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Spectral Variability Analysis of In-Situ Hyperspectral Remote Sensing at Leaf and Branch Scales for Tree Species at Tropical Urban Forest

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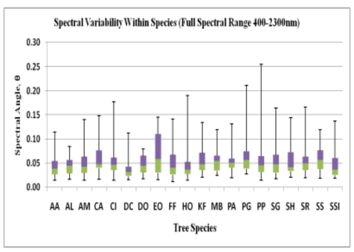
Graphical abstract



Abstract

Spectral variability analysis has been carried out on in-situ hyperspectral remote sensing data for 20 tree species available in tropical forest in Malaysia. Five different spectral ranges have been tested to evaluate the influence of intra-species spectral variability at specific spectral range given by different spatial scales (i.e. leaf to branch scales). The degree of intra-species spectral variability was not constant among different spectral ranges where the influence of spatial scale towards intra-species spectral variability at these spectral ranges was found increasing from leaf to branch scale. The ratio of leaves to non-photosynthetic tissues has made branch scale significantly influent the intra-species spectral variability. Results have shown that a specific spectral range was species sensitive on the intra-species and inter-species spectral variability in this study. This study also suggested the use of species sensitive wavelengths extracted from specific spectral range in hyperspectral remote sensing data in order to achieve good accuracy in tree species classification.

Keywords: In-situ Hyperspectral; intra-species variability; tropical forest

Abstrak

Analisis variasi spektral telah dilaksanakan ke atas data lapangan penderiaan jauh hiperspektral untuk 20 spesies pokok yang terdapat di hutan tropikal di Malaysia. Lima julat spektrum yang berbeza telah diuji untuk menilai pengaruhan spektral variasi intra-spesies pada julat spektrum yang berasaskan skala ruang (iaitu skala daun hingga dahan pokok) yang berbeza. Darjah variasi spektral intra-spesies adalah tidak malar antara julat spektrum yang berbeza di mana pengaruh skala ruang terhadap variasi spektral intra-spesies pada julat spektrum ini didapati meningkat daripada skala daun hingga dahan. Nisbah daun kepada tisu bukan fotosintesis telah menjadikan skala dahan mempengaruhi variasi spektral intra-spesies secara ketara. Keputusan menunjukkan bahawa julat spektrum tertentu adalah spesies sensitif pada variasi spektral intra-spesies and inter-spesies dalam kajian ini. Kajian ini juga bercadang penggunaan panjang gelombang spesies sensitif yang dijana daripada julat spektrum tertentu dalam data penderiaan juah hiperspektral bagi mencapai ketepatan yang baik dalam pengkelasan spesies pokok.

Kata kunci: In-situ Hyperspectral; intra-species variability; tropical forest

1.0 INTRODUCTION

Tropical forest is a pool of high diversity in tree species, spatial distribution mapping of these species using remote sensing is a challenging task due to the problem of spectral similarity among tree species. Amongst other remote sensing data, hyperspectral remote sensing has been used widely to achieve good accuracy in mapping tree species in tropical forests. Many studies have successfully demonstrated the tree species discrimination at tree branch or individual tree crown scale, particularly in using airborne and in-situ (ground based) hyperspectral data.[1-3] However, study of tree species discrimination at leaf scale is still on demand as not many studies have been carried out for tropical forests in Malaysia. Thereby, hyperspectral analysis at leaf scale study is needed in knowledge mining regarding spectral properties of tree species in this region.

In the mapping task of various tree species in tropical forest, spectral variability of individual spectra is an important factor which will significantly influent the accuracy of species discrimination process.[4] Previous studies have agreed that classification process is better in accuracy when the case of among-species spectral variation is much greater than intra-species variation.[4-6] They concluded that large intra-species spectral variability induces increasing in misclassification errors and leads to a low tree species discrimination accuracy.

