UNIVERSITI PUTRA MALAYSIA

APPLICATION OF INSITU SENSORS AND REMOTE SENSING DATA FOR DETECTION EARLY STAGE Ganoderma boninense IN OIL PALM

SEYEDEH PARISA AHMADI

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By

SEYEDEH PARISA AHMADI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

January 2018

DEDICATION

Dedicated with Love to

My Kind Father, Naser

and

My Beloved Mother, Mozhgan

You are loved beyond words and missed beyond measure

and

My hero Mehrzad

For His Love and Sacrifices

I wish I could Give Him More Love

Special Thanks to My Supervisor, Farrah Melissa for Her Endless Support

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

APPLICATION OF IN-SITU SENSORS AND REMOTE SENSING DATA FOR DETECTION OF EARLY STAGE *Ganoderma boninense* IN OIL PALM

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January 2018

Chairman: Assoc. Prof. Farrah Melissa Muharam, PhD
Faculty: Engineering

Ganoderma boninense is a causal agent of basal stem rot (BSR) and is responsible for a significant portion of oil palm (*Elaeis guineensis*) losses, which can reach USD 500 million a year in South East Asia. At the early stage of this disease, infected palms are symptomless, which imposes difficulties in detecting the disease. In spite of the availability of tissue and DNA sampling techniques, there is a particular need for replacing costly field data collection methods for detecting *Ganoderma* in its early stage. This study evaluated the use of insitu and remote sensors to early detect the *Ganoderma* infected oil palms before the visual symptoms are manifested (mildly infected). The study was conducted in Machap sub-district belonging to United Malacca Berhad located in Melaka, Malaysia (2.402° N and 102.327° E) (WGS 84 coordinate system). Initially an experiment was carried out to determine the best insitu sensors that could be utilized for early detection of *Ganoderma* in oil palms. During the field experiments, leaf samples of healthy (T1), mildly (T2), moderately (T3) and severely-infected (T4) palms were measured using a Minolta SPAD-502 chlorophyll meter and a SC-1 leaf Porometer to obtain relative leaf chlorophyll content and stomatal conductance, respectively. Afterwards spectral reflectance readings data were acquired using a GER 1500 spectroradiometer from 1016 spectral signatures of foliar samples in four disease levels (T1 to T4) and 2 fronds (9, 17). Various artificial neural network (ANN) architectures were applied to the datasets to verify the proficiency of various combinations of input variables, learning optimization methods and different numbers of neurons on the hidden layer by MATLAB 2014a software. The neural network chosen in this study was multi-layer and back-propagation (BP) due to the ability to learn and determine nonlinear combinations. 70.0% of data were assigned for the purpose of training the network, while the remaining 30.0% of data were allocated for testing model accuracy.Subsequently in imaging processing study, 287 oil palm samples were classified into three disease levels (T1 to T3) using ANN, whereby the principle of the classification is to seek for the most representative image configurations and network properties while adjusting for the best canopy circle radius, threshold limit, best neuron numbers of hidden layer and the best mean and standard deviation values from different combination of spectral bands (green,

