A Decade of Remote Sensing Research in Ganoderma Disease in Malaysia

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Introduction

- Remote sensing has been used in agriculture for decades. Previously, remote sensing imageries were obtained from the spaceborne based sensor which provides a large area coverage and coarse spatial resolution.
A decade of research ...

• The research on the use of hyperspectral remote sensing for Ganoderma Basal Stem Rot (BSR) disease was initiated in 2007 with the key to achieve early detection.

• Fundamental studies were designed to:
  • Establish baseline information on characteristics of the disease from remote sensing point of view.
  • Understanding of the disease characteristics that from the reflectance.
  • Propose a best technique for aerial disease detection.
A decade of research ...

• In 2013, an R/G/NIR on the UAV platform was flown to map the disease severity using several multispectral indices. The accuracy of the R/G/NIR for Ganoderma BSR detection is between moderate to low.

• Recent technology has shown the utilisation of UAV based multispectral system for site specific identification in agricultural management.

• Currently, a more comprehensive disease severity index was established to validate the series of significant bands in previous research on a different airborne hyperspectral sensor (Pika-L).
A decade of research ...

- The significant bands must be proven accurate and reliable for a large scale disease-management approach and development of standard indices for Ganoderma BSR across sensor.

- Fundamental studies were designed to:
  - Establish baseline information on characteristics of the disease from remote sensing point of view.
  - Understanding of the disease characteristics that from the reflectance
• Knowledge on the crops for better yield and lower cost
• Research in precision farming is costly.
• Know about certain things but uncertainty on many others.
• Research to look into one problems without knowing the underlying issues.
• Resolving one issues at a time.
• Productivity /yield
• To reduced cost and increased profitability
Issues in Agriculture

- Monitoring agricultural areas: time and labour consuming – dealing with large area of homogenous crop.

- Disease and pest detection and control are important phases in agricultural management.

- Cultural practices combined with biological and chemical control have been considered as the best approach for controlling diseases and pests.

- Remote sensing provides a possible solution to the intensive sampling required for site-specific pest management.
Ganoderma disease in oil palm

• What is known: Ganoderma a soil borne fungi
• What is need to be known/relationship
  • water/rainfall
  • humidity
  • Climate – eco ecological zones
  • Temperature
  • Soil
  • Species of the fungi
  • Methods of dispersion
  • Methods of infection

• Models??
Ganoderma BSR

• Fatal disease – most serious disease of oil palm in Malaysia for over 80; severe economic loss in Malaysia.

• The soil-borne fungi attack from the roots and progressively spread to the stem and bole system.

• Prevents water and nutrient uptake: foliar symptoms and gradually affects the growth and yield, eventually leading to the death of the palm.
Detection of Ganoderma BSR

- Visual interpretation - middle or late stages of disease pathology commonly time-consuming, destructive and expensive.

- Aerial detection – enable treatment at the early stage of the infection and avoid more extensive damage and losses.

- Wet lab detection - subclinical symptom of *Ganoderma* GSM test, PCR-DNA molecular, ELISA-polyclonal antibody and GanoScan1 tomography.
Pathological Symptom

- The visible symptom of is seen at later stage: infestation of the pathogen has damaged the stem and bole of the oil palm.

- Four *Ganoderma* species to be associated with oil palm in Malaysia: *G. boninense*, *G. zonatum*, *G. miniatocinctum* and *G. tornatum* but *G. boninense* is the most aggressive (Idris, 1999).
Pathological Symptom
Sensors for disease and stress detection in plants

Molecular methods
Bio-chemical analysis
Biomarker-based sensor
Remote Sensing

Remote Sensing

Spectroscopic Techniques
Visible-near infrared spectroscopy
Fluorescence spectroscopy
Mid infrared spectroscopy
Fluorescence imaging
Hyperspectral imaging
Multispectral Imaging
RADAR
Others