Discussions on spectral variability have been presented in articles to look at those factors which contribute to the variability in tropical forests. Studies found that different factors correspond to intra-species spectral variability at various spatial scales. For examples, a study[1] has reported that leaf age and healthiness are the two main factors that contribute to intra-species variability at leaf scale. The leaf surface greenness, chemical pigments (chlorophyll and carotene levels) and water content are controlled by age and healthiness of leaf, and the difference in these leaf components may induces variation at reflectance of spectra among leaves of a same species. Furthermore, when up-scaling to branch level, the ratio of non-photosynthetic tissue (e.g. bark, fruit or flower) to leaves is also one of the main factors that leads to intra-species spectral variability.[1-3] Besides, studies found that intra-species spectral variation was also significantly influenced by study site and season where the degree of variability at leaf and branch scales was enlarged due to samples taken from multiple sites and seasons.[6-7] However, the evergreen tropical forest trees in Malaysia are expected not be influenced by seasonal variability, but the flowering process of certain tree species could lead to intra-species variability across time and sites.[7]

Hyperspectral remote sensing data has numerous continuous narrow bands, which contain spectral information that reflect chemical and physical properties of target tree species. Among hundreds of spectral bands, only those discriminating spectral bands are needed to achieve promising result in tree species classification process. Analyses on spectral variability is important because underestimation of intra-species spectral variation will lead to low classification accuracy.[4] Spectral angle and spectral amplitude were the two widely used metrics to quantify intra-species spectral variation.[4-6] Based on mathematical formulae, spectral angle, θ indicates the difference in shape and while spectral amplitude, D responses to the difference in reflectance between test and reference spectra.[8] Many previous studies agreed that spectral angle is insensitive towards effect of illumination during spectra collection which is well to coexist with spectral amplitude metric in tree species discrimination works. [4-6]

Several studies had been conducted on intra-species spectral variability of forest tree species, including tropical forests.[1-2] However, there is still lack of such study in this tropical region, particularly intra-species variability at different spectral ranges. Thus, works on spectral variability analysis of ground based hyperspectral remote sensing data have been carried out for selected tree species available in tropical forest in Malaysia. Spectral variability analysis in this study was focused on leaf and branch scales and five different spectral ranges have been tested to examine the influence of intra-species spectral variability given by different spatial scales at specific spectral range.

2.0 DATA COLLECTION AND PROCESSING

A field campaign was conducted to collect leaf samples from 20 selected tree species (Table 1) in a patch of secondary forest which is managed by Johor Bahru Tengah Municipal Council. This study site is located in an urban forest park (103°3´52.96´´ E, 1°0´59.47´´N) where about 16 km from the town of Johor Bahru, Southern part of Peninsular Malaysia. In data collection process, 5-9 trees of each individual tree species were randomly selected and about three branches have been cut off from each tree. The leaf samples in fresh condition were sent to laboratory for in-situ hyperspectral data measurement.

In-situ hyperspectral measurements were collected using a full range (350-2500 nm) Analytical Spectral Devices (ASD) FieldSpec portable spectroradiometer and a pair of 500 watt tungsten lamps was used to generate stable light source (electromagnetic radiation) throughout the data collection process. The hyperspectral sensor (with an eight degrees viewing angle filter) was positioned at nadir above leaf sample. The white reflectance and dark current calibration were done to ensure the quality of spectra collected. Three sets of in-situ hyperspectral data (first data set covers the spectra of tree branch for each individual species while the second (leaves facing up) and third (leaves facing up with some were reversed) data sets were spectra of leaves detached from each branch) were measured from each tree branch to provide sufficient data to study spectral variability at branch and leaf scales. From the aspect of remote sensing analysis, leaf reflectance in the real world is mainly contributed by leaf surface scattering and some portions of leaf abaxial side (another side of leaf surface) scattering. For all data sets, 12-17 spectra were measured for each individual tree species (Table 1) but spectrum measurement of leaves facing up was skipped for two species (*Bucida Molineti* and *Samanea Saman*) due to the difficulty to ensure all very small leaflets facing towards sensor.

