material. When degradation on water quality takes place, unpleasant odors and tastes can result due to the excessive amounts of algae. Furthermore, microorganisms associated with eutrophication may pose health risks to consumers. It is important for water resource managers to find the most efficient way to diagnose the condition of drinking water sources. This may be especially demanding when assessing water quality damage in large inland rivers when field measurements may be time consuming, costly, and limited logistically (Gitelson et al., 1993). Increases in water quality parameters such as chlorophyll *a*, turbidity, total suspended solids (TSS), and nutrients are symptomatic of eutrophic conditions. Concentrations of these parameters can provide insight on the extent of eutrophication and the potential impact on aquatic biota and overall water quality. It would be advantageous to resource manager to be able to detect eutrophic conditions using multiple sites in a river without relying on field measurements.

A flight strip over the Ampang Reservoir (Figure 33) with a UPM-AISA airborne hyperspectral sensor indicated that some parts of the water in the reservoir are turbid (pinkish). In order to measure and estimate chlorophyll *a*, turbidity and phosphorus, water quality samples and hand-held spectrometer data have to be collected directly from the reservoir. Using correlations between the ground-truth data and combinations of spectral bands from the remotely sensed data, spectral indices can be developed which could be used to estimate chlorophyll *a*, turbidity and phosphorus. Studies in the US by Shafique et al. (2001) and Australia by Jupp et al (1994) reported success stories of using airborne hyperspectral sensor for similar work on river quality. Similarly, Boardman et al. (1995) reported that if there is an incidence of oil spill, the oil molecules, what was just a thin, thin oil sheen, can be detected with the AVIRIS since oil spectrum can be easily differentiated from clear or polluted water as shown in Figure 34. Having such specific information means that federal agencies working on the cleanup can target where their efforts will do the most good.

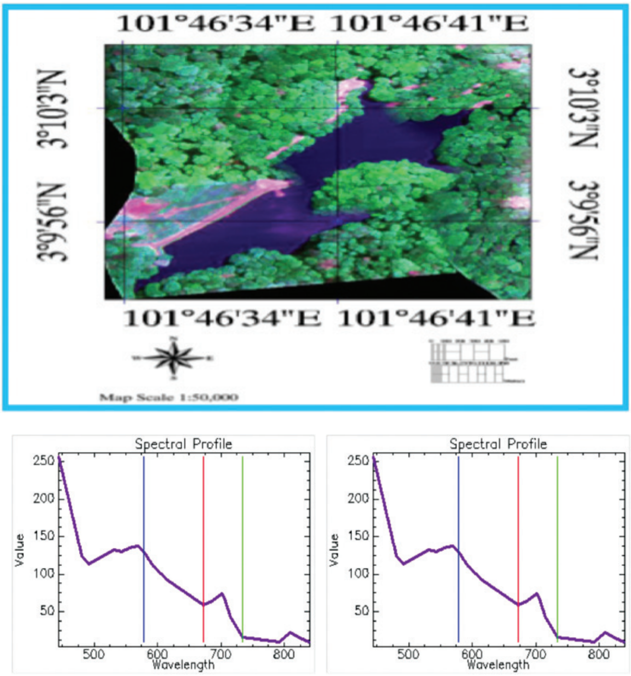


Figure 33 A UPM-AISA hyperspectral sample image of Ampang Reservoir (top in blue) and spectral signatures (bottom) showing the impact of its water quality arising from forest land cover (in green) and land use (in pink).

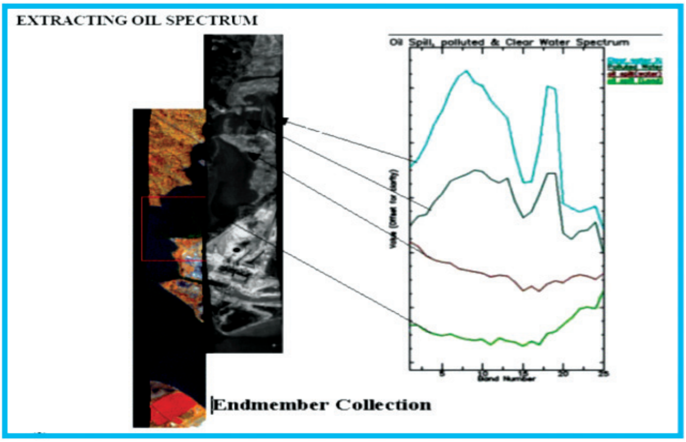


Figure 34 Extraction of oil spectrum signatures from clear and polluted water
(Source: Boardman et al., 1995)

Surveillance and Security

Hyperspectral military surveillance is the implementation of hyperspectral scanning technology for military surveillance and intelligence purposes (Figure 35). Hyperspectral imaging is particularly useful in military and police surveillance because of measures that military and police entities now take to avoid airborne surveillance. Airborne surveillance has been in effect since soldiers used tethered balloons to spy on troops during the American Civil War, and since that time we have learned not only to hide from the naked eye, but to mask our heat signature to blend into the surroundings and avoid infrared scanning, as well. The idea that drives hyperspectral surveillance is that hyperspectral scanning draws information from such a large portion of the light spectrum that any given object should have a unique spectral signature in at least a few of the many bands that get scanned. For example,

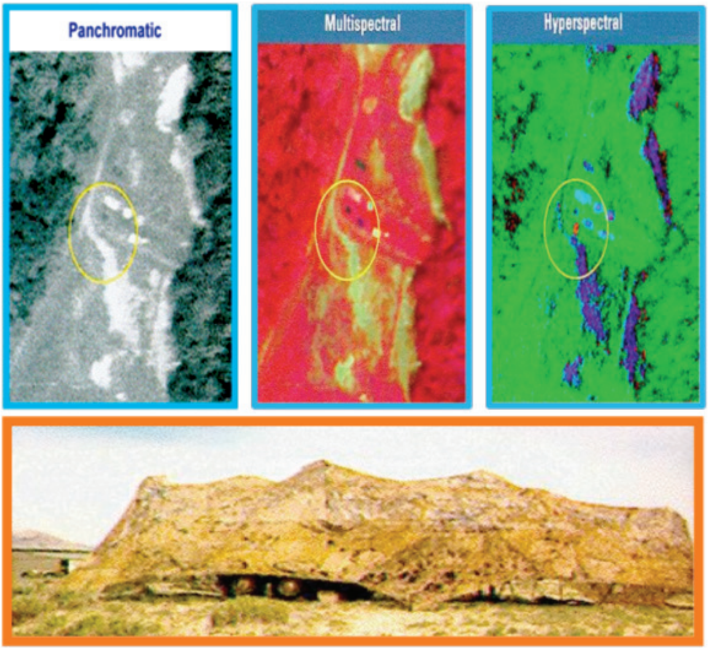


Figure 35 A camouflaged test object as clearly detected and mapped by a hyperspectral sensor as compared to the multi and panchromatic sensors
(Source: http://www.fas.org/irp/imint/hyper.htm)

a compact system combining a multi-gigapixel, high-resolution sensor; wide-field optics; an ultra-high-bandwidth, real-time airborne processing system; and a ground station for interactive multi-target designation, tracking, and exploitation can be developed. The airborne processing system can simultaneously and continuously detect and track the presence and motion of thousands of small or large targets over a certain reguired area of interest. It is expected that the next generation of real-time hyperspectral speceborne surveillance systems will increase wide-area, high-resolution collection capabilities by one to two orders of magnitude over current airborne hyperspectral assets with give an unprecedented ability to track everything on the ground in real time.

Meanwhile, in the UK, the Defence Science and Technology Laboratory (Dstl), Ministry of Defence scientists, technicians and engineers, have completed a trial which could help disrupt terrorist activities using the hyperspectral eyes in the sky. The experiment, the first of its kind in the UK, used cutting edge sensors that capture a range of images and data, in support of defence, security and crime prevention. The trial, at Dstl's Porton Down site near Salisbury, was designed to assess a range of emerging technologies and understand how they may be used to identify and defeat terrorist networks by tracking insurgents' movements.