Modified from Reza Ehsani (2010)
## Remote sensing research on Ganoderma

<table>
<thead>
<tr>
<th>Year</th>
<th>Project</th>
<th>Description</th>
<th>Equipment</th>
<th>Disease Severity Index</th>
<th>Methods/ Findings/ Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Early detection Hyperspectral remote sensing for Ganoderma disease detection</td>
<td>Initial idea on hyperspectral remote sensing for Ganoderma disease detection.</td>
<td>GER1500 Spectroradiometer AISA DUAL Hyperspectral Imaging System</td>
<td>Established DSI for nursery, young and mature palm for early detection of Ganoderma</td>
<td>Spectral Analysis, Hyperspectral Vegetation Index, Band Ratios, Continuum Removed, Significant Bands The DSI is too optimistic to be achieved. Results from spectral analysis provides significant bands in all three levels of experiments GIS Mapping on the ground census and</td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td>Experiments in nurseries, Experiments in young palm, Experiments in mature palm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Equipment**
- GER1500 Spectroradiometer
- AISA DUAL Hyperspectral Imaging System
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<th>Findings/ Conclusion</th>
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<tbody>
<tr>
<td>2013</td>
<td>Utilisation of UAV RGB/NIR</td>
<td>Mapping of Ganoderma BSR using a multispectral on UAV platform</td>
<td>Canon IXUS (modified) RGBNIR on Swinglet</td>
<td>New DSI for multispectral mapping</td>
<td>Supervised classification with and without filtering with several window sizes</td>
<td>Moderate results when using RGB/NIR on UAV for Ganoderma detection in plantation</td>
</tr>
<tr>
<td>2017</td>
<td>High Resolution Image on Ganoderma detection</td>
<td>Mapping of Ganoderma BSR using a high-resolution multispectral image on satellite platform</td>
<td>Kompasat 3A Satellite Image, Parrot Sequoia RG/NIR/RedEdge on Ebee</td>
<td>Re-establishing new DSI for Ganoderma detection which includes a more variation in disease severity</td>
<td>In progress</td>
<td>In progress</td>
</tr>
<tr>
<td>2018</td>
<td>Hyperspectral Remote Sensing</td>
<td>Validation on significant band from previous hyperspectral campaign</td>
<td>ASD Spectroradiometer Pika-L Resonon Hyperspectral Imager</td>
<td></td>
<td>In progress</td>
<td>In progress</td>
</tr>
<tr>
<td>2019</td>
<td>Data Fusion Optical and Microwave Remote Sensing</td>
<td>To established data fusion image analysis for Ganoderma Disease detection using RADAR and high-resolution multispectral image</td>
<td>ALOS-PALSAR, Komsat 3</td>
<td></td>
<td>In progress</td>
<td>In progress</td>
</tr>
</tbody>
</table>
Development of DSI

- Using human eye as a detector could only lead to more severe deaths of oil palm plantation because some of the pathological effects of Ganoderma will only be seen at a later stage or in some cases it could not be seen at all.

- Airborne hyperspectral remote sensing data offers a better approach in detecting oil palm stress over wide plantation area (Shafri and Hamdan, 2009).

Airborne hyperspectral imaging utilised imaging spectrometry mounted on the airborne platform that acquires images in many narrow, contiguous spectral bands throughout the visible, near infrared, mid infrared and thermal infrared portions of the spectrum (Nisfariza, 2012; Yang et al., 2011, Izzuddin 2010; Lillesand et al., 2004).
<table>
<thead>
<tr>
<th>Severity</th>
<th>Classification</th>
<th>Visual Assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Seedlings not inoculated and not infected with <em>Ganoderma boninense</em>, seedling is healthy.</td>
<td>Leaves and tree looking healthy. Absence of white mycelium or fruiting body (<em>Ganoderma</em>) at stem base.</td>
</tr>
<tr>
<td>T2</td>
<td>Seedlings inoculated and infected with <em>Ganoderma boninense</em>, WITHOUT foliar symptoms but with white mycelium or fruiting body at stem base.</td>
<td>Leaves and tree looking healthy without any foliar symptom of BSR disease. Presence of white mycelium or fruiting body (<em>Ganoderma</em>) at stem base.</td>
</tr>
<tr>
<td>T3</td>
<td>Seedlings inoculated and infected with <em>Ganoderma boninense</em>, WITH foliar symptoms and with white mycelium or fruiting body at stem base.</td>
<td>Yellowing, browning or drying of some leaves due to <em>Ganoderma</em> infection. One or two new leaves remain as unopened spears. Decline of older leaves. Presence of white mycelium or fruiting body (<em>Ganoderma</em>) at stem base.</td>
</tr>
</tbody>
</table>
DSI 2008
@ Nursery Trials
## Severity

