IN-SITU HYPERSPECTRAL REMOTE SENSING FEATURE EXTRACTION OF SELECTED COMMON TROPICAL RAINFOREST SPECIES

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DEDICATION

This thesis is dedicated to my beloved family who fully supported and trusted in me during my PhD study

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ABSTRACT

Hyperspectral remote sensing has potentials in solving dilemma due to high diversity of tropical tree species during tree spatial distribution mapping for forest management and conservation. This research aims to establish a multi-level tree species classification strategy which has capability in dealing with high diversity of tropical tree species in Malaysia. Three research objectives were formed namely, 1) to evaluate the influence of spatial scale in within species spectral variability of tropical tree, 2) to examine the effectiveness of multi-level classification strategy in improving tree species classification accuracy, and 3) to study the influence of spatial scale and species grouping methods in multi-level tree species classification. A total of 20 tropical tree species and in-situ hyperspectral remote sensing data were collected at tree branch and leaves spatial scales. Spectral variation analysis has revealed a significant influence of remote sensing data spatial scale on within species spectral variability where tree branch spatial scale data dominated the upper range of this variability in the majority of the tree species in this research. Support Vector Machine (SVM) and Maximum Likelihood Classifier (MLC) methods were adopted in the multi-level classification strategy to classify tree species using 32 vegetation indices extracted from in-situ hyperspectral data. The multi-level classification strategy has resulted in a 5% improvement in the classification accuracy from the ordinary classification for both SVM and MLC classifiers. The improvement was marked from 69.41% to 74.56% and from 64.98% to 69.53% in SVM and MLC tree species classifications respectively. Four tree species classification scenarios were designed in combinations of two spatial scales data (i.e. leaves spatial scale and tree branch with leaves spatial scale) with two species grouping modes to study the influence of these variables on the performance of multi-level SVM classification. Tree species data at tree branch spatial scale has proven its influence on the classification accuracy where SVM produced the accuracy at 77.21% and 72.79% for leaves spatial scale and tree branch with leaves spatial scale respectively at the first level in the multi-level classification strategy. Later, the multi-level SVM classification strategy has made a 2% improvement in the classification accuracy for tree species classification scenarios in the next two levels of classification. Two designed tree species groupings namely mode A (grouping based on individual classification accuracy) and mode B (grouping based on individual misclassification error) have presented influence on the multi-level SVM classification performance. The influence was shown in the number of sub-groups and tree species in sub-groups formed by the two grouping modes. Out of the four tree species classification scenarios, the multi-level SVM classification strategy has the best performance in the case of leaves spatial scale with species grouping mode A with a classification accuracy recorded at 79.2%. This research has proven multi-level classification strategy has its capability in handling a high number of tropical tree species with promising accuracy in tree species spatial distribution mapping.