In order to avoid the influence of random spectral noise in variability evaluation, wavelengths lower than 400 nanometers and greater than 2300 nanometers of all spectra have been discarded. Two-thirds of samples were randomly selected from each data set as test spectra while the remaining samples of all data sets were bundled up as reference spectra. Mean spectra were calculated from the reference data set for each tree species. In intra-species spectral variability analysis, each test spectrum was compared with the mean spectrum of the same species. Spectral angle, θ and spectral amplitude, D were used to calculate the differences in spectral shape and in percent of reflectance between test spectrum and reference spectrum respectively. The variation given by spectral angle and spectral amplitude metrics have no conflict in justifying spectral variability since different aspects were considered by these metrics. In this study, intra-species variability of five spectral ranges, namely full spectral range (400-2300 nm), the visible range (400-700 nm), red edge range (680-75 nm), near infrared range (700-1300 nm), and short-wave infrared range (1300-2300 nm) have been evaluated. Spectral separability (interspecies variability) among different species has also been analyzed by using spectral angle. The test was run by comparing mean reference spectra of all 20 tree species in a pair-wise way and all five spectral ranges have been evaluated.

$$\text{Spectral Amplitude, } D = \left[\frac{1}{\lambda b-\lambda a}\int_{\lambda a}^{\lambda b}[S_R(\lambda)-S_T(\lambda)]^2\right]^{1/2} \quad \text{(Eq. 1)}$$

As suggested by a previous study, when the sampling interval was uniform during spectra collection, the integral in spectral amplitude was replaced with a summation as the equation below.[5]

$$\text{Spectral Amplitude, } D = \left[\frac{1}{N-1}\sum_{i=1}^{N}[S_R(\lambda)-S_T(\lambda)]^2\right]^{1/2} \quad \text{(Eq. 2)}$$

$$\text{Spectral Angle, } \theta = COS^{-1}\left[\frac{\int S_R(\lambda)S_T(\lambda)d\lambda}{[\int S_R(\lambda)^2 d\lambda]^{1/2}[\int S_T(\lambda)^2 d\lambda]^{1/2}}\right] \quad \text{(Eq. 3)}$$

S_R and S_T are reference spectra and test spectra respectively while λ_a and λ_b are the spectral range interval. N is the number of wavelengths for spectral range tested.

Table 1 List of tree species and hyperspectral data sample sets in this study

Species Name	Species Code	Number of Tree Samples	Number of Leaves Sample Spectra			Total Number of Sample Spectra
			Branch	Leaves Facing Up	Mixture (Leaves Facing Up and Reversed)	
Alstonia Angostiloba (Pulai)	AA	7	21 (14) [a]	21 (14)	21 (14)	63 (42)
Bucida Molineti (Pokok Doa)	AL	6	18 (12)	-	18 (12)	36 (24)
Aquilaria Malaccenis (Karas)	AM	7	20 (14)	20 (14)	20 (14)	60 (42)
Calophyllum Spp. (Bintagor)	CA	6	17 (12)	17 (12)	17 (12)	51 (36)
Cinnamomum Iners (Medang Teja)	CI	8	23 (14)	23 (14)	22 (14)	68 (42)
Dyera Costulata (Jelutong)	DC	6	17 (12)	17 (12)	17 (12)	51 (36)
Drybalanops Oblongifolia (Keladan)	DO	5	14 (9)	14 (9)	14 (9)	42 (27)
Eugenia Oleina (Kelat Paya)	EO	7	21 (14)	21 (14)	21 (14)	63 (42)
Fragea Fragans (Tembusu)	FF	8	24 (14)	23 (14)	24 (14)	71 (42)
Hopea Odorata (Merawan Siput Jantan)	HO	9	27 (15)	27 (15)	27 (15)	81 (45)
Kayea Ferrea (Penaga Lilin)	KF	8	24 (14)	24 (14)	23 (14)	71 (42)
Maniltoa Browneoides (Handkerchief Tree)	MB	8	23 (14)	23 (14)	23 (14)	69 (42)
Pterygota Alata (Kasah)	PA	6	12 (8)	12 (8)	12 (8)	36 (24)
Palouium Gutta (Nyatoh Taban)	PG	8	24 (14)	24 (14)	24 (14)	72 (42)
Peltophorum Pterocarpum (Jemerlang)	PP	8	24 (14)	24 (14)	24 (14)	72 (42)
Syzygium Grande (Jambu Air Laut)	SG	7	21 (14)	21 (14)	21 (14)	63 (42)
Shorea spp. (Meranti)	SH	6	16 (11)	16 (11)	16 (11)	48 (33)
Shorea Roxburghii (Meranti Temak Nipis)	SR	9	27 (15)	27 (15)	27 (15)	81 (45)
Samanea Saman (Hujan-hujan)	SS	7	21 (14)	-	21 (14)	42 (28)
Shorea Singkawang (Meranti Sekawang Merah)	SSI	8	21 (14)	21 (14)	21 (14)	63 (42)

[a]Bracket in the table above shows the number of spectral sample used in the intra-species spectral variability analysis.