<table>
<thead>
<tr>
<th>Severity</th>
<th>Classification</th>
<th>Visual Assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Healthy palm.</td>
<td>Leaves and tree looking healthy. Absence of white mycelium or fruiting body (Ganoderma) at base stem.</td>
</tr>
<tr>
<td>T2</td>
<td>Palm infected with Ganoderma spp. w/o any foliar symptoms but w white mycelium or fruiting body at base stem.</td>
<td>Leaves and tree looking healthy. Presence of white mycelium or fruiting body (Ganoderma) at base stem.</td>
</tr>
<tr>
<td>T3</td>
<td>Palm infected with Ganoderma spp. with foliar symptoms and white mycelium or fruiting body at base stem.</td>
<td>Yellowing or drying of some leaves. One or two new leaves remain as unopened spears. Declination of older leaves. Presence of white mycelium or fruiting body (Ganoderma) at base stem.</td>
</tr>
</tbody>
</table>
DSI Plantation - 2010

T1

T2

T3
Data Acquisition & Equipment
Hyperspectral Approach

Spectroradiometry

- Nursery (seedlings)
  - 10 months old
  - 24 months old

- Plantation
  - 5 years old young palm
  - 17 years old mature palms

Hyperspectral Imaging

- Plantation
  - 5 years old young palm
  - 17 years old mature palms
Research Works

• Two hyperspectral sensors were employed: handheld (GER1500) and imaging systems (AISA Eagle) at three experiment levels: the nursery, the field and airborne.

• Series of significant bands were able to discriminate Ganoderma BSR at different severity level. This investigation has led to a framework and methods of hyperspectral data collection and analysis in oil palm. Nevertheless, utilizing hyperspectral mapping for oil palm plantation is cost intensive.
Main Findings

Ganoderma RedEdge location is established – a distinctive values of healthy at 720 nm and disease between 660 – 680 nm.

Relationship of the disease with age is confirmed, whereby in younger palms; disease is more prominent and can be detected more easily than in the matured palms.

Significant bands were established.
Baseline study of possibility the use of remote sensing in detecting *Ganoderma* BSR.

- Massive ground works.
- Wavelength 400nm to 1050nm.
- 1.5 nm intervals
- 512 bands
AISA Dual Hyperspectral System

- A scale up study from ground to aerial data.
- Wavelength 400nm to 2500 nm
- 5nm interval
- 244 bands
- 0.68m resolution
- Specim, Finland.
Data Acquisition and Equipment
Study Area – Planted Palm / Airborne

- Oil palm plantation in Seberang Perak, Perak, Malaysia (4° 6’ N 100° 53’ E).
- Data acquired October, 2010

Mature palm 17 years old
Young palm 5 years old
AISA Hyperspectral Image
The hyperspectral image acquired 20 October 2008, effect of fluctuations in solar illumination during flight. [Unfavourable weather in October, the month for monsoon transition period in the country].
### Disease Severity Index (DSI) 2013