ABSTRAK

Penderiaan jauh hiperspektrum berpotensi dalam penyelesaian dilema disebabkan oleh kepelbagaian spesis pokok tropika yang tinggi semasa pemetaan taburan ruang pokok untuk pengurusan dan pemuliharaan hutan. Penyelidikan ini bertujuan untuk membina strategi klasifikasi spesis pokok tropika pelbagai peringkat yang berkemampuan dalam menangani kepelbagaian spesis pokok tropika di Malaysia. Tiga objektif kajian dibentuk iaitu, 1) untuk menilai pengaruh skala ruang dalam variasi spektrum dalaman spesis pokok tropika, 2) untuk mengkaji keberkesanan strategi klasifikasi pelbagai peringkat dalam meningkatkan ketepatan klasifikasi spesis pokok, dan 3) untuk mengkaji pengaruh skala ruang dan pengelompokan spesis dalam klasifikasi spesis pokok pelbagai pringkat. Sejumlah 20 spesis pokok tropika dan data penderiaan jauh hiperspektrum di situ dikumpulkan pada skala ruang dahan pokok dan daun. Analisis variasi spektrum telah menunjukkan pengaruh yang signifikan daripada skala ruang data penderiaan jauh terhadap variasi spektrum spesis di mana data skala ruang dahan pokok mendominasi julat pembolehubah dalam kebanyakan spesis pokok penyelidikan ini. Kaedah Mesin Sokongan Vektor (SVM) dan Pengelas Kemungkinan Maksimum (MLC) telah dipakai dalam strategi klasifikasi pelbagai peringkat untuk mengklasifikasikan spesis pokok menggunakan 32 indeks tumbuh-tumbuhan yang diekstrak daripada data hiperspektrum di situ. Strategi klasifikasi pelbagai peringkat telah menghasilkan peningkatan sebanyak 5% dalam ketepatan klasifikasi dari klasifikasi biasa pada kedua-dua pengklasifikasi SVM dan MLC. Peningkatan ini ditandakan dari 69.41% kepada 74.56% dan dari 64.98% hingga 69.53% masing-masing di klasifikasi spesis pokok SVM dan MLC. Empat senario klasifikasi spesis pokok direka bentuk dalam kombinasi data dua skala ruang (iaitu skala ruang daun dan dahan pokok dengan skala ruang daun) dengan dua pengelompokan spesis untuk mengkaji pengaruh pemboleh ubah ini terhadap pretasi klasifikasi pelbagai peringkat SVM. Data spesis pokok pada skala ruang dahan pokok telah membuktikan pengaruhnya terhadap ketepatan klasifikasi di mana SVM menghasilkan ketepatan pada 77.21% dan 72.79% untuk skala ruang daun dan dahan pokok dengan skala ruang daun masing-masing pada peringkat pertama dalam strategi klasifikasi pelbagai peringkat. Seterusnya, strategi klasifikasi SVM pelbagai peringkat telah memberikan peningkatan sebanyak 2% pada ketepatan klasifikasi untuk senario klasifikasi spesis pokok dalam dua peringkat klasifikasi berikutnya. Pengelompokan spesis pokok yang direka iaitu cara A (pengelompokan berdasarkan ketepatan klasifikasi individu) dan cara B (pengelompokan berdasarkan ralat klasifikasi individu) telah menunjukkan pengaruh terhadap prestasi klasifikasi SVM pelbagai peringkat. Pengaruh ini ditunjukkan dalam jumlah kelompok kecil dan spesis pokok dalam kelompok kecil yang dibentuk oleh dua cara pengelompokan. Daripada empat senario klasifikasi spesis pokok, strategi klasifikasi SVM pelbagai peringkat mempunyai prestasi terbaik dalam kes skala ruang daun dengan pengelompokan spesis cara A iaitu ketepatan klasifikasi dicatatkan pada 79.2%. Penyelidikan ini membuktikan strategi klasifikasi pelbagai peringkat mempunyai kemampuan dalam menangani sebilangan besar spesis pokok tropika dengan ketepatan yang menyakinkan dalam pemetaan taburan ruang spesis pokok.

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LIST OF ABBREVIATIONS

SVM	-	Support Vector Machine
MLC	-	Maximum Likelihood Classifier
LDA	-	Linear Discriminant Analysis
RDA	-	Regularized Discriminant Analysis
QDA	-	Quadratic Discriminant Analysis
L-SVM	-	Linear Support Vector Machine
RBF-SVM	-	Radial Basis Function Support Vector Machine
MLP-ANN	-	Multilayer Perceptron Artificial Neural Network
K-NN	-	k-Nearest Neighbour Algorithm
AA	-	Alstonia Angostiloba
AM	-	Aquilaria Malaccensis
BM	-	Bucida Molineti
CA	-	Calophyllum Spp.
CI	-	Cinnamomum Iners
DC	-	Dyera Costulata
DO	-	Drybalanops Oblongifolia
EO	-	Eugenia Oleina
FF	-	Fragea Fragans
HO	-	Hopea Odorata
KF	-	Kayea Ferrea
MB	-	Maniltoa Browneoides
PA	-	Pterygota Alata
PG	-	Palouium Gutta
PP	-	Peltophorum Pterocarpum
SG	-	Syzygium Grande
SH	-	Shorea spp.
SR	-	Shorea Roxburghii
SS	-	Samanea Saman
SSI	-	Shorea Singkawang

LIST OF SYMBOLS

ϴ	-	Spectral Angle Metric
D	-	Spectral Amplitude Metric
λi	-	Reflectance Value at Wavelength *i*
N	-	Total Number of Wavelengths
S_M	-	Mean Spectrum
S_T	-	Target Spectrum
λ	-	Wavelength

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CHAPTER 1

INTRODUCTION

1.1 Background

In the current modern lifestyle, forest is seemed not associated with human beings especially for communities who live in urban areas as our daily needs are mostly available in city. In fact, sustainability of human's communities is incontrovertibly supported by forests surrounding our settlement. For instances, sources of fresh water supply for household usage are originated from water catchments in forests, and forest also has a vital role in carbon cycle on the Earth as well as the food chain sustainability in human life.

