

Original Research Article

Remote Sensing for Detection of *Ganoderma* Disease and Bagworm Infestation in Oil Palm

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Abstract: Two major disease and pest in oil palm are *Ganoderma* disease and bagworm infestation. *Ganoderma* disease caused by *Ganoderma boninense* and bagworm infestation caused by *Metisa Plana* have caused significant losses to the oil palm industry. Therefore, early detection and control are important to reduce the losses. This paper reviewed the existing approaches, challenges and future trend of aerial remote sensing technology for *Ganoderma* disease and bagworm infestation in oil palm. The aerial remote sensing technology comprises of multispectral, hyperspectral camera and radar which have different platforms such as satellite, aircraft and Unmanned Aerial Vehicle (UAV). The aerial multispectral and hyperspectral remote sensing analyse spectral signatures from visible and near infrared spectrum range for the detection of disease and pest attacks. Studies have showed that satellite- based multispectral remote sensing only provide moderate accuracy (<70%) compared to UAV-based multispectral remote sensing (>80%) for the detection of disease and pest infestation. Similarly, our study using multispectral camera onboard UAV showed 90% of accuracy for moderate and severe *Ganoderma* disease detection in oil palm. Meanwhile, application of aerial hyperspectral remote sensing for *Ganoderma* disease demonstrated potential for the early detection of *Ganoderma* disease in oil palm and in addition, can be used to detect early pest infestation in oil palm based on field spectroscopy results. Other than that, radar remote sensing has also been able to differentiate healthy and infected oil palm through the analysis of radar backscatter image of the foliar, frond and crown of oil palm. As a conclusion, aerial remote sensing provides a better and faster disease and pest infestation detection system compared to ground-based inspection which in turn can

provide a more economic and efficient management of disease and pest infestation for large oil palm plantation areas.

Keywords: Oil palm; *Ganoderma* disease; bagworm infestation; UAV; multispectral; hyperspectral; radar satellite.

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1. Introduction

Oil palm is an important commodity crop and industry in Malaysia. The oil palm industry provides significantly to gross domestic product (GDP), gross national income (GNI) and foreign exchange as well as employment (Kushairi *et al.*, 2018). However, the oil palm industry is still facing a major problem where *Ganoderma* disease and bagworm (*Metisa plana*) pest infestation have been found to cause considerable reduction in yield and profit in oil palm plantations (Norman & Basri, 2010; Idris *et al.*, 2016). The *Ganoderma* disease in oil palm is caused by *Ganoderma sp.* which infects the root, bole and lower stem of the oil palm. The infection causes rotting to the oil palm tissue which reduces uptake of water and nutrients from root to the leaves and fruit production (Nuranis *et al.*, 2016). The disease also affects the physiology of oil palm such as chlorophyll and water content and photosynthesis which include gas exchanges (Haniff *et al.*, 2005). These physiology changes due to root infection create stress that can change the spectral signature of the healthy oil palm (Izzuddin, 2010).

Meanwhile, bagworm infestation can cause about 30–40% yield losses (Basri, 1993). Regular census and aerial spraying of bio-insecticide is important to control the infestation (Kamarudin *et al.*, 2017). Current bagworm infestation detection relies on visual inspection on the ground based on the visual symptom of bagworm presence and damage to the foliar (Cheong *et al.*, 2010), which also changes the spectral signatures of the foliar.

Spectral signature can be defined as a function of the incidental electromagnetic wavelength and material interaction with that section of the electromagnetic spectrum (Horning, 2008). Several studies showed that there were unique spectral signatures of crops changes from healthy towards the diseased and infested that are present in different narrow specific wavelengths (Izzuddin, 2010; Lelong *et al.*, 2010; Shafri *et al.*, 2011; Nordiana *et al.*, 2012; Liaghat *et al.*, 2014). These spectral signatures derived from crops can be extracted from the aerial multispectral and hyperspectral remote sensing image.

Remote sensing can be defined as the science and practice of acquiring information about an object without actually coming into contact with it (Horning, 2008). In this paper, the context of aerial remote sensing includes satellite and airborne-based remote sensing. There are two types of aerial remote sensing: 1) optical and 2) radar. The optical sensing consists of multispectral and hyperspectral cameras on-board the satellites and airborne platforms that record imagery of spectral signatures from objects on the ground. The airborne platforms can be represented by a piloted aircraft or an Unmanned Aerial Vehicle (UAV). On the other hand, the radar remote sensing consists of radar antenna system on-board a satellite platform that transmits microwave signals from the Earth orbits to the ground and record back the backscatters from the ground objects.