3.0 RESULTS AND DISCUSSION

Spectral angle, θ and spectral amplitude, D were the metrics used in this study to evaluate intra-species spectral variability at leaf and branch scales of 20 tropical forest tree species in Malaysia. The intra-species spectral variation at leaf and branch scales of testing spectra has been presented with box-and-whisker plot (Figure 1). In the plots, the lower and upper boundaries of box show the first quartile (25^{th} percentile) and third quartile (75^{th} percentile) of intra-species spectral variation for each tree species. The boundary between these two colors in the box indicates the median value of variation and the two vertical ended lines are the minimum and maximum values of the variation range.

We found that intra-species spectral variation was not identical among the 20 tree species and there was a remarkable contrast in that variation between some species in this study. For examples, *Peltophorum Pterocarpum (PP)*, *Palouium Gutta (PG)*, and *Hopea Odorata (HO)* have significant spectral variation while *Bucida Molineti (AL) and Drybalanops Oblongifolia (DO)* were the two species which have less significant spectral variation when intra-species spectral variability of the full spectral range was evaluated with spectral angle metric. Intra-species spectral variability of species *PP*, *PG*, and *HO* was enlarged by spectral samples in the third quartile (75^{th} percentile) of variation range which have significant difference in spectral angle when was compared with their mean spectrum. In fact, these tree species have experienced less significant intra-species spectral variability if the third quartile of variation range was excluded. Thus, selection of training samples should be careful to exclude samples from the third quartile in order to minimise the intra-species spectral variability in classification.