The trial included airborne, ground-based and vehicle-mounted sensors, both optical and radar, new data processing techniques, two airborne radar sensors that track moving targets from long range, electro-optical camera that can identify people in unusual poses, such as holding a weapon, wide-area surveillance of static and moving targets, 3D imagery and colour and shape interpretation. Looking to the future, this research will help us to look for anomalies both in behaviour and environment, and work towards surveillance alerts to appropriate forces before an incident occurs. A primary goal of using hyperspectral remote sensing image data was to discriminate, classify, identify as well as quantify materials present in the image. Other important applications are subpixel target detection, which allows one to detect targets of interest with sizes smaller than the pixel resolution, and abundance estimation, which allows one to detect concentrations of different signature spectra present in pixels (Figure 36). In remote sensing image analysis, the difficulty arises in the fact that a scene pixel is mixed linearly or nonlinearly by different materials resident in the pixel where direct applications of commonly used image analysis techniques generally do not work well.

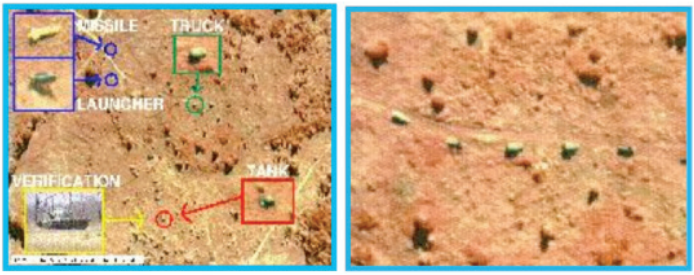


Figure 36 Detection of military heavy weapons and trucks during an airborne campaign test
(Source: http://www.fas.org/irp/imint/hyper.htm)

Search-and-Rescue (SAR) for Missing Aircrafts

For search-and-rescue (SAR) operations such as the Bell 406 Long Ranger helicopter in Bario-Ba'Kelalan or the RMAF NURI Sea-King helicopter in Genting-Sempah of Pahang, or the RMAF fighter jet Hawk (Figure 37), the UPM-AISA hyperspectral was able to derive a complete reflectance spectrum between the undisturbed tree crowns, a damaged, burnt or slashed tree tops/canopy or a foreign object tucked in the sand bed off the coast. An anomaly especially metal like foreign object that penetrates into the tree crowns of a dense forest or tucked under the shallow seabed can easily be detected. Using an advanced Spectral Angle Mapper (SAM) digital analysis and two archives spectral signatures of flying and "parked" NURI helicopters, in addition to ground supporting data from the civilian eye-witnesses, spectral matching of images was applied to identify and map the missing helicopter (Kamaruzaman, 2010c). Similar approach was operationalized in the SAR of the Bell 406

Long Ranger in Bario-Ba'Kelalan, Sarawak (Kamaruzaman, 2008a) and the RMAF Hawk 208 single-seater fighter jet using the presence of a target of unknown *a-priori* characteristics. (Figure 38). Except for the RMAF NURI helicopter, the UPM-AISA hyperspectral sensor had some difficulties in mapping the crashed Sarawak Hornbill Bell Long Ranger and RMAF Hawk fighter jet, despite anomalies have been used to detect and locate the wreckage.

Figure 37 The UPM-AISA hyperspectral technology has also been used to map the unseen and missing aircrafts that crashed into Bario-Ba'Kelalalan, Mersing-Pantai Lanjut coast and Genting-Sempah using the DNA anomaly approach

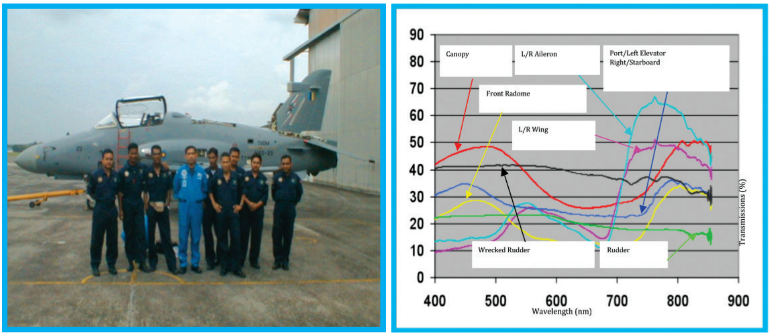


Figure 38 Archived field spectral signatures registered for the RMAF Hawk 208 single seater fighter

Archaeology

Some would argue that the greatest advancement in archaeology since the shovel is remote sensing, or being able to "see" an archaeological site without actually excavating it. This type of "seeing" can take place either from the air or the ground, perhaps the most spectacular remote sensing tools are those that create images of earth from the sky. A case study by Aqdus et al. (2008) in an area of arable farmland in eastern Scotland used data provided by three NERC ARSF airborne sensors CASI 2, ATM and a Rollei Digital Camera. These data have been enhanced using various image processing techniques and have proved successful in discovering more archaeological crop marks in the CASI 2 hyperspectral multi-spectral imagery (Figure 39) than in the standard photographic data acquired at the same time. The presence of structures and hollows in the top subsurface is likely to cause variations in humidity in the surface. These variations affect both vegetation, and some physical features of the ground such as thermal conductivity and capacity. These thermal anomalies due to different evaporation can be noticed in the first hours of the day. The examination of these anomalies, carried out by the use of techniques of digital processing of images in the spectrum bands particularly sensitive to the above mentioned indicators, enables the photo interpreter to determine possible signs of underground structures of archaeological interest. The application of the hyperspectral remote sensing in archaeology allows acquiring, with rapidity, a lot of information connected to the territory; and for this reason, with the development of sensors, there exists the necessity to take advantage offered by the GIS to manage process and file the spatial dates acquired with the remote sensing techniques. Aqdus (2009) then used GIS maps and overlaid on the historical and contemporary layers and on the DEM in order to produce, for each study area, a prediction map of archaeological finds (Figure 40). The major advantage of using hyperspectral data is that it widens the window of recovery of sites in any given season, though it still does not entirely remove the problem of differential recovery resulting from varying weather and crop patterns. The major, current, disadvantage is the poorer resolution of hyperspectral data compared to digital photography.

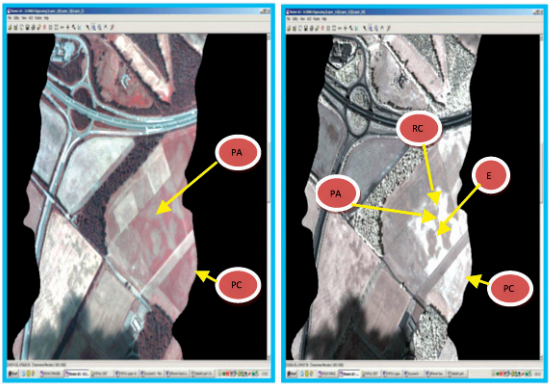


Figure 39 CASI 2 Bands 4, 3, 2 showing archaeological features, pit cluster (PC) and pit alignment (PA) and Bands 14, 12, 10 with sharpen filter showing pit alignment (PA), rigs cultivation (RC), enclosure (E)
(Source: Aqdus et al., 2008)

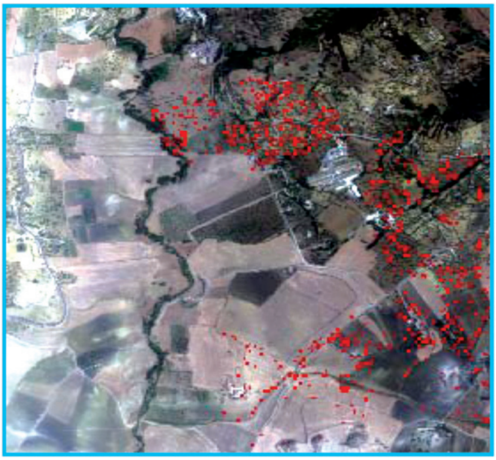


Figure 40 Prediction map of archaeological finds overlaid on MIVIS image
(Source: Aqdus et al., 2008)