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T0</strong></td>
<td>Healthy palm&lt;br&gt;Canopy looks healthy, no presence of <em>Ganoderma</em> fruiting body</td>
</tr>
<tr>
<td><strong>T1</strong></td>
<td>Mild infected palm&lt;br&gt;Canopy looks healthy, presence of <em>Ganoderma</em> fruiting bodies or stem rotting</td>
</tr>
<tr>
<td><strong>T2</strong></td>
<td>Moderate infected palm&lt;br&gt;Canopy yellowing and wilting (&lt;50%), presence of <em>Ganoderma</em> fruiting bodies and stem rotting (&lt;30%)</td>
</tr>
<tr>
<td><strong>T3</strong></td>
<td>Severe infected palm&lt;br&gt;Canopy yellowing and wilting (&gt;50%), presence of <em>Ganoderma</em> fruiting bodies and stem rotting (&gt;30%)</td>
</tr>
</tbody>
</table>
DSI 2018 – 5 Classes
UAV Mission
Unmanned Aerial Vehicle (UAV)

UAV has become commercially available nowadays – have the **advantages of high spatial and temporal resolution** characteristics compared to airborne and satellite platforms.

The advancement of remote sensing technology in providing a **synoptic view** – provides possibility to monitor a large plantation state of vigorousness and stress due to disease, pest and nutrient deficiency.

UAV promotes the remote sensing technology in **detection and monitoring** of existing plot infected with *Ganoderma* BSR.
# UAV Multispectral Sensor

## Sensor – Platform Comparison

<table>
<thead>
<tr>
<th>PLATFORM</th>
<th>UAV</th>
<th>UAV/ AIRCRAFT</th>
<th>SATELLITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SENSOR</td>
<td>Multispectral E.g, Parrot Sequoia</td>
<td>Hyperspectral e.g Pika – L</td>
<td>Multispectral: E.g. Landsat - 8</td>
</tr>
<tr>
<td>NUMBER OF BANDS</td>
<td>3 – 7</td>
<td>220–288</td>
<td>5 – 11</td>
</tr>
<tr>
<td>RANGE OF BANDS</td>
<td>RGB/NIR</td>
<td>VIS/ NIR</td>
<td>VIS / NIR / TIR</td>
</tr>
<tr>
<td>GROUND RESOLUTION</td>
<td>4 – 10 cm</td>
<td>6 cm – 12 cm</td>
<td>30m for VIS/NIR 100m for TIR 15m for Panchromatic</td>
</tr>
<tr>
<td>VEGETATION INDICES</td>
<td>Basic vegetation indices NDVI</td>
<td>Huge number of hyperspectral vegetation indices can be used or develop based on specific crop to evaluate the vegetative properties.</td>
<td>Limited vegetation indices NDVI GNDVI SAVI EVI MSAVI NDMI</td>
</tr>
<tr>
<td>SPECTRAL RESOLUTION</td>
<td>Low – limited number of band combinations for visual assessment.</td>
<td>High – vast number of band combinations for visual assessment.</td>
<td>Low – limited number of band combinations for visual assessment.</td>
</tr>
<tr>
<td>SPATIAL RESOLUTION</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
## Hardware

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wingspan</td>
<td>110 cm (43.30in)</td>
</tr>
<tr>
<td>Weight</td>
<td>1.1 kg (2.42lb)</td>
</tr>
<tr>
<td>Motor</td>
<td>Low-noise, brushless, electric</td>
</tr>
<tr>
<td>Radio link range</td>
<td>3 km nominal (up to 8 km² / 1.86 mi²)</td>
</tr>
<tr>
<td>Detachable wings</td>
<td>Yes</td>
</tr>
<tr>
<td>Sensor (supplied)²</td>
<td>Parrot Sequoia</td>
</tr>
</tbody>
</table>

## Software

- Flight planning and control software: eMotion Ag
- Image processing software (optional): Pix4Dmapper Pro/Ag

## Operation

- Automatic 3D flight planning: Yes
- Cruise speed (mph): 40-110 km/h (11-30 m/s or 25-68 mph)
- Wind resistance: Up to 45 km/h (12m/s or 28 mph)
- Maximum flight time: 55 minutes
- Automatic landing accuracy: Linear landing with ~ 5 m (16.4 ft)