red, and NIR bands) from CIR images obtained from a unmanned aerial vehicle (UAV). Simultaneously, the number of hidden neurons and termination error were optimized given various classification input in order to correctly classify the imaged palms to their corresponding severity classes. For this purpose, the dataset was randomly split into three sets, 60.0% for model training, 20.0% for model validating, and 20.0% for model testing. In the second stage and for improvement of image processing study, support vector machine (SVM) classifier was performed on UAV and Pleiades imagery to identify early *Ganoderma* infected oil palms. In the first phase, spectral features and structural features were extracted for feature extraction. In the spectral features part, the descriptors include red (R), green (G), blue (B), near-infrared (NIR) digital numbers and a vegetation index (VI) was considered. Statistical parameters like average, variance and grey-level co-occurrence matrix (GLCM) was set as a structural feature which provides several statistics information about the texture of an image. In the next phase, the SVM classifier was trained to achieve the best classification using training data and test data integrated with selected features. The results and consequences of this study showed that the chlorophyll meter, leaf porometer and spectral indices from the spectroradiometer, mNDVI, GNDVI and VOG1, were found beneficial to differentiate between T1 and T2. Nonetheless, the combination of VOG1-stomatal conductance obtained from frond 9 and 17 could discriminate the T2 palms from the T1 ones with accuracies ranging from 66.67% to 73.68% regardless of time of measurements. The results obtained from the spectroradiometer analysis presented that the healthy oil palms and those which were infected by *Ganoderma* at early stage (T2) were classified satisfactorily with an accuracy of 83.33%, and 100.0% in 550-560 nm, respectively, by ANN using first derivative spectroradiometer data. The results further indicated that the sensitive frond number modelled by ANN provided the highest accuracy of 100.0% for frond number 9 compared to frond 17. The results acquired from the UAV classification in the third study indicated that classification error of 12.29% was achieved which generated by the ANN network by 219 neurons, green and NIR bands, canopy circle radius of 35 pixels and 1/8 threshold limit. The total classification accuracy for training and testing the dataset was 97.52% and 72.73%, respectively. Finally, the findings from fourth study showed that the best prediction results of using SVM classifier were obtained from the UAV image with an overall accuracy of 68.28% compared to Pleiades with an overall accuracy of 64.52%; also the early *Ganoderma* infection (T2) could be detected with an accuracy of 64.07% and 64.49%, respectively. Even though at first glance the classification accuracy was moderate, the level of details provided by the imageries suggests that the accuracies were acceptable. In conclusion, for early detection of *Ganoderma*, better accuracies were derived from the spectroradiometer which is a destructive and ground based method and still requires individual leaf sampling. This method is still considerably time-consuming and laborious compared to the rapid, nondestructive approach of canopy reflectance using UAV or satellite imagery. The latter, nonetheless, gained reasonable accuracy and is appropriate for field applications involving mass screening of oil palm plantations that are commonly cultivated in thousands of hectares in seeking for potentially infected individual palms. This study concluded that remote sensing approach combined with data mining approaches such as ANN algorithms have great potential in monitoring vast plantation areas in a rapid and inexpensive manner.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PENILAIAN TERHADAP PELBAGAI SISTEM PENDERIAAN JARAK DEKAT DAN JAUH UNTUK PENGESANAN AWAL POKOK KELAPA SAWIT YANG DIJANGKITI PENYAKIT *Ganoderma*

Oleh

SEYEDEH PARISA AHMADI

January 2018

Pengerusi: Prof. Madya Farrah Melissa Muharam, PhD
Fakulti: Kejuruteraan

Ganoderma boninense adalah agen penyebab penyakit reput pangkal batang (BSR) dan menyebabkan kerugian besar dalam industri kelapa sawit (Elaeis guineensis) yang boleh mencecah sehingga USD500 juta setahun di kawasan Asia Tenggara. Pada peringkat awal penyakit ini, tiada gejala pada pokok yang dijangkiti, dan ini mengakibatkan kesukaran untuk mengesan penyakit ini. Walaupun terdapat teknik pensampelan tisu dan DNA, terdapat keperluan khusus untuk menggantikan kaedah pengumpulan data lapangan yang mahal untuk mengesan penyakit *Ganoderma* pada peringkat awal. Kajian ini menilai Penilaian Terhadap Pelbagai Sistem Penderiaan Jarak Dekat Dan Jauh Untuk Pengesanan Awal Pokok Kelapa Sawit Yang Dijangkiti Penyakit *Ganoderma* sebelum kemunculan gejala visual. Kajian ini dijalankan di ladang kelapa sawit yang dimiliki oleh United Malacca Berhad yang terletak di mukim Machap, Melaka, Malaysia (2.402° N and 102.327° E) (system koordinat WGS 84). Di dalam kajian pertama, satu eksperimen telah dijalankan untuk menentukan penderia jarak dekat terbaik untuk pengesanan awal penyakit *Ganoderma* pada pokok kelapa sawit. Sampel daun kelapa sawit sihat (T1), dijangkiti tahap awal (T2), dijangkiti tahap sederhana (T3) dan dijangkiti tahap lewat (T4) diukur dengan menggunakan meter klorofil Minolta SPAD-502, porometer daun SC-1 dan spektroradiometer GER 1500 untuk mendapatkan kandungan relatif klorofil daun, konduktansan stomatal, dan bacaan pantulan spektra. Di dalam kajian kedua, data pembalikan spektra diperolehi dengan menggunakan spektroradiometer GER 1500 pada profil spectrum 1016 daripada sampel foliar pada empat tahap penyakit (T1 hingga T4) dan 2 pelepah (9,17). Pelbagai senibina jaringan pembuatan neural (ANN) telah dianalisa terhadap data pembalikan spektra untuk mengenalpasti kecekapannya dari segi pembolehubah, kaedah pengoptimuman pembelajaran dan nombor neuron yang berbeza pada lapisan tersembunyi dengan menggunakan perisian MATLAB 2014a. Rangkaian neural yang dipilih pada kajian ini adalah berbilang lapis dan perambatan balik kerana kemampuannya untuk mempelajari dan menentukan kombinasi tidak linear. Di dalam kajian ini, 70.0% data telah ditetapkan untuk tujuan latihan rangkaian, manakala baki 30.0% data diperuntukkan untuk menguji ketepatan model. Di dalam kajian ketiga, untuk