Mineral and Material

Mineral recognition is an initial application area of hyperspectral remote sensing. Hyperspectral sensors can be used for resource mapping, geological surveys, sorting within the mining industry, and generally within mineralogy. The field spectral measurement shows that the distinguishable spectral features for different minerals can be seen clearly in short-wave infrared region. They are caused by the bending-stretching features of OH-, CO32-, Al2+-OH, Mg+-OH and SO42- borne minerals. Very exciting results have been obtained in stratigraphic and lithologic mapping of minerals and materials by hyperspectral technique (Clark et al., 1990; Lau et al., 2003; and Neville et al., 2003). For instance, the different strata from Cambian-Ordovician, Silurian, Devonian, Carboniferous and Permain Periods in the Keping area West Tarim have been clearly separated and classified for its dominant minerals of each stratum (Freek et al., 2006). Due to the different dominant minerals in these two strata i.e the calcite for Cambian-Ordovician and dolomite for Permian strata, two strata of Cambian-Ordovician and Permian have been clearly separated. The depth of the absorption band is closely related to the amount of the minerals in the rocks. By analysis of the wavelength location and intensity of the absorption, the distribution of clay and carbonate minerals in the area can be identified and then mapped. The weathering and alteration products of mineral deposits, especially clays can also be among the most valuable data that need to be collected. Clays and oxides can be readily differentiated by the spectra utilized for remote sensing. By correlating the alteration products to parent materials, potentially valuable ores may by distinguish without the need for extensive soil sampling programs (Whittington, 2005). Another valuable component of spectral analysis is differentiating various types of vegetation. Changes in plant cover may indicate a change in lithologies. This image and the associated spectral analysis of different clay alteration were crucial in the location of a set of copper prospects for Noranda. Figure 41 illustrated a hyperspectral data image that was able to determine those spectral signatures directly associated with a known copper (Cu) prospect on the top of the image. Given the similarity of signatures of the two southern features, new exploration opportunities can be identified. These were later verified in the field to be legitimate prospects.

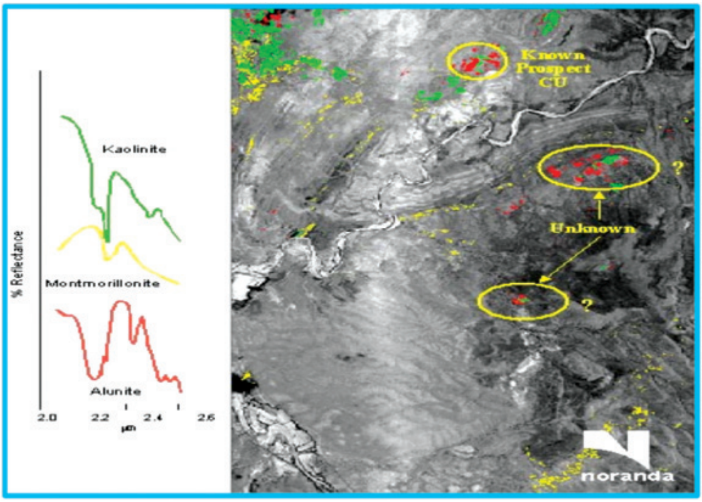


Figure 41 Lithologic mapping of a known copper (Cu) prospect versus unknown materials with airborne hyperspectral data
(Source: http://www.space.gc.ca/asc/eng/satellites/hyper_geo logy.asp)

In Israel, mineral identification was based on spectral mixture analysis of color composite bands 1, 20, and 48 (Anker et al., 2009). Figure 42 showed the result of mineral classification/stratigraphy/lithology for alluvium, chert, dolomite, sandstone, chocolate clay, bauxite, limestone, gypsum, basalt, kaolinitic, pottasic using DAIS Hyperspectral Data of Makhtesh Ramon/Israel. More established results on mineral mapping and lithology can be found in Australia using the HyMAP sensor (Taylor et al., 2005).

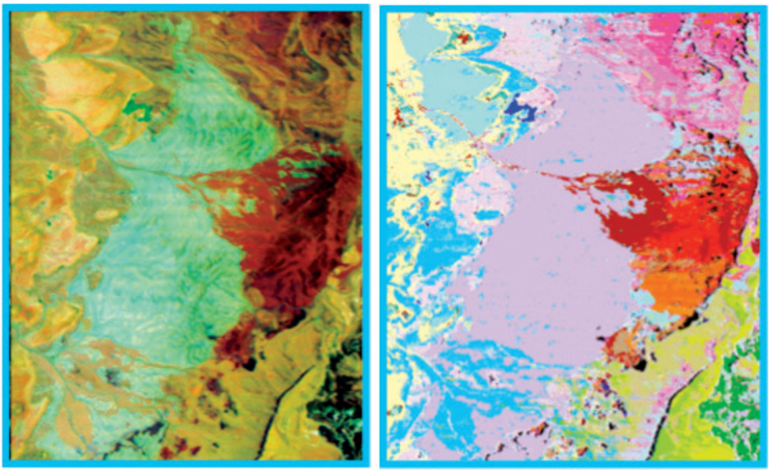


Figure 42 DAIS Hyperspectral data (left) of Makhtesh Ramon, Israel showing mineral lithology stratification (right)
(Source: Anker et al., 2008)

Usually, hyperspectral data needs additional processing to extract spectral endmembers and map the mineral locations and abundances. These analyses followed standardized on the shelf software Analytical Imaging and Geophysics (AIG) methodologies consisting of reduction to apparent reflectance using ATREM, spectral data reduction using the Minimum Noise Fraction (MNF) transformation, spatial data reduction using the Pixel Purity Index (PPI), an n-Dimensional Visualizer to determine image endmembers (Boardman et al., 1996), identification of endmembers using their reflectance spectra in the Spectral Analyst, and mineral mapping using Mixture-Tuned Matched Filtering (Boardman, 1997; 1998a; 1998b). Typical results of mineral mapping with an Australian HyMAP sensor from Kruse et al. (2000) are shown in Figure 43.

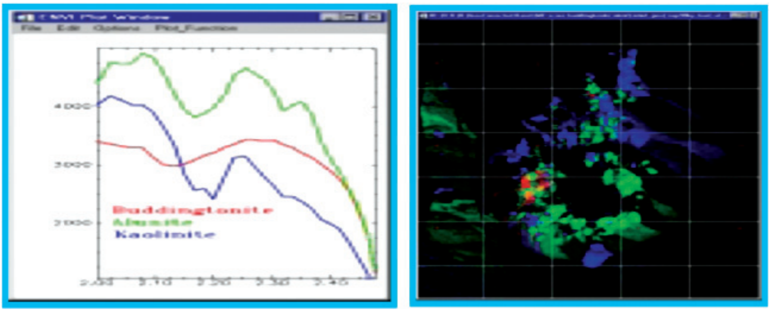


Figure 43 Mineral Mapping Application of the Australian HyMAP: Left: single-pixel apparent reflectance spectra of spectral endmembers and Right: Mineral map (Buddingtonite, Alunite, Kaolinite coded as RGB).
(Source: Kruse et al., 2000)

HYPERSPECTRAL ISSUES, OUTLOOK AND FUTURE RESEARCH PRIORITIES

From the "Unseen" to be Seen?

Although the potential of hyperspectral remote sensing is exciting, there are special issues that arise with this unique type of imagery. For example, many hyperspectral analysis algorithms require accurate atmospheric corrections to be performed. To meet this need, sophisticated advance atmospheric correction algorithms need to be developed to calculate concentrations of atmospheric gases directly from the detailed spectral information contained in the imagery itself without additional ancillary data. These corrections can be performed separately for each pixel because each pixel has a detailed spectrum associated with it. Several of these atmospheric correction algorithms are available within commercial image processing software. However, several image analysis algorithms have been successfully used with uncorrected imagery. For example, the BandMax tool owned by the Galileo Group has been widely used with radiance imagery. Many hyperspectral analysis approaches require the use of known material spectra. Known spectra can guide spectral classifications or define targets to use in spectral image analysis (Kamaruzaman, 2006c, Kamaruzaman et al., 2009; and Mohd Hasmadi et al., 2010). Some investigators collect spectral libraries for materials in their field sites as part of every project (Kamaruzaman et al., 2010; Kamaruzaman, 2009h; and Kutser et al., 2006). Several high quality spectral libraries are also publicly available. Some investigators (Kamaruzaman, 2007b; Manolakis and Shaw, 2002) derive spectral libraries from the image to be analyzed using specially designed algorithms available in commercial software. This approach ensures that the spectra will always be exactly comparable to the image pixel spectra. Finally, hyperspectral imagery is often not as readily available as other types of remotely sensed data. In particular, there are few spaceborne hyperspectral sensors. Nevertheless, several previously launched hyperspectral sensors are acquiring imagery from space, including the Hyperion sensor on NASA's EO-1 satellite, the CHRIS sensor on the European Space Agency's PROBA satellite, and the FTHSI sensor on the U.S. Air Force Research Lab's MightySat II satellite. The EROS Data Center provides Hyperion imagery at a relatively low cost to the general public (http://edc.usgs.gov/products/satellite/eo1.html). A more comprehensive list of current hyperspectral sensors is available on http://www.RSInc.com.