Malaysia as one of the tropical countries has wide ranges of flora and fauna species in its dense rainforests. Our inland rain forest areas mainly are covered with dipterocarp forest which is inhabited by tree species from the *Dipterocarpaceae* family and these forests could be further named by their altitude above mean sea level, i.e. lowland dipterocarp forest is considered up to 300 meters above mean sea level, hill dipterocarp forest and upper dipterocarp forest are located between 300 to 750 meters and between 750 to 1200 meters respectively above mean sea level (WWF Malaysia, 2017). Due to the rapid urban development and agricultural activities which have replaced lowland dipterocarp forests with buildings and plantations in the past years, the remaining lowland dipterocarp forests are in stress (Pryde et al., 2015).

In conjunction with the reducing of lowland dipterocarp forests in Malaysia, the roles of urban forests as one of the components in urban areas are highlighted by environmental advocates, landscaping planners, researchers in social science or environmental studies, and government agencies. In the urban forestry conference which was held in Sarawak back in year 2009, research papers have discussed several issues regarding the sustainability of urban forest biodiversity, economic and social values of urban forests toward healthy life style of residences, air quality, urban heat islands, water management, and tourism activities in urban areas (Urban Forestry Conference, 2009). The managing and monitoring upon all forest types including urban forests as valuable resources in Malaysia is so important to ensure their sustainability in playing roles.

Spatial distribution of tree species has relationships with forest structure, biodiversity and ecosystem, and flora species richness which are indicators toward forest sustainability. By understanding the spatial distribution of tree species, growing status of a forest or any threatened tree species could be identified for conservation. A rapid tree species mapping is one of the key tasks could provide valuable information into knowledge about a specific forest which enhance the conservation process as well as efforts in forest resources management and monitoring (Naidu and Kumar, 2016). Field inspection or on the ground survey for tree species inventory and mapping is time consuming method especially in tropical forest which has high species richness (Fricker et al., 2015). Thus, other potential methods are urged to deploy in tree species mapping for effective forest management and conservation to secure forest sustainability.

For the practice on the Earth, remote sensing is a scientific practice in analyzing the Earth surface and its atmosphere for a range of applications using remotely sensed data and mathematical approaches. Remotely sensed data could be either in imagery or non-imagery values that are measured by sensors in different types such as optical imaging, radar scanning, and lidar scanning. In this context, sensor is parked on a platform which at a nadir distance ranges several meters up to a few hundred kilometers that is extended from the target on the Earth to the space and the platform could be ground instrument, drone, aircraft shuttle or satellite. From the past, numerous mathematical approaches and models have been adopted to simulate, predicting, explaining, and estimating in qualitatively or quantitatively about real situations happened either in past, present or future on this planet based on remote sensing data.

Remote sensing itself has outstanding advantages in data collection for tree species identification and mapping. The data collecting process is scans through the forest at a nadir distance from top of forest canopy which could be done for a large scale of forest areas in a short time and this operation could be repeated any time as all needed resources are in place with good weather condition. Remote sensing data with viewing angles from sensor onto the top of canopy also reveals the forest canopy scenario at landscape scale better than that of viewing from the ground. On the other hand, on the ground tree species survey is costly and time consuming where transportation and traveling are needed to send survey crew to the specific sites in the forest and it requires experts to identify tree species on site (Fricker et al., 2015). Besides, ground survey is also constrained by weather condition and accessibility in the forest where these factors might pose danger to survey crew members.

The rapid development in technology coincides with progressive capacity building on knowledges in the field of remote sensing has provided more data types to be applied in tree species identification and mapping. Optical remote sensing in the form of spectral data such as multispectral or hyperspectral has been proven could able to give insightful information related to chemical substances and physical properties of leaves, non-photosynthetic tissues, and canopy structure of tree. Radar and Lidar could penetrate canopy layer into tree crown which able to collect tree structural information such as crown size and its shape, density of crown, and tree branch characteristic for tree species identification. By having distinguishable information from different remote sensing data, there is high feasibility to develop remotely tree species identification and mapping for forest at landscape scale. The key issue is how accurate and precise the species identification result could be achieved after data analysis process, it is a prominent research gap to be solved in tropical forests as an intrinsic feature of this forest type is high biodiversity in tree species.