kajian pemprosesan imej, 287 sampel kelapa sawit diklasifikasikan kepada tiga tahap penyakit (T1 hingga T3) menggunakan ANN, dengan prinsip klasifikasi adalah untuk mencari konfigurasi imej dan sifat rangkaian yang paling bersesuaian dengan tahap jangkitan penyakit. Konfigurasi imej dan ciri-ciri rangkaian untuk radius bulatan dan had ambang terbaik, bilangan neuron lapisan tersembunyi yang terbaik dan nilai purata dan sisihan piawai kombinasi spektrum yang berbeza (band hijau, merah, dan NIR) daripada imej komposit inframerah yang diperolehi daripada pesawat udara tanpa pemandu (UAV) telah dinilai. Dalam masa yang sama, bilangan neuron tersembunyi dan pengoptimuman penamatan ralat juga dioptimumkan menggunakan pelbagai input klasifikasi yang betul dengan kelas tahap jangkitan penyakit yang sepadan. Bagi tujuan ini, kumpulan data dibahagikan secara rawak kepada tiga set, 60% untuk latihan model, 20% untuk pengesahan model, dan 20% untuk pengujian model. Di dalam kajian keempat, pengkelasan Mesin Vektor Sokongan (SVM) telah dilakukan pada imej UAV dan Pleiades untuk mengenal pasti pokok kelapa sawit yang dijangkiti oleh penyakit *Ganoderma* pada peringkat awal. Dalam fasa pertama, ciri spektrum dan struktur telah diekstrak. Deskriptor bagi ciri spektrum termasuk nombor digital jalur merah (R), hijau (G), biru (B), inframerah dekat (NIR) dan indeks vegetasi (VI). Parameter statistik seperti purata, varians dan matriks kejadian bersama aras kelabu (GLCM) ditetapkan sebagai ciri struktur yang menyediakan beberapa maklumat statistik mengenai tekstur imej. Dalam fasa seterusnya, pengkelas SVM dilatih untuk mencapai klasifikasi terbaik menggunakan data latihan dan data ujian yang disepadukan dengan ciri-ciri terpilih. Hasil kajian pertama menunjukkan bahawa Meter klorofil, porometer daun dan indeks spectra dari spektroradiometer iaitu mNDVI, GNDVI and VOG1 didapati bermanfaat untuk membezakan antara T1 dan T2. Walaubagaimanapun, gabungan VOGI-konduktans stromatal yang diperolehi daripada pelepah 9 dan 17 boleh membezakan pokok kelapa sawit yang dijangkiti awal (T2) dengan yang sihat (T1) dengan ketepatan dari 66.67% kepada 73.68% tanpa mengira masa pengukuran. Hasil kajian kedua menunjukkan bahawa pokok kelapa sawit yang sihat dan yang telah dijangkiti oleh penyakit *Ganoderma* pada tahap awal (T2) telah berjaya dikelaskan dengan ketepatan 83.33%, dan 100.00% dengan menggunakan panjang gelombang 550-560 nm oleh ANN melalui spektra derivatif pertama. Keputusan kajian ketiga pula menunjukkan bahawa bilangan pelepah yang sensitif yang dimodelkan oleh ANN ialah pelepah 9 berbanding pelepah 17 yang memberikan ketepatan tertinggi iaitu 100%. Hasil klasifikasi terbaik yang dihasilkan oleh rangkaian ANN adalah 219 neuron, hijau dan NIR band, jejari radius 35 piksel, dan had ambang 1/8, dengan ralat klasifikasi 12.29%. Jumlah ketepatan klasifikasi untuk latihan dan ujian kumpulan data masing-masing adalah 97.52% dan 72.73%. Akhirnya, hasil penemuan kajian keempat menunjukkan ramalan terbaik menggunakan pengkelas SVM didapati daripada imej UAV, dengan ketepatan keseluruhan 68.28%, dan 64.52% untuk Pleiades. Jangkitan awal penyakit *Ganoderma* juga dapat dikesan dengan ketepatan masing-masing sebanyak 64.07% dan 64.49%. Walaupun ketepatan klasifikasi adalah sederhana, ketepatan ini adalah bersesuaian memandangkan maklumat yang diperolehi daripada imej mudah diganggu oleh faktor yang tidak berkaitan dengan penyakit. Sebagai kesimpulan, untuk pengesanan awal penyakit *Ganoderma*, ketepatan yang lebih baik diperolehi dari spektroradiometer yang memerlukan kaedah pengumpulan data lapangan dan masih memerlukan sampel daun individu. Kaedah ini masih mengambil masa yang banyak dan rumit berbanding dengan pendekatan menggunakan imej UAV yang cepat dan tidak memerlukan sampel lapangan. Walaupun, penggunaan imej UAV tidak dapat memberikan ketepatan seperti kaedah lapangan tetapi ianya sesuai untuk penggunaan di lapangan untuk menyaring penyakit secara besar-besaran di mana pokok kelapa sawit lazimnya ditanam di kawasan ribuan hektar. Kajian ini menyimpulkan bahawa pendekatan penderia jarak jauh digabungkan dengan pendekatan perlombongan data seperti algoritma ANN, mempunyai potensi besar untuk memantau penyakit di kawasan perladangan yang luas dengan cepat dan menjimatkan kos.