Merger of Air and Spaceborne Hyperspectral with LiDAR Data

The heart of the future hyperspectral imaging system should consist of two main instruments. One, a waveform light detection and ranging (LiDAR) system, maps the three-dimensional physical structure of the trees. LiDAR is a close cousin of RADAR, except that it bounces laser light off its targets instead of radio waves. The LiDAR system provides bare earth models, canopy height models, and a variety of forest structure metrics. From this analysis, the minimum required level of canopy structure information that can also be obtained from airborne LiDAR data is assessed at spatially explicit scale. Once the most contributing structure parameters are available from airborne LiDAR data, combined with its quantified effect on hyperspectral signals, a procedure can be developed to build an advanced hyperspectral imagery pre-processing chain that considers the impact of forest and vegetation structure and its bidirectional effects on the captured signal. Finally, a methodology based on deep belief neural networks will be developed to produce forest parameters from the hyperspectral remote sensing thematic data derived from the traditional and advanced hyperspectral imagery pre-processing chains. Basically, this approach aims at identifying forest canopies components that contribute the most to the captured reflectance values of airborne sensors. Or stated otherwise, this adds a third and vertical dimension to the horizontal and thus, two dimensional characters of hyperspectral imagery. With this knowledge, monitoring and detecting changes in the vegetation state can be differentiated in contributions of physiologic changes like growth and contributions due to vegetation structure affecting the captured airborne hyperspectral reflectances.

The second device is a hyperspectral imager, which gathers information about the biochemistry of the forest by measuring the wavelengths of light reflected by trees and other vegetation. These two sensors should be integrated (may be coined as HyperDAR-the hyperspectral and LiDAR data) on the fly to construct a complete three-dimensional picture. There is a need to gather and blend incredibly detailed physical and chemical data in a way that has not been done before. They need to essentially devise a way to do a virtual 'CSI scan' of the tropical forest ecosystem. Strictly speaking, the instruments are portable and designed to plug into just about any small aircraft. This will enable the future UPM team to deploy the merged sensor anywhere in the tropical forested region. It also allows razor-sharp scanning that other remote sensing equipment, much of which rides on satellites or in high-altitude aircraft, cannot equal. Depending on how low the plane flies, resolution can range from 1 m/pixel to as fine as 20 cm/pixel–precise enough to make out the individual branches and leaves on trees.

Plans should be underway to use such merger to map the species diversity of the tropical forest ecosystems and discover which species are disappearing, and how quickly. Similarly, forest engineers and surveyors must know where they are surviving, where the forests are being illegally cut down and what factors are vital for their health. This information can aid conservation efforts in Malaysia, and elsewhere by identifying the most threatened areas, as well as diversity "hot spots" where many species beat the odds and persevere. In some areas, the threat is from foreign, "invasive" species that out compete the natives for space and resources. Hopefully, the newborn sensor can map and track these species, gathering data that can be used to inform the effort to stem the invasion. The newborn sensor should have an unparalleled ability to measure and map the structure, composition, and physiology of the tropical forest ecosystems. The forest conservation and management potential is unique in Malaysia-and in the world, for that matter.

Continued data collection along with excellent supporting ground truth and the development of application algorithms are the highest priorities. The advent of space borne hyperspectral sensors aboard our own satellite should be an exciting opportunity. This sensor, along with the numerous airborne sensors, will provide data that can be used for application development activities in our country and in the region. Another focus should be ensuring wide access to the data and associated ground truth which have been and are being collected. This would encourage algorithmic development. Technology activities should focus on developments that would lead to lighter and cheaper instruments such as lightweight optics and focal plane arrays with integrated spectral selection components. The development of future satellite hardware could possibly be deferred until a better appreciation of the utility of spaceborne data is gained. However, given the utility that airborne data have shown so far and the long lead time required for the procurement of operational satellite instruments, it is appropriate now to begin development of a follow-on system.

It is now up to the forest surveyors, public and private to invest in the development of the analysis technologies, the information products and the applications that will generate the dollars that will keep the new millennium satellites flying. The question is: are forest engineers/surveyors, the public and private sectors, or anybody ready for the deluge?

Availability of Data from Ultraspectral Sensors

A few ultraspectral sensors have been reported available for some highly selected applications. For example, the JPL's Atmospheric Emission Spectrometer (AES), comprising four separate FT-IR devices with common optics, each with four detectors to spatially resolve the scene. The AES produces thousands of bands at better than 1 cm –1 resolution over a broad infrared spectral range. (http://www.techexpo.com/WWW/opto-knowledge/atmos-retrieval.html).

The Infrared Imaging Spatial Heterodyne Spectrometer (IRISHS) is a new pushbroom Fourier transform ultraspectral imager with no moving parts. IRISHS is a new imaging spectrometer for remote sensing being developed by Los Alamos National Laboratory for use in identifying and assaying gases in the atmosphere when viewed against the Earth's background. The prototype instrument operates between 8 and 11.5 um (although the current IR camera operates from 8 - 9.5 um). On the other hand, the Tropospheric Emission Spectrometer (TES) is an Earth Observing System Chemistry Platform instrument where the demonstration version of the TES is the AES. Meanwhile, the ultraspectral imager for Cessna 206 deployment was designed and built by Kestrel Corporation (http://www.kestrelcorp.com).

This instrument has a 15-degree FOV, with an IFOV of 1.0 mrad. The targetted spectral resolution is better then 1.5 cm^{-1} over 2,000 to 3,000 cm^{-1} and 0.4 cm^{-1} over 850 to 1,250 cm using 512 spectral channels. The device will use a variety of spectral enhancement techniques to achieve this unprecedented spectral resolution. A computer simulation of the optical systems demonstrates sub-wave number resolutions and signal to noise ratios of over 900 (http://www.kestrelcorp.com).

CONCLUSION

The future of hyperspectral remote sensing is promising since preserving our forest environment, managing forests, sustainable development and global warming threats are reasons forest engineers and surveyors are using hyperspectral technology. With increased awareness of geospatial technologies and its role in society, forestry has and must continue to embrace hyperspectral remote sensing to adapt to these changing circumstances. This lecture has highlighted the development of hyperspectral sensing applications in Malaysia, with particular emphasis to tropical forestry mapping, monitoring, analysis and other different applications. A number of airborne and spaceborne imaging sensors, with largely similar characteristics are now operational in some advance countries like the US and EU. These sensors are currently operating, and at least one or two spaceborne hyperspectral sensor are providing imagery for the general public. However, airborne data acquisitions benefit greatly over satellite based missions because the user has influence on the mission in terms of time schedules, flight line arrangements, calibration measurements, spectral/spatial resolutions, and acceptable weather conditions. Unfortunately, airborne hyperspectral sensors are often very expensive due to fact that limited spatial coverage and multiple flight lines may be required to cover a study area. Also, data processing is usually complex and can cause problems.

This lecture has shown that there is a wide range of techniques, ranging from empirical to physically-based modeling approaches that have proven useful for analysing hyperspectral imaging data for forest mapping, monitoring and analysis. The latest development of a US and EU air and space borne imaging spectrometer presents new opportunities for detailed environmental assessment and monitoring. However, since hyperspectral sensing research is still in its infancy in Malaysia, these new developments come with their own challenges in terms of human, financial and physical resources. Pre-processing and analysis of hyperspectral sensing data from the US based satellite, in particular, can only be achieved through collaboration between research institutions and application specialists before developed research and applications can be viewed as truly operational in the context of "seeing the unseen" Malaysian environment captured. The availability of commercial hyperspectral analysis tools is good, and these tools are continually becoming easier to use and more effective. A combined flexible, programmable air-and space borne imaging spectrometer with extreme radiometric, spectral and spatial properties will certainly serve as a development tool for upcoming and future hyperspectral sensor systems. Such an instrument with a broad range of applications must be a dedicated single use optimized system. These may be super or ultra spectral applications specific bands which definitely have a huge potential in assessing and monitoring the Earth's "unseen" ecosystem. As newly commissioned hyperspectral sensors provide more imagery alternatives, and newly developed image processing algorithms provide more analytical tools, hyperspectral sensing technology is positioned to become one of the core technologies for geospatial mapping and monitoring of the "unseen" Mother Earth.