The detection of disease and pest infestation in the field is important to assist in disease and pest control, so as to prevent further losses. Current disease and pest detection technique uses visual inspection or ground census, *Ganoderma* Selective Medium (GSM), field spectroscopy and also molecular lab-based detection kit for each individual oil palm in the field (Ariffin *et al.*, 1993; Shafri *et al.*, 2011 Idris *et al.*, 2016; Nordiana *et al.*, 2012). As a result, the ground detection requires high cost for labour and time consuming. Hence, a faster detection technique that can cover a wide oil palm area is needed to assist managers to plan and conduct faster control and replanting works to avoid further loss. In this, aerial remote sensing showed the potential as a solution for faster disease and pest detection measures in oil palm.

The optical aerial remote sensing provides imageries that can identify the location and sets apart healthy and diseased or infested crops through the classification of the spectral signatures from an image. The multispectral imaging measures sunlight in a small number (typically 3 to 15) of spectral bands while hyperspectral imaging provides hundreds of narrow bands measured in percentage of reflectance from visible to near infrared spectrum region (Schowengerdt, 2007). Additionally, current advancement in the multispectral and hyperspectral cameras have introduced the use of a light-weight camera that can be mounted onto small UAV at a lower cost compared to previous technology which had bulky and expensive cameras which can only be mounted onto large piloted aircrafts. Meanwhile, radar remote sensing is a satellite-based active imaging system that can capture images during day and night, and does not have cloud cover problem but provide lower spatial resolution. Therefore, in this study, the application of the optical (multispectral and hyperspectral) and radar aerial remote sensing for detection of *Ganoderma* disease and pest infestation in oil palm was discussed.

2. Materials and Methods

The flowchart of methodology is shown in Figure 1.