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APPROVAL

I certify that a Thesis Examination Committee has met on 12 January 2018 to conduct the final examination of SEYEDEH PARISA AHMADI on her thesis entitled "Application of in-situ sensors and remote sensing data for detection early stage *Ganoderma boninense* in oil palm" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student is awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

AISA	Airborne Imaging Spectroradiometer for Applications
ANN	Artificial Neural Network
ANOVA	One-Way Analysis of Variance
ARVI	Atmospherically Resistant Vegetation Index
BP	Backpropagation
BSR	Basal Stem Rot
C-320	Cyranose 320
CV	Cross Validation
DA	Discriminant Analysis
DBH	Diameter at Breast Height
DLS	Damped Least-Squares
DNs	Digital Numbers
EDTA	Ethylenediamine-Tetraacetic
e-nose	Intelligent Electronic Nose
FT-IR	Fourier Transform Infrared
FOV	Field-of-view
GBNDVI	Green Blue Normalised Difference Vegetation Index
GER	Geophysical and Environmental Research Corporation
JM	Jeffries-Matusita
GIS	Geospatial Information System
GNSS	Global Navigation Satellite System
GSD	Ground Sampling Distance
GSM	*Ganoderma* Selective Medium
GNDVI	Green Normalized Difference Vegetation Index
HCA	Hierarchical Cluster Analysis
HLB	*Huanglongbing*
HRS	Hyperspectral Remote Sensing
IPVI	Infrared Percentage Vegetation Index
K	Potassium
LAI	Leaf area index
LDA	Linear Discriminate Analysis
LM	Levenberg-Marquardt
MIR	Mid-Infrared
MNF	Minimum Noise Fraction Index
mNDVI	Modified Normalized Difference Vegetation Index
MOS	Metal Oxide Sensors
MPOB	Malaysia palm oil board
MRS	Multispectral Remote Sensing
MRS_{705}	Modified Red Edge Simple Ratio
MSR	Modified Simple Ratio
N	Nitrogen
NDVI	Normalized Difference Vegetation
NIR	Near Infrared
OIF	Optimum Index Factor
P	Phosphorus
PCA	Principal Component Analysis
PCR	Polymerase Chain Reaction

PST	Puccinia striformis Westend. f. sp. tritici Eriks
PIF	Pseudo-Invariant
PLS	Partial Least Square Regression
R^2	Coefficient of Determination
RGB	Red, Green, Blue
RS	Remotely Sensed
SAM	Spectral Angle Mapper
SAVI	Soil Adjusted Vegetation Index
SPAD	Soil Plant Analysis Development
SR	Simple Ratio
SVM	Support Vector Machine
SVIs	Spectral vegetation indices
SC-1	Stomatal conductance
TCARI	Transformed Chlorophyll Absorption Reflectance Index
TVI	Transformed Vegetation Index
TLS	Terrestrial Laser Scanning
UAV	Unmanned Aircraft Vehicle
VI	Visible
VIS	Vegetation Index
VNIR	Visible Near Infrared
VOG1	Vogelmann Red Edge Index 1