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BIOGRAPHY

Hj. Kamaruzaman Jusoff is the sixth child born to Jusoff Taib (Allahyarham) and Che Wok Abdullah (Allahyarhamah) in Kota Bharu, Kelantan on 28th. March 1958. He is married to Rohaita Abdul Fathel and has five young lovely daughters (Nur Syazana, Nur Atirah, Nur Afifah, Nur Amira and Nur Syifa Alysya) ranging from the age of 9 to 23 years old. He received his formal education in Sultan Ismail College, Kota Bharu, Kelantan where he was raised in a poor family of seven children (Mamat @ Mohamad, Abdullah, Malek, Rakiah, Rohayah, and Ahmad Afip). His alma mater for the last 30 years, Universiti Putra Malaysia (UPM), has been where he was conferred Bachelor of Science in Forestry. Thereafter, he continued his Master's degree in Forest Engineering at the University of New Brunswick, Canada (under the Commonwealth Scholarship and Fellowship Plan) and Faculty of Engineering and Forestry, UPM. In 1989, he continued his PhD studies at Cranfied University, UK under the Overseas Research Student (ORS) Award's Committees of the UK Vice Chancellors and returned home with a PhD in 1992.

Two years after his return to UPM, he was awarded an Associate Professor and then when again to University Dundee Scotland for his postdoctoral work with Profesor A.P Cracknell under the British Chevening Research Attachment Award 1996. Two years later, he was seconded to the Malaysian Center for Remote Sensing (MACRES, now known as Malaysian Remote Sensing Agency) as the Deputy Director in-charge-of Research and Development. While at MACRES, he developed the AIRSAR-NASA-Malaysia airborne radar campaign and flew with the NASA scientists on-board the NASA DC-8 McDonald Douglas aircraft. He then went occasionally to the Jet Propulsion Laboratory (JPL) in Pasadena and California Institute of Technology (CalTech), USA to further his training skills in airborne radar image processing and planned future airborne radar flight campaign missions in Malaysia. While at CalTech and NASA JPL, he developed his long-term goals to achieve excellence in the field of applied remote sensing research and commercialization to contribute towards attaining a top notch Research University status through the pursuit of knowledge on sustainable development of tropical forest resources vis-a-vis an engineered environmental management and conservation. His goals rendered strategies to (a) develop remote sensing techniques for assessing, estimating and managing forest resources for national strategic defense, security and planning to meet the demand of an increasing Malaysian population; (b) unravel some of the mysteries at the macro/micro-scale relating to forest resources depletion which is on the verge of extinction, (c) operationalize air and spaceborne hyperspectral remote sensing technology for practical and economical use in Malaysia especially in tropical forest inventory, management and conservation for national security, plantation forestry and forest operations and sustainable eco-tourism management, and (d) commercialize an informative and precise natural resources and agricultural mapping system based on an integrated high precision air and spaceborne remote sensing survey and audit system towards achieving the top rank world university ranking. After a year’s contract with MACRES, he was offered a permanent position as the Foundation Dean and Professor, School of International Tropical Forestry with Universiti Malaysia Sabah, Kota Kinabalu. However, he had to decline the offer and decided to accept a Professorial appointment with UPM.

As an academician, his mission has been to contribute to the advancement of research and commercialization at UPM through his contributions as well as those of his colleagues and postgraduate students. He has promoted and strengthened UPM’s remote sensing team especially in the application of space remote sensing for mapping and surveying of natural resources and environmental management. Being the founder of the Remote Sensing/GIS Research Group (Chairman), his scholarship and leadership has managed to develop, coordinate and lead UPM Master's Remote Sensing/GIS program (parked in the Faculty of Engineering since year 2000), lead two Malaysian Intensive Research Priority Areas (IRPA) projects worth RM 2.7 million (Project Head), and lead UPM's Precision Agriculture R&D Project under an IRPA funding of RM482, 000. Being a dynamic and proactive researcher, he was given the trust by MOSTE (now MOSTI) in September 2000, an IRPA grant for RM172, 000 to pursue further research on paddy precision farming. This has led to the set-up of a Center for Precision Agriculture and Bio-resource Remote Sensing (CPABRS) at Lebuh Silikon in 1999 under the Institute of Bioscience, UPM. The establishment of THEMAP Malaysia Total Value Added Reseller (TVAR) at UPM in joint venture with CSIRO, THEMAP International, Canberra, Technoquip Sdn. Bhd, GISAT Sdn. Bhd. and Yayasan Sabah came later into the scene where airborne hyperspectral sensing research experience was first introduced and gained momentum in the year 2001. Along the same line, he has also assisted UPM in collaboration with CSIRO on the set up of an airborne sensor projects to be implemented for precision forest fire mapping and agriculture in Malaysia. In line with such research and commercialization (R & C) activities, a joint venture (JV) company Skyeyes Precision Sensing Sdn. Bhd. was set up and served as a Consulting Director to commercialize some of his R & C products in the form of precision satellite image maps for natural resource environmental management and strategic planning. While having a full status research lab with research grants from MOSTI, he has assisted more than 40 postgraduate students of the Faculty of Forestry and Institute of Bioscience in preparing their Master's and PhD thesis and provided the leadership for young academics to advance their career in remote sensing and space technology application in forestry, precision agriculture and marine science.

As a Professor in Forest Engineering Survey he also served as the Technical Head of the IRPA Panel Sector Environment and Expert Panel for Sector Science and Engineering to evaluate research projects on GIS/Remote Sensing and Science/Engineering and has become the country's focal point for R & D in remote sensing/GIS for forestry and bio-resource application. He has also been invited as an Expert in space technology application by Astronautic Technology Sdn. Bhd to assess the technical specification of the Malaysia Ground Receiving Station (MGRS) tender. In his course of duty, he has also provided advice to the Secretary General, Ministry of Science, Technology and Environment as to the strategic pricing and reconfiguration of the above station. In addition, he was also one of the Satellite Technology Expert Group Team Members to advise the Malaysian Government on the formation, direction and vision of the Malaysian Space Agency (MSA) set-up. Being a proactive user of satellite remote sensing data from 1999 to 2002, he was invited to chair the User Group Requirement Satellite Mission Design Parameters for RazakSAT, the Malaysian Near Equatorial Orbital (NeqO) that was successfully launched on 14th. July 2009 using a Falcon-1 launch vehicle.

In the period of 1999-2002 also, he had successfully promoted the use of forest information and space technology especially in satellite forest remote sensing and the database management of forestry information technology and precision agriculture research. Internationally, his services were sought by the International Union of Forestry Research Organization (IUFRO), International Timber Trade Organization (ITTO), Japan Overseas Forest Consultancy

Association (JOFCA), National Space Development Agency of Japan (NASDA), UN Office for Outer Space Affairs, European Union (EU), Environmental Research Institute of Michigan (ERIM), Food and Agriculture Organization (FAO), International Labour Organization (ILO), International Society for Photogrammetric and Remote Sensing (ISPRS), Canadian Institute of Forestry (C.I.F), CSIRO and NASA. He was also invited by Sultan Qaboos University (SQU), Sultanate of Oman in 2001 to deliver a special lecture on the Development of Remote Sensing/GIS and his R & D experiences in Malaysian Remote Sensing/GIS to the College of Engineering, SQU. In the same year, he was also offered the Founding Director's post cum Professor for a contract of three years at the Remote Sensing/GIS Centre and Department of Bio-resource & Agriculture Engineering, SQU, Muscat. However, having duly considered his sense of purpose and belonging to UPM he had to turn down the offer again.

From 2002 onwards, after having a chance to chat and network with remote sensing scientists and experts through related international conferences in EU, USA, Japan and Australia, he managed to get a sense of vision for airborne hyperspectral sensing technology and also visualize the future of global forest geospatial technology markets. After squeezing time out of his packed daily routine schedule, he moved into business (commercialization) and product marketing and definition of the newly developed UPM-AISA sensor products. Since the global mapping and survey technology has moved from the traditional field survey to spaceborne and recently airborne, he was always ready with solutions for the modern precision forestry mapping and other survey needs. The current company, APSB that he has served as an Airborne Sensing Advisor (ASA) since 2003, is the only 100% local Bumiputra leading developer in airborne hyperspectral imaging industry in Malaysia. Although high resolution satellite data is available, there is still a huge demand for airborne spectrometry solutions for forest and other applications survey and mapping.