## Result

- Nominal coverage at 120 m (400 ft)²: 200 ha (~500 ac)
  - GSD multispectral: 12 cm/px (4.72 in/px)
  - GSD RGB: 3.1 cm/px (1.22 in/px)
- Maximum coverage at 2,000 m (6,500 ft)²: 3,000 ha (~7,400 ac)
  - GSD multispectral: 2 m/px (6.56 ft/px)
  - GSD RGB: 55 cm/px (2.16 in/px)
Flight Planning
# Image Acquired From UAV

<table>
<thead>
<tr>
<th>Band</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spectral (nm)</td>
</tr>
<tr>
<td>RGB</td>
<td>400-750</td>
</tr>
<tr>
<td>NIR</td>
<td>760-900</td>
</tr>
</tbody>
</table>
Ground Truth
Image Analysis

<table>
<thead>
<tr>
<th>DS</th>
<th>RGB Image</th>
<th>NIR Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>![T0 RGB Image]</td>
<td>![T0 NIR Image]</td>
</tr>
<tr>
<td>T1</td>
<td>![T1 RGB Image]</td>
<td>![T1 NIR Image]</td>
</tr>
<tr>
<td>T2</td>
<td>![T2 RGB Image]</td>
<td>![T2 NIR Image]</td>
</tr>
<tr>
<td>T3</td>
<td>![T3 RGB Image]</td>
<td>![T3 NIR Image]</td>
</tr>
</tbody>
</table>

Analysis on Severity Index - suggested that both RGB and NIR images give significant difference ($p < 0.05$) between all indicated DSIs of BSR disease.
RESULTS

RGB orthophoto image in Experiment 1. RGB orthophoto image in Experiment 2.
NIR orthophoto image in Experiment 1.

NIR orthophoto image in Experiment 2.
Results using Adaptive Filtering (7x7) and Supervised Classification for NIR (a) ML - Enhanced Frost (b) MD – Frost (c) NN - Local Sigma; dan RGB (a) ML- Enhanced Lee (e) NN – Frost (f) MD - Enhanced Lee.

The adaptive filtering increased the accuracy of classification to up to 8%, with average 42% accuracy.
GIS and Remote Sensing

- Identification and digitizing of polygon on the selected palms which has been categorized into four states of palm health known as H, HS, G and GS.
• To incorporate all data collected by remote sensing with the census to develop a time series of disease spread over time. Multi sensor and multi temporal.
What is next?

• Ganoderma Workshop 2014 (MPOB and Malaysian Oil Palm Stakeholders):
• Early detection tools – more sensitive, precise and localize
• Standardize the methods and classification – visualize
• Faster, cheaper and precise remote sensing and GIS
• Aerial detection – need estimation for the statistical analysis using hyperspectral remote sensing.
• Estate experience 1 UAV for 500 ha per day, depend on certain limitation
Remote Sensing Research on *Ganoderma in MPOB*

- Spectroradiometer (GER1500)
- Hyperspectral (AISA DUAL)
- Multispectral (UAV Swinglet)
- Hyperspectral UAV (DJI Matrix 200)
- RADAR
Future Developments

• **Develop** specific vegetation index for Ganoderma based on significant bands.
• **Modeling** on the relationship of *Ganoderma* disease with factors such as soil type, moisture content, nutrient.
• **Index mapping** of *Ganoderma* disease for areal based identification for management and planning purposes.
• New UAV hyperspectral system – using band selection.
• GIS mapping, hotspots and prediction of disease dispersion.
• RADAR (Radio Detection and Ranging) fusion with hyperspectral imagery.
Way Forward

• Digital Transformation of Agriculture Industries
• Agriculture 4.0
• Hyperspectral – digital transformation of the agricultural data
• Big data and analytical capabilities
• New processing techniques – deep learning
• New technologies of hyperspectral on drone etc.
• Technology becomes cheaper and new cutting-edge will be introduced.
Acknowledgement

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    http://itrc.um.edu.my
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