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Malaysia, with more than five million hectares of land under oil palm cultivation, produces up to 18 million tons of palm oil each year. About 12% and 27% of the world's total production and exports of oils and fats is provided through Malaysian palm oil industry. Indonesia and Malaysia jointly produce 84% of the world's total oil palm, mainly to fulfill high demands of palm oil for food and industrial processes (Ommelna et al. 2012). The export revenue for palm oil and palm oil-based products accounted for a RM77.85 billion in 2017. It is estimated that the livelihood of some 2.5 million people in Malaysia depends on the oil palms (Alam et al. 2015). Based on Cramb and Sujang (2013) study, smallholders that posses 3 ha of mature palms in Malaysia, even with low contributions of labor and capital, were able to yield around 12 tons per ha and subsequently earn about RM7,000 per year.

Palm oil, as one of the prominent vegetable oils in food and in several other industries, plays an important role in terms of the economic aspect, especially in large producer countries as it has great contribution in producing vegetable oil palm. The oil is extracted from the oil palm kernel that used in various industries such as for production of processed foods and cooking oils. Its derivatives are also used to produce cosmetics, soaps, shampoos and detergents. It could be applied as biofuel as well (Unilever Sustainable Agriculture Initiative, 2014).

According to Malaysian Palm Oil Board (MPOB) report, the production and export of palm oil has increased rapidly in Malaysia between 2012 and 2013 (Khairunniza-Bejo & Vong 2014). However, the annual production of oil palm plantations has been diminished due to disease attacks such as *Ganoderma*, erwinia, fusarium oxysporum, and pestalotiopsis. Oil palm tree, despite its productivity, is known as an exhibiting host for several fungus and viroid that can trigger diseases, can affect palms through disorder, impact the fresh fruit bunch productivity in varying degrees such as withering of leaf, shortening of trunk, short and small fruit bunches.

One of the greatest diseases that threaten oil palm productivity and affects plantations in Malaysia and Southeast Asia is basal stem rot (BSR), caused by a white rot fungus known as *Ganoderma* boninense. *Ganoderma* infection as a serious plant root system disease was reported at oil palm plantations in Malaysia in 1930 through identification of *Ganoderma* lucidum pathogen (Thompson 1931; Ariffin et al. 1992).

The *Ganoderma* infections are possible even at palm's early age. The disease can certainly disrupt palm growth through the rotting of palm roots and eventually would kill the palms (Usha and Singh, 2003; Aji, et al. 2013). The yield loss inflicted on oil palm production due to *Ganoderma boninense* has been estimated to cost producers as much as USD 500 million a year and causes significant post-harvest losses about USD 56 million to USD 375 million a year in South East Asia.

At the early stage of this disease infection, palms are symptomless and hence, BSR identification is very difficult. Symptoms of infection such as i) stem rotting or decaying that restricts the uptake of water and nutrients to the fronds, ii) chlorosis as indicators of loss of leaf pigments, iii) fronds wilting and hanging down to form a skirt around the trunk disease (Turner and Gillbanks, 1974), iv) crown flattening and spear leaves un opening, and v) stem fracturing (Rees et al. 2012), are usually manifested when it has already reached a critical stage and thus imposing challenges on effective disease management.

Systematic plant protection strategies are necessary for a better disease management of oil palm, and thus, for performing plant protection operation in timely and reliable manner, information regarding their pest and disease nature, the extent and spatial distribution of the disease along with their potential and limitations is very important. In spite of availability of some techniques for identifying BSR such as (i) colorimetric method using ethylenediaminetetraacetic acid (EDTA) (Natarajan et al. 1986), (ii) *Ganoderma*-selective media (GSM) (Ariffin and Idris, 1992), (iii) polyclonal immunizer (PAb) (Darmono, 2000), (iv) polymerase chain reaction (PCR) (Idris et al. 2003) and (v) electronic-nose (e-nose) devices (Markom et al. 2009; Abdullah et al. 2011), these aforementioned techniques are time-consuming, expensive and impractical for large plantation areas. Therefore, an ideal system for identification of infections requires precise preparation, speed, and includes nondestructive methods, especially at the disease early stage.