His other business goal is to think of how airborne geospatial technologies can be made operational in other than forestry engineering survey and mapping segment and these include precision agriculture, business, facilities management, eco-tourism, project management, telecommunication, power transmission lines, transportation highway management, military intelligence, search-and-rescue operations (SAR) and national security. Future research and commercialization may therefore incline towards web-based solutions that will further data availability for every sector. Having access to more data should enable more businesses and organization to use the information for analysis and critical decision-making. His message to young forest engineering survey and forest geo-informatics researchers and students is that there is great potential in forest geospatial technologies especially in the future spaceborne hyperspectral and airborne ultraspectral sensing opportunities. As a Professor in Forest Engineering Survey, he believes that it is exciting to be starting out in this field at this time when there are so many rapid advancements in the industry and technology. His special advice is to encourage them to get a solid basis in the latest spaceborne and airborne ultraspectral imaging technology and focus on learning the application in the industry. His future target and hope is to realize a UPM Joint Airborne Laboratory Aircraft Campaign Program in Malaysia and Asia-Pacific region for different applications especially in the sustainable management of forest and natural resources with top world ranking universities he used to be attached as Visiting Professor, as in Harvard and Yale. Hopefully, this will be accomplished through funding from the Ministry of

Science, Technology & Innovation's INNOFUND-E, Agri-Dana and the Ministry of Natural Resources and Environment.

While promoting advance research in satellite-based remote sensing from 1999-2002, he felt the need for an advancement in further training of his chosen field of applied remote sensing. Under a special fund by Infoterra Ltd. UK in 2001 and SPECIM Ltd, Finland in 2002, he worked with his former Professor, Dr. Giles D'Souza, Mr. Timo Hyvarinnen (Managing Director) and Mr. Jukka Okkonen (Product Manager), respectively at the famous industrial complex in Oulu, Finland where Nokia handphones were manufactured. Not only did he acquire extensive product design and marketing experience in the software/hardware of airborne hyperspectral sensor, in addition to a business development course for professors organized by Ministry of Entrepreneur and Co-operative Development, Malaysia but also was well equipped with his product commercialization and networking. Since then, he has specialized and devoted his research activities under the main theme of airborne hyperspectral imaging for forestry and other different applications such as precision agriculture, environment, oil spills, search-and-rescue operations, transportation highways, military intelligence, police security, mineralogy, and other related applications. This is the turning point of his professorial career in UPM where he started to commercialize his sensor mapping product from his former attachment at Forest Geospatial Information and Survey (FGISL) Lab in Lebuh Silikon for mapping and surveying of our Mother Earth.

Being an active research teacher with a research and commercial approach, to-date, he has added and disseminated a total of more than 300 publications within the last three years in the forms of papers in citation indexed, refereed and peer reviewed impact journals, indexed proceedings, papers presented, reports, thesis and power points hardcopy prints. Request and invitation for presentation of UPM-AISA airborne hyperspectral image data came from more than 10 government and private agencies all over Malaysia including Sabah and Sarawak, amongst others include Forestry Department of Peninsular Malaysia HQ, Department of Agriculture (DOA), Department of Environment, Kemubu Agriculture Development Authority (KADA), Kompleks Perkayuan Kelantan (KPK), PLUS Highways, Royal Customs Department, Police and Armed Forces. In recognition of his contributions as a successful academic entrepreneur, he was the first local Malaysian Professor invited by UiTM Shah Alam to deliver an inaugural public lecture entitled *Academic Entrepreneurship: A Malaysian Research University Perspective* in 2007. His achievements were given local and international recognition and were invited to be included in the publication Malaysian Green Directory 2004 and Marquis WHO’s WHO in Science & Engineering and WHO’s WHO in America & Asia 2007, based in the United States and 100 The Lifetime of Achievement 2003, 2004 and 2005, The Outstanding Scientists of the 21st. Century-Inaugural Edition and The Global Year of Science 2006, Top Scientists 2006, based in U.K. Being one of the world's leading achievers of remote sensing application in tropical forestry approaching the end of the millennium, his work has been accepted for inclusion in OUTSTANDING PEOPLE OF 20th CENTURY, 2000 OUTSTANDING INTELLECTUALS OF THE 21st. CENTURY, IBC LIFETIME AWARD based in Cambridge, UK. His research work and noteworthy achievements of lasting value to humankind and of international importance have also been recognized by Marquis Publisher based in New Jersey, USA who presented his biographical profile in the 16th Edition "WHO's WHO IN THE WORLD 1999. He has also been selected by a leading Biographical Reference Book Publisher, i.e the International

Biographical Centre (IBC) in Cambridge, UK from a very small percentage for the important accolade INTERNATIONAL MAN OF THE YEAR 1999-2000. This prestigious award-issued by way of warrant of Proclamation has been made available to only a few illustrious individuals whose achievements and leadership stand out in the International Community. Due to his illustrious accomplishment and contributions to society, the American Biographical Institute, Inc. has also nominated him for the prestigious title MAN OF THE YEAR 2000. He was also honored by the IBC for the prestigious THE 20th AWARD FOR ACHIEVEMENT in Forest Survey (Remote Sensing/GIS), and received a coveted appointment in the world of biographical research and reference as a DEPUTY DIRECTOR GENERAL (ASIA). As if those accolades halted there, he was also offered and recommended by the ABI Trustees the exclusive opportunity to be selected among a small group to receive the most prestigious honor and become an AMERICAN BIOGRAPHICAL INSTITUTE, INCORPORATION (ABI) FELLOW. This ABI's recognition is a representative of true meritorious deeds to his exceptional accomplishments of sharing ideas and experiences of global concern and interest in the area of remote sensing/GIS application in forestry.

In determining his professorial contributions and achievements in the field of forest engineering survey and applied remote sensing, he has used the following criteria, namely professional services rendered to local and international agencies, invitation to present plenary papers, publications towards global R & D as well as contribution of ICT in tropical forest sustainable management. Early in his career as an Associate Professor in 1994, he shouldered a substantial research program on applications of satellite-based remote sensing, working with high resolution former US spy satellites such as IKONOS-1 and QUICKBIRD, despite being tight with responsibilities as Forestry Faculty's Deputy Dean (Research & Business) and later UPM Kemena Campus's Director (Designate). Ever since the official formation of APSB's Project Office based in FGISL, Lebuh Silikon, UPM, he directed, administered and managed contract research projects and activities on the application of airborne hyperspectral sensing/GIS in forest conservation, management and agriculture. Heading a team of UPM-APSB's airborne hyperspectral imaging research workers, he was also responsible for the administration, supervision, budgeting and monitoring of these activities which represent the bulk of his present contract research and commercialization program in UPM. He also served Malaysian Space Agency (AAN), and Astronautic Technology Sdn Bhd (MOSTI's GLC) as a Technical Expert Panel for "the making and design" of the RAZAKSAT sensor wavelength band range of applications. Besides, he assisted the Outer Space Division (BAKSA) [now known as National Space Agency-ANGKASA] in the earlier preparation of TIUNGSAT-1 remote sensing sensor. In similar capacity, he contributed to MOSTI GLC's Astronautic Technology Sdn. Bhd (ATSB) in the mission design parameters for NeqO satellite launch. His expertise in applied remote sensing has also been requested by Agensi Angkasa Negara-AAN (a Malaysian National Space Agency) under MOSTI to set the RAZAKSAT 2.5-5 m spatial resolution sensor parameters design for forestry and natural resources applications and specification acquisition of an integrating sphere. His other professional services with The National Space Agency is his appointment as the Technical Assessment Committee Member for the tender in the Supply, Delivery, Installation, Integration, Testing, Commissioning and Warranty of an Optical Sensor Test and Calibration System/ Integrating Sphere. In addition, he was the Assessor for AAN to evaluate the *Best Undergraduate Thesis Publication in the Field of*

Aerospace. His services were also rendered to the National Institute of Public Administration (INTAN) in coordinating the Research Methodology Module for Senior Government Officers PhD program continuously for four years from 1995 to1999. His expertise has also been the contribution to the Malaysian Science and Technology Encyclopedia Project as a reviewer for remote sensing articles.