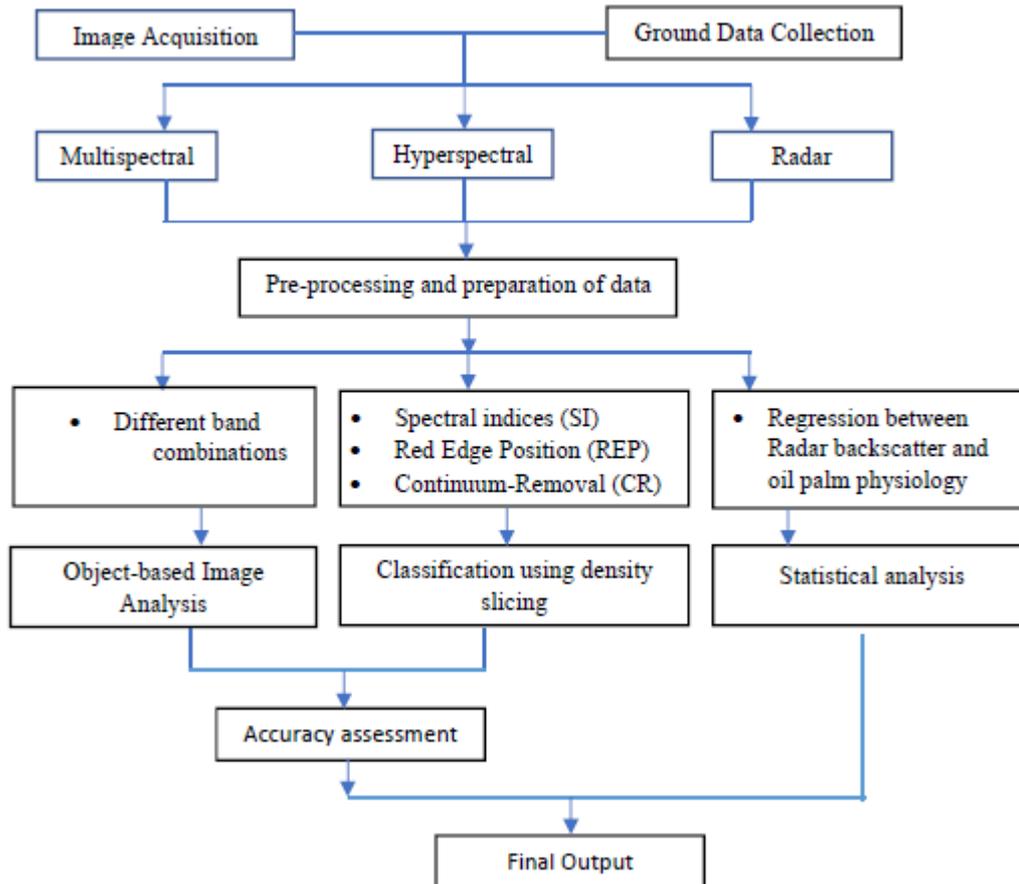


Figure 1. Flowchart of methodology

2.1 Remote Sensing Images Acquisition

This study acquired three types of different remote sensing imageries which are: 1) multispectral image from UAV; 2) hyperspectral image from airborne fixed-wing platform; and 3) radar satellite. The multispectral image was acquired using Sequoia multispectral camera mounted on DJI Phantom 4 UAV (Figure 2) over eight years old oil palm area. The multispectral camera acquires four spectral bands which are: 1) green (G); 2) red (R); 3) red edge (RE); and near infrared (NIR).

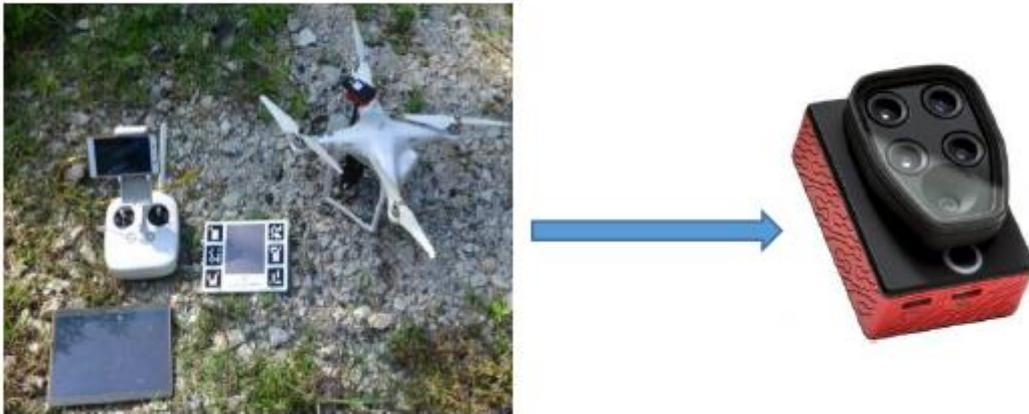


Figure 2. Sequoia multispectral with DJI Phantom 4 UAV system.

Then, the hyperspectral image was acquired using AISA SPECIM Eagle hyperspectral camera on-board a fixed-wing piloted Skyvan aircraft (Figure 3). The hyperspectral camera acquired 128 spectral bands images over 7 and 13 years old oil palm area.

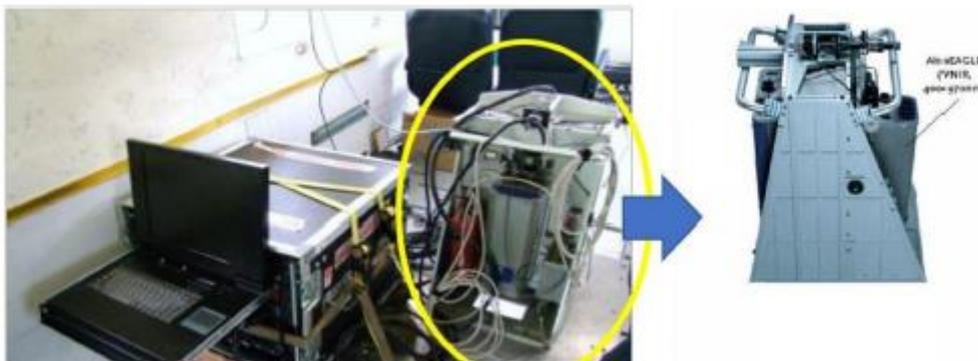


Figure 3. AISA SPECIM Eagle hyperspectral camera on-board Skyvan aircraft.

Radar image was acquired using ALOS-PALSAR satellite (Figure 4) over 8 eight years old oil palm.