1.2 Problem Statements

Ganoderma infections could be managed by sanitation i.e. removal of diseased palms, application of fungicides such as hexaconazole, azoxystrobin, and carbendazim, cultural practice such as soil mounding, and the use of a highly effective biocontrol strain for example Trichoderma spp or mycoparasitism (Sariah et al. 2005; Mee et al. 2017; Idris et al.2010 and Hidayati et al. 2014). These control measures are aimed at minimizing disease incidence during replanting, prolonging the productive life of the infected palm, and delaying the progress of *Ganoderma* infection. However, removing the infected trees is the only effective way to prevent the spread of this disease. Although not all scientists agree on how oil palms are infected and how the disease spreads, detection of early infected palms without significant symptoms can save them. If these palms could be detected, the chances of the infection to progress through application of fungicides, soil mounding, trunk injection by fungicide hexaconazole or *GanoEF* biofertilizer containing endophytic fungus could be minimized (Ariffin and Idris 2002).

Like in other crop production practices, detecting plant health condition is the first vital step in controlling diseases. In *Ganoderma* related studies, indeed, many have attempted to detect *Ganoderma* infections at mild or late stage of infection (Ahmadi et al. 2017). Most of these studies acquired high accuracies but either at mild or late stage when the disease at its advanced stage i.e. visible symptoms of the infection are already manifested and correction actions would be inefficient.

One of the major challenges in the detection of BSR is that the foliar symptoms appear in an advanced stage of the disease and one only way for detection is to find the fruiting body visually around the trunk of oil palm. Currently, the most commonly used method for detection of BSR is polymerase chain reaction (PCR) analysis. The PCR method is to confirm the presence of fungus through the extraction of the fungus and the DNA of fungus will be purified and amplified with using gel electrophoresis. Although the definitive method such as the PCR so far provides the most reliable detection, this method has some drawbacks, however, such as being sensitive to direct or carry-over contamination (Corless et al. 2000). In addition, many sample collections need to be done to eradicate amplification inhibitors. This diagnostic process is often difficult and expensive and requires special facility chemical that is not easily available and should be done by experts in DNA technique. Per tree cost for the PCR test is USD 100 (http://www.biotech.cornell.edu) where the test is recommended for small scale applications and thus not appropriate as a preparative experiment method in large scale plantation due to these constraints (Sankaran et al. 2010). Methods such as the colourimetric and DNA based model can be used as robust detection tools too but again they are not very practical at the asymptomatic stage under field conditions due to the same reason as the PCR. In other techniques like the e-nose, skilled operators should consider all external disease symptoms of each tree in order to differentiate between healthy and unhealthy oil palm in addition to involving a complex gas mixture in the analysis. In this limelight, several authors have conducted research in order to detect BSR; however, the lack of algorithm and principles for conducting the detection of this disease within plantation areas remains a major setback.

Remotely sensed techniques could be applied for early detection and nondestructive methods for disease identification, plant diseases and stress monitoring in both minor and major scales and in field conditions (Huang et al. 2007; Qin et al. 2009; Wang et al. 2009; Sighicelli et al. 2009; Yang and Cheng 2001; Graeff et al. 2006; Yang et al. 2007; Belasque et al. 2008; Naidu et al. 2009). The emergence of high-quality measurement devices such as spectroscopic and image techniques from a decade ago had directed the courses of disease control efforts towards providing better and more accurate knowledge for detection of disease at its early stage, potentially for the BSR. There is a long list of image and non-image datasets proposing a wide array of views from any part of our globe. Based on recent investigations, geospatial technologies comprising of remotely sensed sensors have been found as an efficient and applicable techniques for BSR detection (Markom et al. 2009; Meor et al. 2009; Azahar et al. 2011; Abdullah et al. 2011; Santoso et al. 2011; Abdullah et al. 2012) and classification (Shafri et al, 2009; Lelong et al. 2009; Nisfariza et al. 2010; Lelong et al. 2010; Shafri et al. 2011; Liaghat et al. 2014) as well as determination of distribution pattern (Santoso et al. 2011; Azahar et al. 2011; Kheirandish et al. 2012).

To overcome the aforementioned limitations of destructive BSR detection methods, this study seeks to develop operational methods to facilitate extraction of *Ganoderma* infected palms at their early stage by using remote sensing data. Thus far, neither laboratory nor remotely sensed method is suggested to represent early detection of BSR infection on site.

1.3 Objective of the study

The main objectives of this thesis is to detect early *Ganoderma* infection in oil palm plantations with focus on using various in-situ and remote sensing methods. In general, this study determined and compared measurements of in-situ and remote sensing data at different spatial scales of spectral measurements.