His active participation in airborne hyperspectral sensing R & D projects was given recognition by the International Union of Forestry Research Organizations (IUFRO) based in Austria to lead and represent the Malaysian remote sensing scientists and serve as the Deputy Coordinator/Co-Chair for IUFRO Div. 4 “Remote Sensing & World Forest Monitoring” since 2000. His earlier participation in the US airborne sensor campaign AIRSAR NASA PACRIM program has also been given recognition by the Australian government (CSIRO) to further collaborate with UPM on a hyperspectral imaging forest inventory and precision agriculture projects using a CASI sensor. Again, he was appointed as the Project Director for a THEMAP Mission 897 and became the first Malaysian to lead such an R & D project with the CSIRO scientists on board a Cessna 404 VeeH Aviation Canberra Aircraft which clocked more than 50 flying hours. His past link with the Australian counterpart was his appointment as the Malaysian/UPM Project Manager for the THEMAP ASEAN Demonstration Program in the ASEAN-AUSTRALIAN Economic Cooperation Program. At the same time, he has recognized airborne remote sensing as an important area of aerospace technology policy to be developed further in Malaysian R & D program. His extensive contacts in the field of remote sensing/GIS/GPS and experiences in this area were impressed by Infoterra Ltd., UK formerly known as National Remote Sensing Centre, U.K and Spectral Imaging Ltd., Oulu, Finland where he was invited with full expenses covered to deliver an invited talk entitled “Remote Sensing R&D Activities in Malaysia” and observe the AISA airborne imaging spectrometer system in a data collecting mission in the United Kingdom organized by Infoterra Ltd., U.K. The invitation is motivated by the well-recognized reputation of him in the area of remote sensing. His visit led to a scientific cooperation between UPM, Infoterra Ltd. and SPECIM Ltd. in the field of airborne hyperspectral remote sensing after CSIRO. Apart from undergraduate and postgraduate teaching of forest survey, forest engineering, remote sensing and timber transportation for over 13 years, he has contributed perennially more than 350 conference papers at local and international conferences.

His expertise/consultancy and professional services in the field of airborne hyperspectral sensing to the Malaysian government and private agencies include three Final Consultancy Reports entitled Forest Resource Inventory & Analysis of Hutan Simpang Kekal Gunung Stong, Kelantan using UPM-APSB’s AISA Hyperspectral Imaging System submitted to Kelantan State Forestry Department, “Individual Species Mapping and Timber Inventory assessment of Block 53 and 24 other Blocks in H.S.K Berangkat, Kelantan submitted to Kompleks Perkayuan Kelantan (KPK), and Mapping of Rice and Non-Rice Paddies Land Use Cover in Kemubu Agriculture Development Authority (KADA) Bachok District submitted to KADA and the special invitation to the 2005 IUFRO XXII World Forestry Congress in Brisbane to present a plenary paper on the use of airborne hyperspectral sensor developed in Forest Geospatial Information and Survey Lab, Lebuh Silikon, UPM. His recent research products and papers has also been the center of attraction for timely international conference organizers to invite him as Keynote or Plenary Speakers in international recent conferences such as ICACTE’09 in Phuket, Thailand, WHISPERS’09 in Grenoble, France, WSEAS SENSIG’09 in Baltimore, Maryland, 4th IASME/WSEAS EE'09 and 5th. IASME/WSEAS EE'10 in Cambridge, UK, UK-Malaysia-Ireland Engineering Science Conference (UMIES2010) in Belfast, UK, Commonwealth Climate Change Communication Conference (CCCC 2010) in London, UK and many others. In addition, government and private agencies such as Kelantan State Forestry Department, KADA, Kompleks Perkayuan Kelantan, PLUS Highway, Ministry of Defence, as well as Malaysian Maritime Agency (MMA) have invited him for the airborne hyperspectral sensor presentation and requested for his airborne hyperspectral imaging services and digital data to assist in their development program, planning and operations. These projects finally came into reality in 2009 under APSB-UPM Holdings Sdn. Bhd. His international excellence standing in forest surveying/engineering has been recognized by International Union of Forestry Research Organization (IUFRO) with his appointments as Deputy Coordinator/Co-Chairs in Division 3 (Forest Operation and Techniques) and Division 4 (Inventory, Growth, Yield, Quantitative and Management Sciences). He was also given the trust and confidence by international bodies like CSIRO, NASDA, NASA, JOFCA, ILO, FAO, EU and ITTO to serve them as Principal Investigator, Invited Expert Panel and Guest Speaker at Training Workshops. In the capacity as the Professor of Forest Engineering Survey in Malaysia, he represented the Malaysian government as remote sensing expert at international congresses, conferences, workshops and seminars discussing the latest development in remote sensing applications to forestry and other related applications.

Just after being appointed as an Associate Professor, he contributed to UPM to the best of his ability by setting up of the first ever center established in Malaysia, Centre for Precision Agriculture and Bio-resource Remote Sensing in September 1999 to promote the use of aerospace technology in Malaysia in general and in UPM in particular. Being recognized as a pioneer in terms of promoting and adopting precision agriculture in Malaysia through the CPABRS, UPM by a Senior Researcher/Guest Editor at the Regional Science Institute, Sapporo, Japan, he was invited to write an article on the generic topic Precision Agriculture in Malaysia – Progress & Prospects for publication of a special issue of the Journal of Crop Production published by Haworth Food Products Press, New York, USA. By January 2000, this center is fully operationalized with more than 20 highly trained young technical and capable experts in remote sensing /GIS and space technology. It has been to his personal belief that UPM's Centre for Precision Agriculture and Bio-resource Remote Sensing will have all the hall-marks of a relatively mature Malaysian aerospace industry application paradigm. Unfortunately, after two years of active operation, the Center was renamed as Forest Geospatial Information & Survey Lab due to a change and request by UPM's top management. This fully developed research lab originally funded under the MOSTI's IRPA Grant with millions of ringgit worth of modern survey equipment was finally collapsed when the building at Lebuh Silikon had to be demolished to give way for other UPM development projects.

In compliance with his fourth and final strategy and in order to commercialize an informative and precise natural resources and agricultural mapping system based on integrated high precision airborne remote sensing surveying mapping, he was invited and appointed as a Technology Consultant by NetNiaga Sdn. Bhd. In 2003, after almost eight years of researching in the field of forest remote sensing using MOSTI's IRPA Grants, his surveying and mapping products branded as AeroMAP™ has been commercialized through UPM-APSB smart partnerships. This is the first ever surveying and mapping near real-time high precision products locally developed in Malaysia and the Asia-Pacific for various applications. Through an officially-signed agreement between UPM-APSB on 30th. September 2004, he was able to secure for the company a total of RM 307,754 worth of the following projects in 1998 from Dewan Perniagaan Negeri Kelantan, TERAS Teknologi Sdn. Bhd and Sarawak State Government/Chief Minister's Office. In 2005 and 2006, through his recognized and excellent record of professional services and commercialization of forest engineering survey products AeroMAP™ in airborne hyperspectral remote sensing applications, a few more projects were secured from the following clients, namely Kelantan State Forestry Department, Kompleks Perkayuan Kelantan (KPK) Sdn Bhd, Sarawak State Government, Kemubu Agriculture Development Authority (KADA), Talent Global Sdn Bhd, Peninsular Malaysian Forestry Department Headquarters (JPSM), FELDA Agricultural Services (FAS) Sdn Bhd and Ministry of Defense/RMAF using the UPM-AISA airborne hyperspectral sensing. These projects have generated some funds for the university's development through the University Business Center (now, UPM Holdings Sdn Bhd). With his expertise, skills, working experiences and networking to-date that he has established as a Professor since 1999, it is expected that UPM will secure more projects in the future through UPM Holdings.