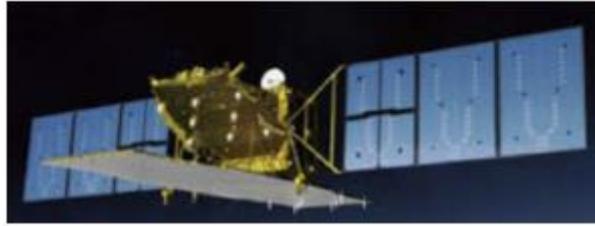


Figure 4. ALOS PALSAR 2 satellite

2.2 Ground Data Collection

Ground data collected in this study consisted of ground census of *Ganoderma* disease and bagworm infestation in the study area. The ground census was conducted using visual inspection of individual oil palm on the ground. The ground census categorised the individual oil palm into four *Ganoderma* disease severity index (GDSI): 1) healthy (T0); 2) mild/early (T1); 3) moderate (T2); 4) severe (T3) infection of *Ganoderma* disease in oil palm (Figure 5). The early or mild infections were not included in data collection due to insufficient amount of training data. Only two oil palms were confirmed as T1 during the ground census. The ground census data was digitised and stored in the Geographic Information System (GIS) software to be overlaid onto the remote sensing image for image classification and accuracy assessment purposes.



Figure 5. The *Ganoderma* Disease Severity Index (GDSI).

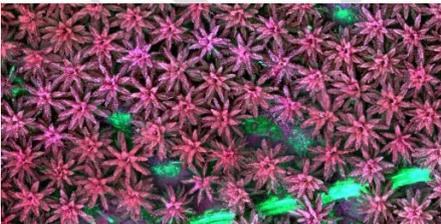
The ground data for *Ganoderma* disease consisted of the ground census of GDSI that tagged with individual oil palm geographic coordinate information were converted into geospatial data as vector file type and stored in GIS software (ArcGIS 10.3). The ground data for bagworm infestation consisted of healthy (P0) and infested oil palm (P1). The ground

data was conducted by visual inspection of bagworm existence on the leaves and fronds of oil palm for occurred damages (Kamarudin *et al.*, 2017).

2.3 Data Pre-Processing and Preparation

The GDSI data recorded during ground census data were stored in a vector file format in GIS system. The GDSI were tagged with geographical coordinate of each individual oil palm in the study area. The multispectral and hyperspectral images were pre- process for radiometric, geometric, orthorectification and mosaicking using pix4D and Caligeo ENVI 4.3 software. The radar satellite imagery was corrected to backscatter image using ENVI 4.3 software. The pre-processed multispectral image used in this study is shown in Table 1.

Table 1. Multispectral image from satellite and UAV over an oil palm area

No.	Type of Platform	Application	Multispectral Image
1.	UAV	<i>Ganoderma</i> disease	
2.	UAV	Bagworm infestation	

2.4 Remote Sensing Image Processing

The multispectral image was processed using Example-Based Image Analysis which is a part of Object based image Analysis (OBIA) methods for classification of four GDSI. The processes were conducted using ENVI 5.0 software. There were five spectral band combinations (Table 2) tested in this study.

Table 2. List of individual band and different band combinations.

No.	Three-bands combinations	Four-band combinations
1	G_R_RE	G_R_RE_NIR
2	G_R_NIR	
3	R_RE_NIR	
4	G_RE_NIR	

The hyperspectral image was processed using several spectral indices (Table 3), red edge position (REP) (Table 4) and continuum-removal (Table 5).

Table 3. Hyperspectral spectral indices.

No.	Spectral indices
1	Normalised Difference Vegetation Index (NDVI)
2	Simple Ratio Index (SRI)
3	Enhanced Vegetation Index (EVI)
4	Vogelmann Red Edge Index (VREI)
5	Carotenoid Reflectance Index 2 (CRI 2)

Table 4. Red edge position (REP).

No.	Red Edge Position (REP)
1	Linear Interpolation(NDVI)
2	Simple Ratio Index (SRI)
3	Enhanced Vegetation Index (EVI)
4	Vogelmann Red Edge Index (VREI)

Table 5. Continuum-removal (CR).

No.	Continuum-removal (CR)
1	Continuum Removed Reflectance(CRR)
2	Band depth (BD)
3	Normalised Band Depth (NBD)
4	Band Depth Normalised to Area(BDNA)

Other than that, the radar image was processed using radar coefficients into radar backscatter values. The radar backscatter values were regressed with several oil palm physiological parameters which were: 1) number of frond and pinnae; 2) height and circumference of trunk; 3) length, depth, width and moisture content of frond; 4) length, width and moisture content of pinnae. The biophysical parameters were regressed with three levels of disease severities which were healthy, mild, and severe.