1.3.1 Specific Objectives

The specific objectives of this study are:

1. To evaluate several insitu sensors on oil palm leaf scale to detect early *Ganoderma* infection, namely SPAD-502 chlorophyll meter, SC-1 leaf porometer and GER 1500 spectroradiometer, concerning different severity levels of *Ganoderma* infection and to develop dimensional indices for detection of early *Ganoderma* infection through a combination of significantly sensitive sensors.
2. To evaluate the use of visible and near-infrared spectral reflectance at leaf scale acquired from a spectroradiometer and analyzed with artificial neural network (ANN) to identify early *Ganoderma* infection.
3. To explore the potential of canopy level spectral measurements acquired from UAV imagery for detection of early *Ganoderma* infected palms under field condition using a novel approach of ANN modelling.
4. To compare the potential of canopy i.e. UAV and satellite i.e. Pleiades level spectral measurement analyzed with support vector machine (SVM) classifier to detect early *Ganoderma* infection.

1.4 Research Framework

This thesis presents new methods for early stage *Ganoderma* infection from different scales of spectral measurement using the combination of spectral band and spatial information. Extensive field survey based on specific standard symptoms on the canopy, visual symptoms and GSM test were collected as main data, besides of in-situ census and remote sensing data. The main goal of this research was to evaluate the applicability of spectral data obtained from different spatial scales i.e. leaf, canopy and satellite to achieve the objectives of this study. Physiological and spectral reflectance made from a spectroradiometer data were collected to represent leaf level measurement, UAV imagery was considered as spectral reflectance measurement made at canopy scale and at satellite level, a satellite imagery acquired from Pleiades was investigated. The study was conducted in Machap estate belongs to United Malacca Berhad located in Melaka, Malaysia (2.402° N 102.327° E) in February 2014. The field of study was selected form 12 years old mature oil palm receiving standard plantation practices. This field was selected since most of the palms remained healthy up to 12 years old and BSR infection increased in oil palms after 12 years of planting (Arrifin et al., 2000). Furthermore, mature palms that are aged between 9 to 15 years, are the most productive plantations in terms of yield (Fairhurst and Härdter, 2003). We identified and marked 374 surveyed palms with four levels of infection based on specific visual symptoms on the canopy and presence of basidiocarps on the basal of palms. To confirm the presence of a *Ganoderma*-related fungus, GSM test was conducted on palms with the absence of *Ganoderma* fruiting body. Trunk samples were acquired from trunk drilling and sent to a laboratory for analysis. As well as GSM test results, the samples were segregated into four classes designated as T1, T2, T3 and T4 (Table 1) (Lelong et al. 2010).

Table 1: Classification of *Ganoderma* severity levels based on visual symptoms and *Ganoderma*-selective media (GSM) test (Lelong et al. 2010).

Severity level	**Visual Symptoms**	**GSM Test**
T1 (healthy)	➢ Healthy leaves and normal palm canopy	➢ Negative GSM test
T2 (mild)	➢ Presence of mycelium in the stem bark, or brittle wood ➢ Healthy leaves and normal palm canopy	➢ Positive GSM test
T3 (moderate)	➢ Presence of mycelium in the stem bark, and fruiting body ➢ Less than 50% foliar symptoms	➢ Positive GSM test
T4 (severe)	➢ Presence of fruiting body at the bottom of the rotten stem ➢ More than 50% foliar symptoms	➢ Positive GSM test

A brief narrative discussion regarding the general methods utilized on this study is presented as Figure 1. At the leaf scale, physiological data such as relative leaf chlorophyll content and stomatal conductance measured from in-situ sensors, and spectral indices from a spectroradiometer were analyzed to investigate the effect of disease severity levels and develop dimensional indices for detection of *Ganoderma* at its early stage. Moreover, an ANN classification method were applied to the spectral reflectance measured from the spectroradiometer, either raw or post-processed, to identify the most sensitive wavelengths and frond number for detection of early stage *Ganoderma* infection.

Considering that using spectroradiometer has some limitations in terms of mass screening of plantations that are commonly large, UAV imagery was used to improve the detection procedure on canopy scale. A neural network classifier model was developed from UAV images by testing different spectral bands combination and network architecture specifications. To further evaluate the capability of remote sensing data, SVM classification method that is one of the recent widely applied algorithm, was used on UAV and Pleiades imagery that representing canopy and satellite scale spectral measurement. The SVM accounted for the use of raw spectral reflectance of the bands, and also textural measurements. Finally, the overall accuracy was computed at each spatial scale and compared to identify the feasibility of the spectral measurements made at that respective spatial scale in assisting the detection of early stage *Ganoderma* infection.