1.2 Problem Statements

Implementation of remote sensing particularly the hyperspectral remote sensing in tree species identification is getting more attentions from the world in the recent years. A list of airborne and spaceborne hyperspectral data poured into the market has boosted the progress of tree species identification studies across a variety of forest types but still limited studies could be found for tropical forests. Some pioneer studies have been conducted in different tropical forests to demonstrate the feasibility of hyperspectral remote sensing in our concerns, which could able to drive passionate efforts given by peers in future works to cope with the challenges posed by environment in tropical forests. Those mentioned challenges for instances are high diversity and unpredictable spatial distribution of tree species, evergreen environment makes traits of different tree species not easily to be seen in remote sensing imagery, complex forest structure, and cost and time-consuming ground data collection in tropical forests.

In Malaysia, limited studies have been done in related to tree species identification using optical remote sensing data either multispectral or hyperspectral data (Jusoff, 2007; Hasmadi et al., 2010; Shafri et al., 2007). Local study has been mainly constrained by weather condition besides of the environmental factors in tropical forest per se in tree species identification. Severe cloud cover in Malaysia has hindered the possibility of cloud free multispectral or hyperspectral data provided by satellite throughout a year. In the context, tree species identification study is failing as heavy cloud cover in optical remote sensing data overhead marked forest area because no any informative digital values could be extracted from the imagery for further processing and analysis. In recent years, progressive affords have been contributed by local parties to adopt unmanned aerial vehicle (UAV) as an alternative platform for carrying optical sensor in data acquisition for getting cloud free remote sensing data.

Awareness of sustainable environment such as forest conservation and low carbon city have been raised up recently by different parties and fortunately positive feedbacks have been presented by large population in Malaysia. Unfortunately, potentials of remote sensing in these related fields are being underestimated by public as less progress in tree species identification using remote sensing has been done in the country. Furthermore, we are still lacking in number of remote sensing specialists and research groups in Malaysia as wide range of remote sensing applications are potential to be implemented here for nation building. In this situation, no doubt more remote sensing studies are urged to carry out particularly in tree species identification which is beneficial to native forests and urban forests management.

Tree species spatial distribution map is an informative input data in forest management and conservation works, however, high diversity of tree species in tropical forests is being the key issue to hinder achievement of precise yet reliable species identification with remote sensing. Different studies have shown that species identification accuracy was decreasing with increased in number of target tree species in a classification (Castro-Esau et al., 2006; Feret and Asner, 2011; Feret and Asner, 2012). Work of Feret and Asner (2012) proved that the accuracy dropped to about 80% in seven different parametric and non-parametric classifiers when species richness reached 17 tree species. However, some common practices found in the tree species classification studies up to date where all of the studies also involved very small number of targeted tree species which is too less compared to real situation of over hundreds of tree species in tropical forests. Their classification schemes used single spectral features selection set and single iteration of classification in handling tree species in different forest types have been discussed as research gap in literature review. These practices are expected to have dilemma of high heterogeneity in tropical forest classification Feret and Asner (2012) and it will highly fail to handle high number of tree species for promising accuracy with current classification scheme. Studies have proven potentials of remote sensing hyperspectral in tree species classification but innovative classification methods or strategies are worth to be studied toward more promising tree species spatial distribution mapping. The multi-level classification strategy that was proposed in current research has potentials to contribute in this research gap which is capable in dealing with high diversity of tree species in tropical environment.

1.3 Research Questions

Research question 1: The degrees of intra-species spectral variability is varying across different spectral ranges in tree species hyperspectral reflectance curve?

Research question 2: High number of tropical tree species classification has promising accuracy with multi-levels classification scheme?

Research question 3: Remote sensing data spatial scale and species grouping has influence on multi-levels classification?

1.4 Objectives

This research was designed with the aim to establish a multi-level tree species classification strategy which has capability in dealing with high diversity of tropical tree species in Malaysia. Three research objectives have been defined along with the aim in current research, they are stated as the following.

1) To evaluate the influence of spatial scale in within species spectral variability of tropical trees.

2) To examine the effectiveness of multi-level classification procedure in improving tree species classification accuracy.

3) To study the influence of spatial scale and species grouping method in multi-level tree species classification.

1.5 Scope of Study

This research was focused to discriminate 20 selected tropical tree species using remote sensing data with a designed research methodology. The main research questions were to what extent multi-level classification procedure can handle 20 tropical tree species classification and if any improvement of overall accuracy in the multi-level classification process. Laboratory collection of *in-situ* hyperspectral data at leaves and branch scales were chosen to carry out this research because of well controlled light source intensity during data collection to minimize uncertainties in classification due to environment factors. Leaves and branch scales have been recognized as good data options to test hypothesis in newly introduced remote sensing classification methods because spectral reflectance at these scales were dominated by chemical substances and physical properties of leaves. Their complexity in intra-species spectral variability is relatively lower than tree crown scale which associated with many external factors in governing spectral reflectance.