The OBIA method used to analyse the multispectral image was conducted by Izzuddin *et al.* (2020). The outputs of the OBIA were then assessed using confusion matrix. The results for hyperspectral image analysis were analysed using comparative statistical analysis (Nisfariza, 2012; Izzuddin *et al.*, 2018). The radar image was analysed using statistical regression analysis (Toh *et al.*, 2018).

3. Results and Discussion

3.1 Ground Data

The ground census recorded manually in the field was digitised and stored in GIS database using ArcGIS 10.3 software. The data was divided into training and testing data. The training data was then used to train the classification algorithm while the testing data was used for accuracy assessment of the image classification output.

3.2 Multispectral Image

For *Ganoderma* disease detection, the multispectral image was processed using OBIA into T0, T2, T3 and T4 and the accuracy assessment was conducted using the confusion matrix. The results are shown in Table 6.

Table 6. Accuracy assessment of classification output for individual band and different band combinations.

Band combinations	Rank	Category Accuracy (%)			Overall Accuracy (%)	Kappa Coefficient
		T0	T2	T3		
G_R_RE	5	85.1	76.9	41.7	82.0	0.8693
G_R_NIR	1	95.03	76.9	58.3	91.8	0.9426
R_RE_NIR	3	90.6	84.6	33.3	86.9	0.9665
G_RE_NIR	4	87.8	84.6	58.3	85.9	0.7929
G_R_RE_NIR	2	93.4	76.9	41.7	89.3	0.8941

The results showed that the multispectral image was unable to distinguish between healthy and early infection of *Ganoderma* disease in oil palm but have high accuracy in discriminating between healthy, moderate and severe *Ganoderma* disease infection. The best band combination to differentiate between healthy, moderate and severe infection is the G, R and NIR band combinations (Figure 6).

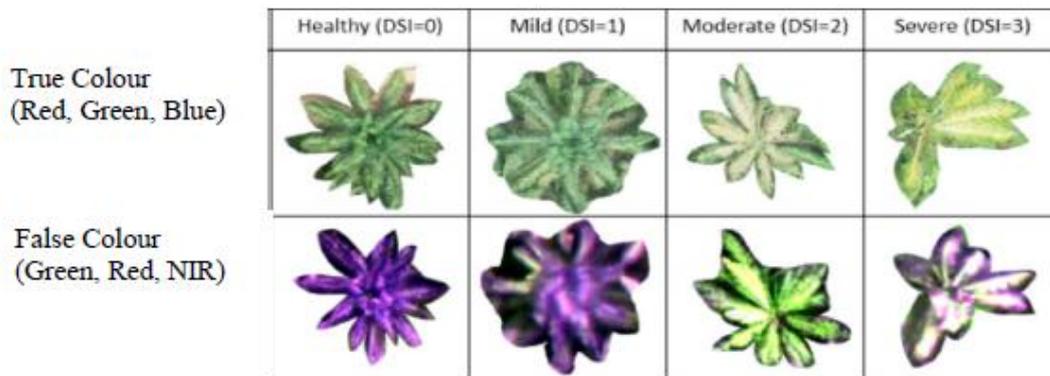


Figure 6. Comparison of true colour band combinations with the best false colour band combinations for *Ganoderma* disease detection in oil palm.

For bagworm infestation detection, the analysis was only conducted using multispectral imagery. The image obtained was analysed for comparison of healthy and infested oil palm. The results suggested that band combinations of RE, R and G is the best to visually differentiate healthy and infested oil palm (Figure 7).

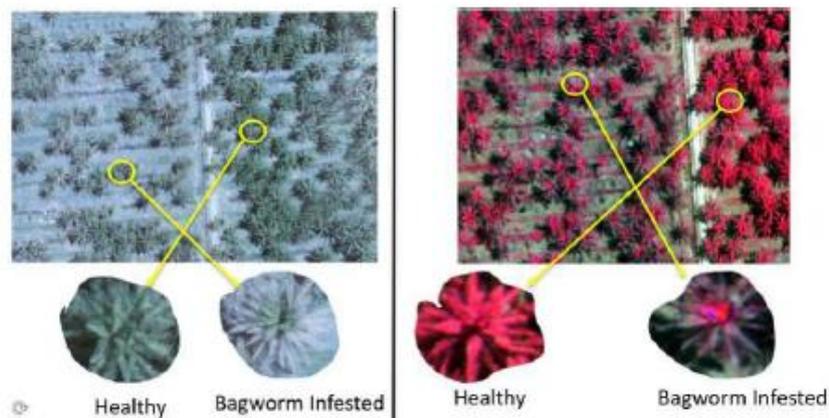


Figure 7. Comparison of true colour band combinations with the best false colour band combinations for bagworm infestation detection in oil palm.