Having taken the lead, shared and with his noteworthy achievements of lasting value to human kind and of university importance, he was nominated by Faculty of Forestry UPM for the Vice Chancellor Fellowship Award 2005 and was awarded Service Excellence Award 2005. In December 2005, he was awarded a SEAMEO-SEARCA Professorial Chair at University of Philippines at Los Banos (UPLB) to present a public lecture on his successful research product on the airborne hyperspectral imaging system technology for precision agriculture of rice and oil palm. In 2006/7, he was awarded the first Malaysian recipient of the prestigious Erasmus Mundus Visiting Scholar at four top-notch remote sensing based universities in the EU (ITC, The Netherlands; Lund University, Sweden; University of Warsaw, Poland) and UK (University of Southampton) to teach postgraduate Erasmus Mundus students and research in the field of airborne hyperspectral spectroscopy for managing forest and bio-resources. In February 2008, he was invited by Oxford University Centre for Environment (OUCE) at Oxford University to present his professorial lecture to OUCE postgraduate students and staff. Thereafter, he moved to Yale University in March 2008 under the auspices of MOSTI-Academy of Science Brain Gain Malaysia program to be attached to the renowned Yale University's School of Forestry and Environment, Tropical Resources Institute and Center for Earth Observation as a Visiting Professor to work closely with Prof. Lisa Curran as his Host Professor under the Airborne Remote Sensing R&D Program for forest resource and oil palm monitoring and sustainable management. He returned to UPM in late October 2008 to be attached again as a Visiting Scientist with Kyoto University's Graduate School of Engineering at Katsura Campus in Kyoto to work on the use of airborne hyperspectral sensing for water engineering applications. In October-November 2009, he again left, this time for Harvard as a Visiting Professor with the Harvard Forest and Harvard Graduate School of Education.

While at Yale and Harvard, he wrote five books where all have been published in 2008 and 2009 with an editorial assistance of Associate Professor Hjh. Siti Akmar Abu Samah from UiTM University Publication Centre (UPENA). Two more books entitled The ABC's of PhD and Kuala Lumpur Green Valley are upcoming in his book writing series. He is also serving UiTM, USM, UTM and UKM as Professorial Assessor, Host and Co-Chairs for a Singaporean-based International Association for Computer Science and Information Technology (IACSIT), International Organizing Committee Chair for ICACTE08, ICFCC09, ICSAP09, ICIME09, ICFCC09, ICCTD09, ICITE09, ICGIP09, CCCC2010 and many more international conferences. He also serves as ISI Thomson indexed Editors-in-Chief of International Digital Organization for Scientific Information (IDOSI)'s World Applied Sciences Journal (WASJ) and American-Eurasian Journal of Agricultural & Environmental Science (AJAE), Editor for Canadian Research and Development Center of Sciences and Cultures' Canadian Social Sciences (CSS) and Management Science and Engineering (MSE) Journals, Editorial Board Members for World Scientific Engineering Academy Society (WSEAS), Academic Journals and acts as Reviewers for many other renowned journal publishers such as Elsevier, Emerald, just to name a few, in all cross, inter and trans-disciplinary fields of sciences, IT, computer, engineering, social sciences and humanities.

Ever since his return from Yale, Kyoto and Harvard, he has been frequently invited by UiTM Shah Alam, UiTM Kelantan, UiTM Terengganu, UiTM Pahang, UiTM Penang, UiTM Kedah, UiTM Perlis, UKM LESTARI, UKM Faculty of Education, UKM Pusat PERMATApintar Negara, UKM Faculty of Allied Health Sciences, UIAM Gombak, UUM COLGIS, USM@gsb, UPM Faculty of Economics and Management, UPM School of Graduate Studies, UPM Perpustakaan Sultan Abdul Samad, UTM Faculty of Electrical Engineering, Skudai, UTM International Campus, Kuala Lumpur, UNITEN Department of Civil Engineering, UniRazak Capsquare, and Politeknik Kota Bharu to conduct workshops and deliver invited lectures on Impact and Citation Indexed Journal's Writing and Publishing for the Malaysian academia. All these activities open the path of academic drive in research, writing and publication and led to the publication of two international books printed in the

US entitled *Secrets of Successful Journal Writing and Publication Revealed and Academician Career Roadmap*.

Holding strong belief in extending his professorial service to the academia and in his quest for academic excellence, he has developed deep interest in promoting academic leadership development through research which he actively collaborates with UiTM counterpart. Since 2008, he and his research team has completed two research with the endowment of RM90 000 grant awarded by the Akademi Kepimpinan Pengajian Tinggi (AKEPT) under the Ministry of Higher Education. Albeit his endeavor and accolades has marked his illustrious academic milestone, his approachable personality renders the young and aspiring academicians an amicable referral point to achieve outstanding academic status. He seldom, if not hardly fails to let down those who seek his assistance, advice and assurance from his words of wisdom. Indeed, Professor Kamaruzaman Jusoff, an outstanding persona in the world of academia, deserves the standing ovation!


19 July 2009
Kamaruzzaman Jusoff
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1. Prof. Dr. Sulaiman M. Yassin
   The Challenge to Communication Research in Extension
   22 July 1989

2. Prof. Ir. Abang Abdullah Abang Ali
   Indigenous Materials and Technology for Low Cost Housing
   30 August 1990

3. Prof. Dr. Abdul Rahman Abdul Razak
   Plant Parasitic Nematodes, Lesser Known Pests of Agricultural Crops
   30 January 1993

4. Prof. Dr. Mohamed Suleiman
   Numerical Solution of Ordinary Differential Equations: A Historical Perspective
   11 December 1993

5. Prof. Dr. Mohd. Ariff Hussein
   Changing Roles of Agricultural Economics
   5 March 1994

6. Prof. Dr. Mohd. Ismail Ahmad
   Marketing Management: Prospects and Challenges for Agriculture
   6 April 1994

7. Prof. Dr. Mohamed Mahyuddin Mohd. Dahan
   The Changing Demand for Livestock Products
   20 April 1994

8. Prof. Dr. Ruth Kiew
   Plant Taxonomy, Biodiversity and Conservation
   11 May 1994

9. Prof. Ir. Dr. Mohd. Zohadie Bardaie
   Engineering Technological Developments Propelling Agriculture into the 21st Century
   28 May 1994

10. Prof. Dr. Shamsuddin Jusop
    Rock, Mineral and Soil
    18 June 1994

11. Prof. Dr. Abdul Salam Abdullah
    Natural Toxicants Affecting Animal Health and Production
    29 June 1994

12. Prof. Dr. Mohd. Yusof Hussein
    Pest Control: A Challenge in Applied Ecology
    9 July 1994

13. Prof. Dr. Kapt. Mohd. Ibrahim Haji Mohamed
    Managing Challenges in Fisheries Development through Science and Technology
    23 July 1994

14. Prof. Dr. Hj. Amat Juhari Moain
    Sejarah Keagungan Bahasa Melayu
    6 Ogos 1994

15. Prof. Dr. Law Ah Theem
    Oil Pollution in the Malaysian Seas
    24 September 1994

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    Fine Chemicals from Biological Resources: The Wealth from Nature
    21 January 1995

17. Prof. Dr. Sheikh Omar Abdul Rahman
    Health, Disease and Death in Creatures Great and Small
    25 February 1995

18. Prof. Dr. Mohamed Shariff Mohamed Din
    Fish Health: An Odyssey through the Asia - Pacific Region
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19. Prof. Dr. Tengku Azmi Tengku Ibrahim
    Chromosome Distribution and Production Performance of Water Buffaloes
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20. Prof. Dr. Abdul Hamid Mahmood
    Bahasa Melayu sebagai Bahasa Ilmu- Cabaran dan Harapan
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21. Prof. Dr. Rahim Md. Sail
    Extension Education for Industrialising Malaysia: Trends, Priorities and Emerging Issues
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    The Diminishing Tropical Rain Forest: Causes, Symptoms and Cure
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23. Prof. Dr. Ang Kok Jee
    The Evolution of an Environmentally Friendly Hatchery Technology for Udang Galah, the King of Freshwater Prawns and a Glimpse into the Future of Aquaculture in the 21st Century
    14 October 1995

24. Prof. Dr. Sharifuddin Haji Abdul Hamid
    Management of Highly Weathered Acid Soils for Sustainable Crop Production
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    Fish Processing and Preservation: Recent Advances and Future Directions
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    Pesticide Usage: Concern and Options
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27. Prof. Dr. Mohamed Ismail Abdul Karim
    Microbial Fermentation and Utilization of Agricultural Bioresources and Wastes in Malaysia
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    Soil Physics: From Glass Beads to Precision Agriculture
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    Sustained Growth and Sustainable Development: Is there a Trade-Off 1 or Malaysia
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    Back to the Future with the Sun
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    Enzyme Technology: The Basis for Biotechnological Development
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    Will Rural Sociology Remain Relevant in the 21st Century?
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