1.5.1 Study Area

In this research, the list of 20 selected tropical tree species are planted in a patch of urban forest and roadside within compound of an urban park named Hutan Bandar Majlis Bandaraya Iskandar Putri (MBIP). It is located within urban area (1°0′59.47″N, 103°3′52.96″ E) in Skudai, Johor Bahru, Malaysia as shown in Figure 1.1. More than 200 trees from over 30 tropical tree species could be found there and most of the trees have been tagged with scientific name of tree species. Due to factors of accessibility, adequate number of tree species with good information, and short travel distance from laboratory in university, this location was chosen as study area for the research.

In addition, the Pasoh FRIM Research Station which managed by Forest Research Institute Malaysia (FRIM) with coordinates of 2°58′55″N, 102°18′47″ E in Simpang Pertang, Negeri Sembilan, Malaysia was chosen as an additional study area. It is a lowland forest reserve habited with more 800 tree species from 78 families according to census done by FRIM and their research patners. The most famous family in this lowland forest is *Diptrerocarpaceae* family where members from shorea genus are common tree species there.

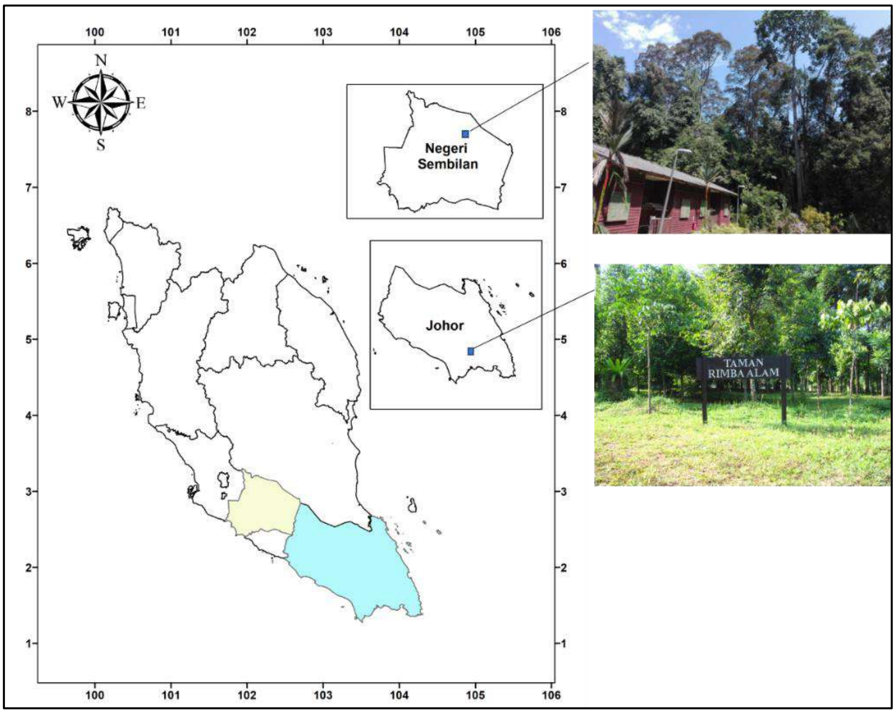

Figure 1.1 Location and site visiting photo of the two study areas

1.5.2 Methodology

This research has attempts to figure out feasibility of multi-level classification strategy which consecutive classification processes were repeated to improve tree species classification overall accuracy at level by level (Figure 1.2). To test on the hypothesis that multi-level classification strategy able to improve overall accuracy at different levels, possible uncertainties that posed onto research data by any natural factors such as sunlight illumination condition, atmospheric effects, tree crown structural and background reflectance must be minimized. Thus, this research has merely focused on reflectance of leaves and branch which have been well understood and described in many previous studies. Besides, a research objective to better understanding on intra-species spectral variability of different tree species, four spectral subsets have been analyzed respectively which were visible range (400 nm - 700 nm), red edge (680 nm - 750 nm), near infrared (700 nm - 1300 nm) and short-wave infrared (1300 nm - 2200 nm). For a comparison, full spectral range (400 nm -

2200 nm) which took intra-species spectral variability from all spectral ranges into account was underwent the analysis as well.