3.3 Hyperspectral Image

The hyperspectral image was processed using the spectral indices, REP and also continuum-removal. The results showed that there are no spectral indices and that REP had the capability for early detection of *Ganoderma* disease in oil palm. However, early detection showed potential by using Band-Depth Normalised to Area (BDNA) in

Continuum-Removal method (Figure 8). On the other hand, the BDNA had low accuracy in classifying moderate and severe infections of *Ganoderma* disease in oil palm. There is a need to integrate the CR methods with SI and REP method to enable the classification of all *Ganoderma* disease severities.

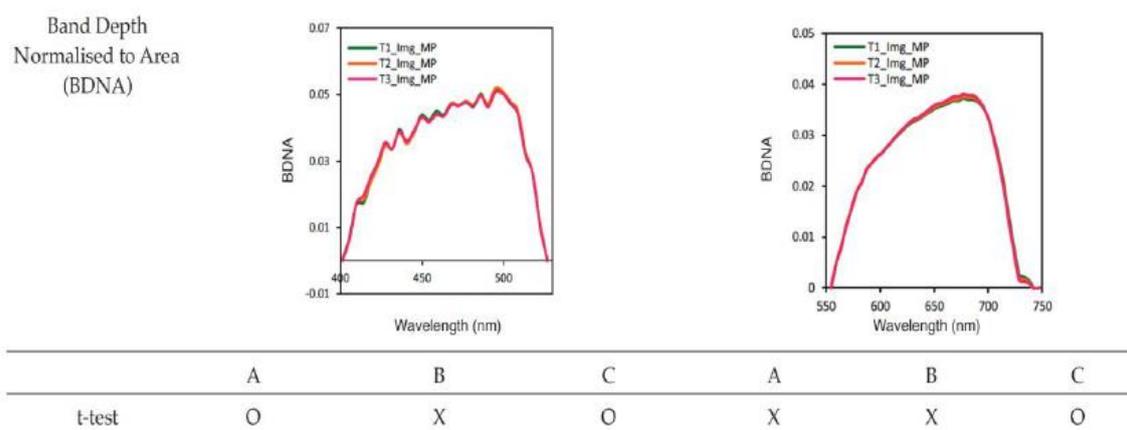


Figure 8. Results of Continuum-Removal (CR) analysis for Band Depth Normalised to Area (BDNA) Note: Results for *t*-test — O (significant difference); and X (no significant difference). *p*-value — 0.05 with 95% confidence level. T1 (healthy), T2 (moderate) and T3 (severe) A - T1 vs. T2, B - T2 vs. T3, C- T1 vs. T3

3.4. Radar Satellite

Several parameters were correlated with the increase of disease severity index which include the number of fronds, number of pinnae, frond length and petiole width. The results showed that the HH polarization decreases drastically while VV undergoes slight decrease in backscatters with increasing disease severity index on 8 years old oil palm. Meanwhile, there were increases in backscatter for all polarization with a small increase in HV/VH for 16 years old oil palm (Figure 9).