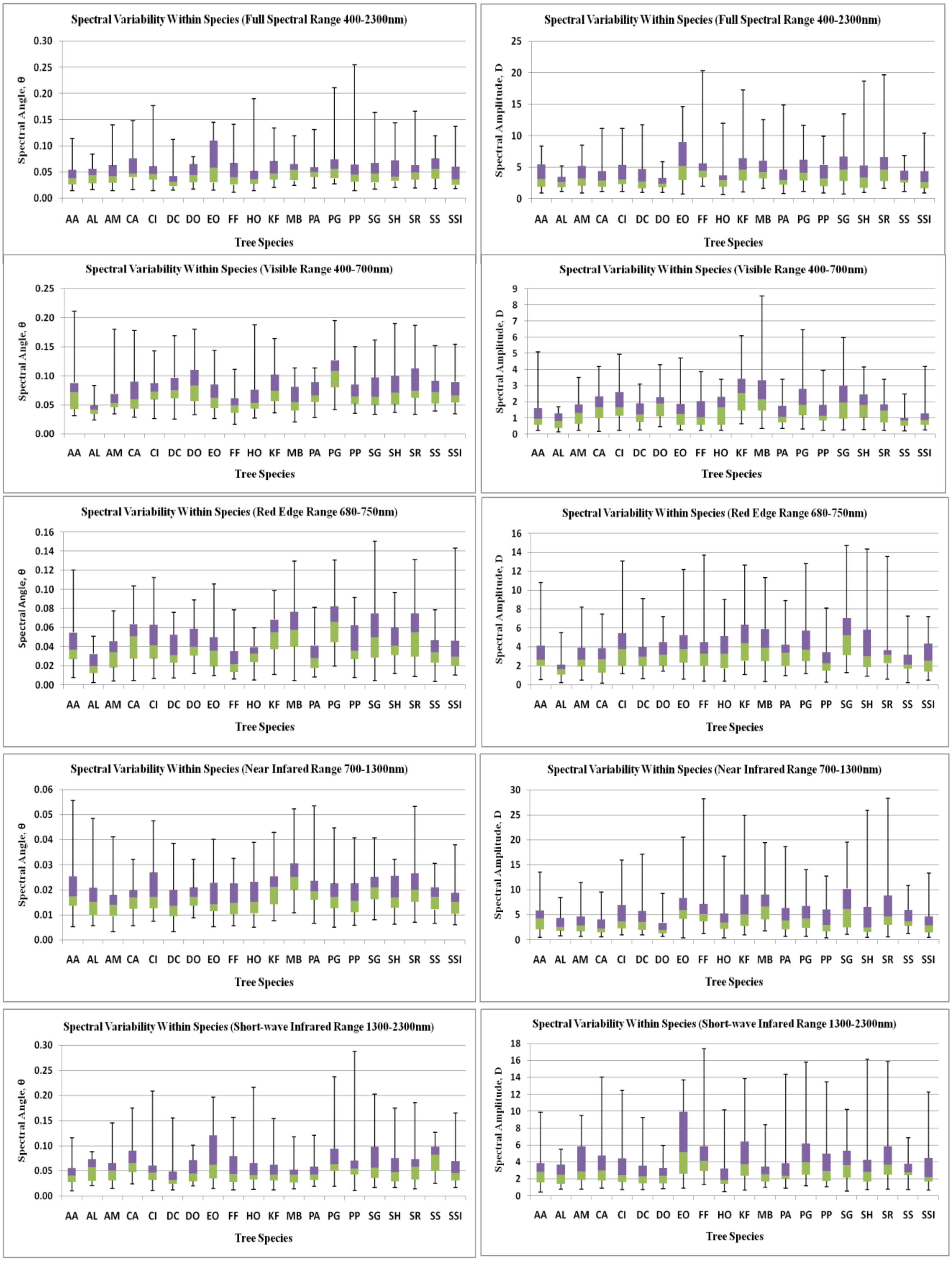


Figure 1 The box-and-whisker plots of the within species spectral variability for spectral angle (left hand side plots) and spectral amplitude (right hand side plots) for five spectral ranges

On the other hand, *Eugenia Oleina (EO)* has the widest middle variation range (between 25th to 75th percentiles) among other tree species in both the spectral angle and spectral amplitude respectively. This variation was mainly influenced by the short-wave infrared range where the middle variation range of this spectral range was recorded about 0.05-0.12 radians in spectral angle and 3-10 percents difference of reflectance in spectral amplitude metric. In this case, wide distribution of intra-species spectral variation among the majority of spectral samples in this species could lead to misclassification errors as training samples might not well representing samples of this tree species.

A previous study[5] has concluded that the degree of intra-species spectral variation was not identical across all spectral ranges. Similar finding was found in this study where the spectral variation range was different among four spectral ranges (the visible, red edge, near infrared, and short-wave infrared). In general, consideration for the intra-species spectral variability up to 75th percentile variation measured by spectral angle metric among all tree species were 0 to 0.13 radians, 0 to 0.08 radians, 0 to 0.03 radians, and 0 to 0.12 radians for the visible, red edge, near infrared, and short-wave infrared spectral ranges respectively. These variation ranges indicate that the visible and short-wave infrared ranges have the highest intra-species variation and followed by the red edge spectral range while the near infrared range has the smallest variation in spectral angle for 20 tree species in this study. Interestingly, we found that intra-species spectral variability of tree species in this study was significantly influenced by different spectral ranges. For instances, *Peltophorum Pterocarpum (PP)* has the largest spectral angle variation range in the short-wave infrared spectral range compared to that in the visible, red edge, near infrared ranges. However, *Alstonia Angostiloba (AA)* has experienced the most significant intra-species spectral variability in the visible range among four spectral ranges as the largest spectral angle variation range was presented in Figure 1. As the degree of intra-species spectral variation is different across all spectral ranges, this study suggested to analyze intra-species spectral variation of given tree species at different spectral ranges so that the variation at specific spectral range could not be underestimated. As agreed in previous studies[4-6], small intra-species spectral variability should be applied to achieve good overall accuracy in tree species classification. Results in this study imply that a tree species should be distinguished from other species based on spectral information from spectral range which has smaller intra-species spectral variability instead of using the same spectral ranges in classifying all target tree species.