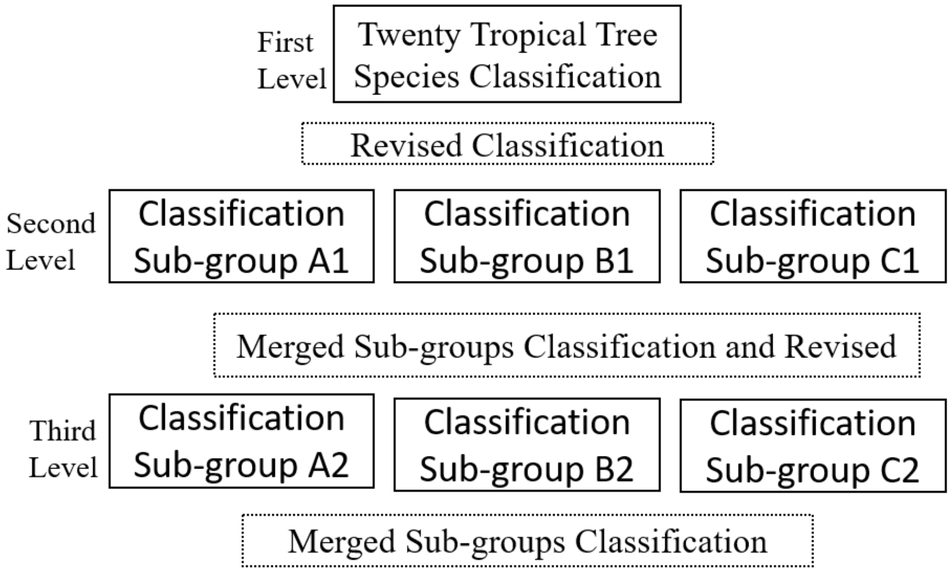

Figure 1.2 The concept of multi-levels tree species classification

1.5.3 Data

Two field campaigns have been conducted in July 2014 and March 2015 where leaves samples have been collected from Hutan Bandar Majlis Bandaraya Iskandar Putri (MBIP) for the 20 tree species. In addition, another field campaign has been carried out to collect leaves and branch samples from Pasoh FRIM Research Station in January 2015. Laboratory spectral measuring was applied to ensure measured signals in hyperspectral remote sensing data were purely contributed by leaves and non-photosynthetic tissue of barks. Thus, collected *in-situ* hyperspectral data was confined to leaves and branch scale without taking tree crown information into account in current research. In this context, input in multi-level tree species classification was only spectral information from leaves samples where other physical parameters of the 20 tree species such as tree crown shape, size, arrangement of leaves and branches, tree height, and diameter at breast height (DBH) were not included.

1.6 Significance of Study

Malaysia as a well developing nation is heading towards sustainable resources and environment managements which is strengthening on forests conservation, land use planning and management, and low carbon city transformation. We have a wide range of forests reserve in different types such as inland tropical rainforests, mangrove forests, and urban forests to be managed and conserved. Currently, Malaysia has lacking tree species spatial distribution landscaping information for forests management and monitoring where only small number of established permanent plots are available in different forests reserve which tree species mapping was done by field inspections. Remote sensing is an effective tool in aspects of budget and time management to deliver the mentioned tasks which requires tremendous of manpower and experts, budget, and it is time consuming in doing field inspections.

Remote sensing hyperspectral data has its advantage in providing numerous spectral bands and many studies have applied it onto tree species mapping in different forest types. However, the current classification schemes with single set of spectral features selection and single level classification process that adopted by previous studies have limitations to handle high number of tree species in real condition of tropical forest. Different studies have commented that optimal spectral features selection was important to achieve the highest overall accuracy due to two key issues which were redundancy of spectral information input into classification has potential to reduce overall accuracy and different target tree species groups have differences in spectral separability needs (Manevski et al., 2011; Adam and Mutanga, 2009; Thenkabail et al., 2004). In order to success towards tree species classification with promising accuracy for high heterogeneity in tropical forests, this research has introduced a new idea of classification scheme which is selection of optimal spectral features sets for different species sub-groups in the multi-level tree species classification process. Most of the previous studied only focused to classify very small number of targeted tree species which was less than 10 tree species and this number is too far from the real condition in tropical forest. The current research attempted to classify a list of 20 tropical tree species with innovative multi-levels classification scheme to prove its feasibility towards high number of tree species classification.

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