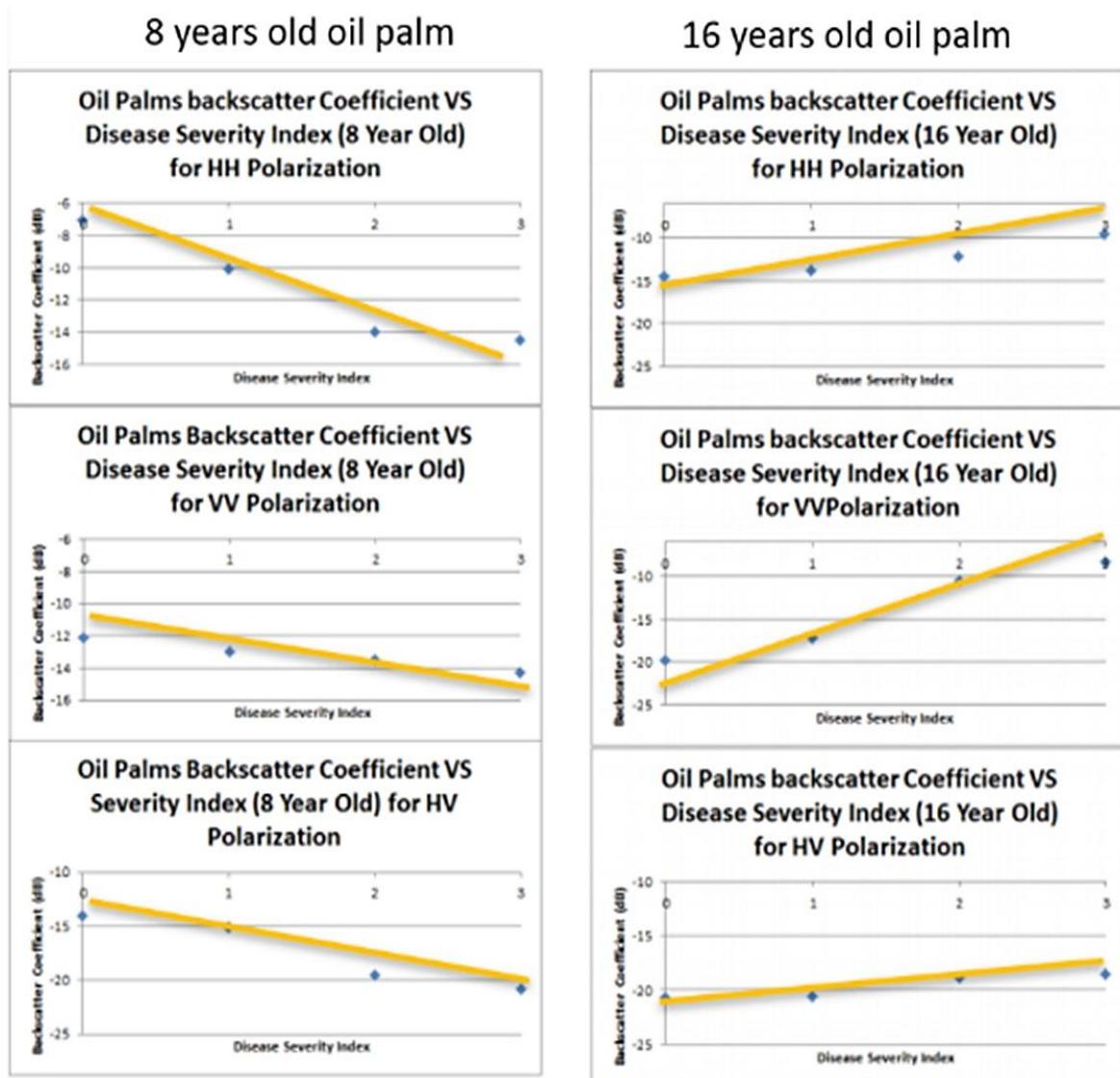


Figure 9. Results of radar imagery to differentiate, healthy, mild and severe *Ganoderma* disease infection in oil palm.

4. Conclusion

Aerial remote sensing using multispectral, hyperspectral and radar sensors were seen to be able to provide assistance for large scale *Ganoderma* disease and bagworm infestation detection in oil palm. The multispectral imaging was capable to differentiate between healthy, moderate and severe infection with overall accuracy more than 90%. However, it was deemed not feasible to detect early (mild) infection of *Ganoderma* BSR disease in oil palm. Meanwhile, the hyperspectral imaging was able to differentiate between healthy, mild and other severity of *Ganoderma* BSR disease in oil palm using Continuum-removal algorithm with p -value < 0.05 using the t-test. Other than that, Synthetic Aperture Radar (SAR) image showed that HH and VV polarisation of L-Band radar also with p -value

<0.05 using the *t*-test image has the capability for detection of the *Ganoderma* disease in oil palm. This study also showed that the multispectral false colour composite has the capability to differentiate between healthy and bagworm-infested oil palm. For future works, analysis of aerial remote sensing image using Artificial Intelligence (AI) and Deep Learning (DL) could facilitate better disease infection and pest infestation detection for precision agriculture in oil palm.

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