Spectral angle and spectral amplitude metrics have resulted different degrees of intra-species spectral variation for all tree species in this study. For examples, *Peltophorum Pterocarpum (PP)* has the largest spectral angle variation range while *Fragea Fragans (FF)* has the highest maximum variation value in spectral amplitude when the full spectral range was evaluated among the 20 tree species. This situation is similar to finding of a previous work where different degrees of intra-species spectral variation have been given by different metrics.[4] This can be explained when two different aspects of spectral difference between test spectra and reference spectra were considered by these two metrics.

Besides, we also found that these different aspects of spectral difference were important in identifying a specific spectral range which has the most significant influence on intra-species spectral variability of tree species. Spectral angle has shown that the visible and short-wave infrared ranges have the largest intra-species spectral variability while the near infrared range has the smallest variation when up to 75th percentile variation was considered for 20 tree species in this study. With similar consideration (up to 75th percentile variation for all species), however, the visible range has the smallest intra-species variation measured by spectral amplitude metric. On the other hand, the near infrared range and short-wave infrared have the largest variation and followed by the red edge range. The situation with inverse order for the visible and near infrared ranges in intra-species variability could be explained by the nature of spectral angle and spectral amplitude metrics. The spectral angle metric detects spectral shape difference which is influenced by kurtosis and skewness of peak or trough along sample spectrum while spectral amplitude metric detects difference in reflectance level. As presented in Figure 2, the near infrared range has significant difference in reflectance level between test and reference spectra compared to visible range. On the other hand, the kurtosis and skewness of green peak lead to remarkable difference in spectral angle compared to near infrared plateau. Perhaps consideration on both spectral shape and reflectance is more useful in analyzing intra-species spectral variability.

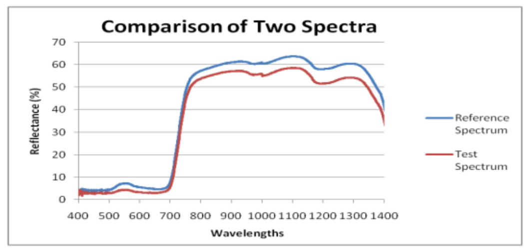


Figure 2 Example to show the kurtosis and skewness at the green peak and difference in reflectance level at near infrared range between test and reference spectra

In order to examine the effect of spatial scale (leaf and branch scales) towards intra-species spectral variability at different spectral ranges, a further analysis was performed on spectral variation after the 75th percentile (third quartile). The number of sample spectra from branch, leaves facing, and mixture (leaves facing up and reversed) data sets was counted and the results have been presented in Figure 3 and Figure 4. For the visible range, spectral angle and amplitude variations after the 75th percentile were dominated by sample spectra from branch scale and mixture data set at leaf scale respectively. This indicates that spectra of branch data set has significant influences towards spectral shape while spectra of mixture data set gave influences on reflectance level at wavelengths ranged from 400 to 700 nanometers. The results of the study have shown that the red edge range was very sensitive towards intra-species variation as the third quartile of spectral angle and amplitude variations for most of the tree species were evenly occupied by spectra from all three data sets. Within red edge spectral range, a near vertical transition slope is connected with the visible and near infrared ranges and shifting of this slope at any small angles could result significant difference in spectral shape and reflectance level between test and reference spectra. On the other hand, the near infrared and short-wave infrared ranges were significantly influenced by spectra from the branch data set in this study and the influence of branch scale was found at the spectral angle and amplitude variations. As tree branch has mixture of leaves and non-photosynthetic tissues, the ratio of leaves to these tissues is the key factor control on spectral reflectance. In general, the branch scale has greater influences on intra-species spectral variability at different spectral ranges compared to leaf scale.