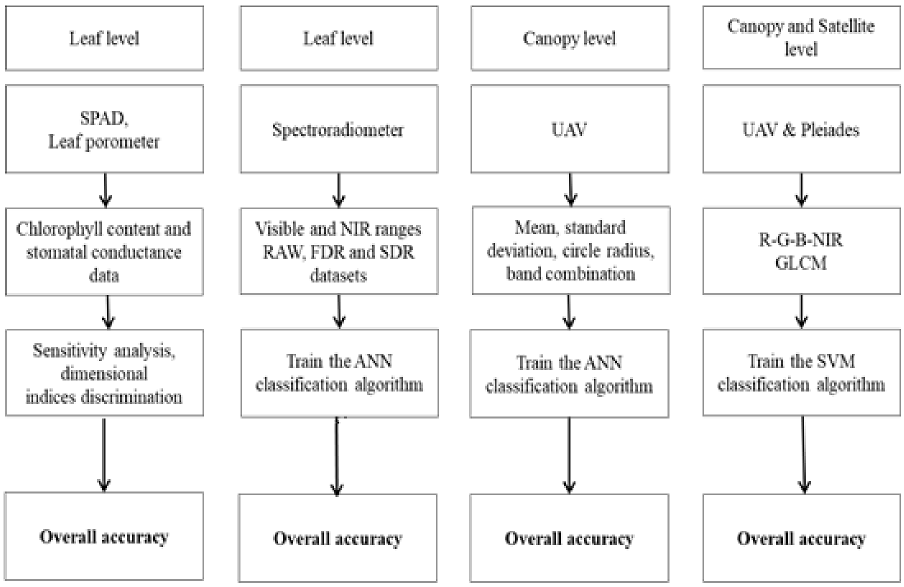

Figure 1: The overall methodology

1.5 Scope and Relevance

While traditional method of *Ganoderma* detections involve time and expensive ground survey in order to be applied in mass area and for large scale assessment with high accuracy, this research study is expected to produce suitable method for early detection of *Ganoderma* using in-situ and remote sensing images.

Nonetheless, only few classification methods were considered in this study, mainly focused on ANN and SVM, and therefore future work is advised to put emphasis on evaluating various classification algorithms, spectral features recorded in other oil palm ages, or UAV and satellite images with other spectral and spatial characteristics.

1.6 Outline of the thesis

The thesis comprises six chapters, each corresponding to the objectives and contributing towards an advance understanding of the remotely sensed precursors. The layout of the thesis followed the University Putra Malaysia alternative thesis format based on publications. Each research chapter (3 to 6) represent its own ‘Introduction’, ‘Methodology’, ‘Result and Discussion’ and ‘Conclusion’. Hence, a specific chapter for methodology was not discussed.

Chapter 1

This first chapter describes the thematic context of the study, the main research problem, the motivation to pursue the research, and the research objectives, questions and goals.

Chapter 2

In order to fill in the research gap related to the use of remote sensing for detection and identification of *Ganoderma* at an early stage, comprehensive reviews were made on previous efforts and past research related to the proposed topic.

Chapter 3

In this chapter, an article titled “Evaluation of insitu sensors in relation to different severity levels of *Ganoderma* as a mechanism for early detection in oil palms” is presented. This chapter examined the sensitivity of insitu sensors and develop a dimensional index through combination of insitu sensors to identify *Ganoderma* infected oil palms.

Chapter 4

This chapter presents the article entitled “Early detection of *Ganoderma* basal stem rot of oil palms using artificial neural network spectral analysis”. This chapter explains an improved framework for early detection of *Ganoderma* and using data obtained from a hand-held spectroradiometer.

Chapter 5

This chapter presents an article entitled “Detection of early stage *Ganoderma boninense* infected oil palms using neural network analysis of UAV imagery”. This article addressed the development of a method to early BSR disease on oil palms using UAV imagery and classification the image with ANN algorithm.

Chapter 6

Chapter six presents an article entitled "Evaluation of support vector machine (SVM) classifier and high spatial resolution images for identification of early *Ganoderma boninense* infected oil palms". This article is a collection of analyses performed on UAV and Pleiades images using support vector machine (SVM) algorithm in focus to early detect *Ganoderma boninense* infection**.**

Chapter 7

Finally, the overall conclusion and recommendation for future work were discussed in this last chapter.

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