Figure 3 Plot of the third percentile of intra-species spectral angle variation for three data sets (branch, leaves facing up, and mixture) at different spectral ranges. The left y-axis is the number of sample spectra while the right y-axis is the percentage of sample spectra from each data set

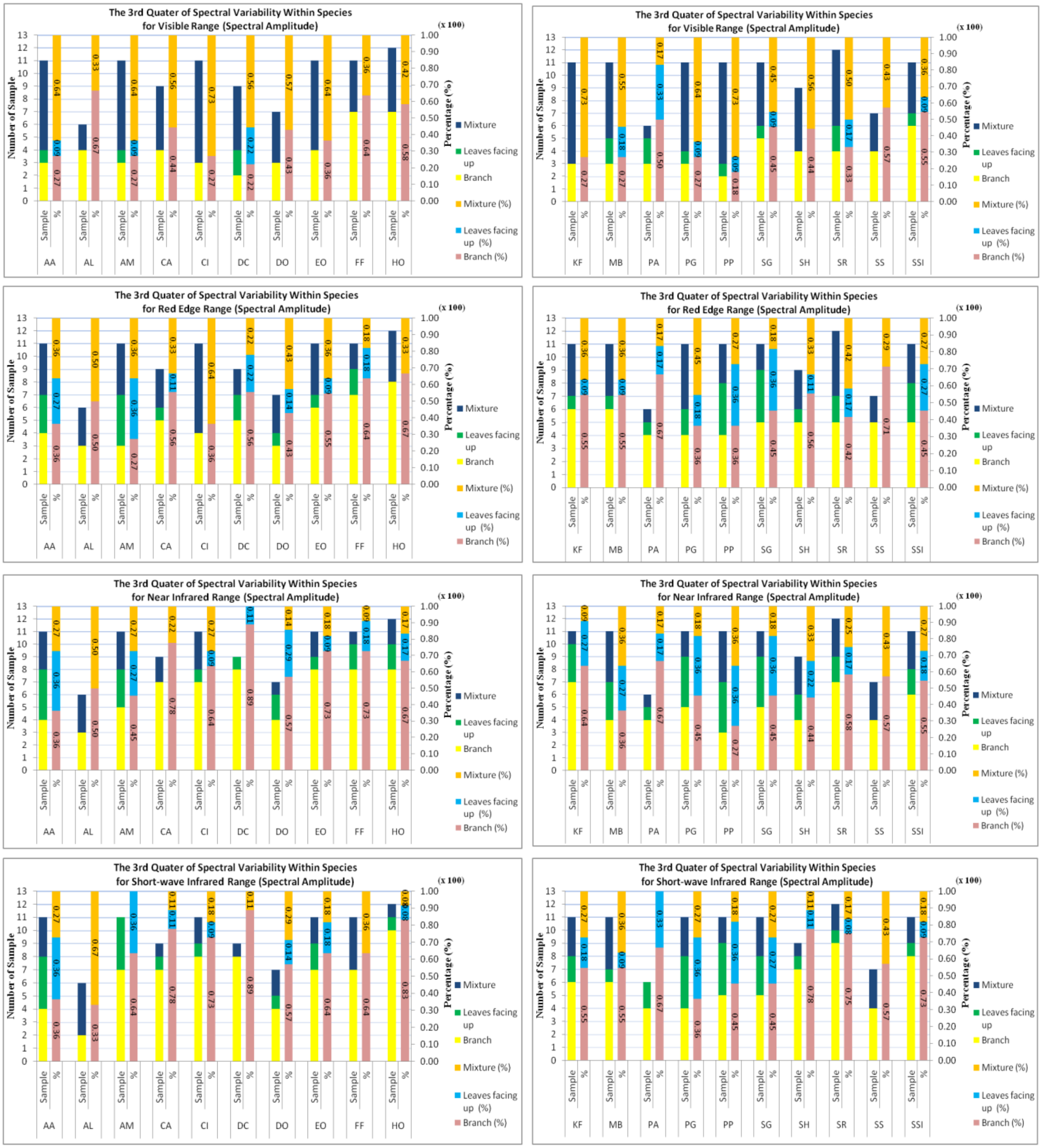


Figure 4 Plot of the third percentile of intra-species spectral amplitude variation for three data sets (branch, leaves facing up, and mixture) at different spectral ranges. The left y-axis is the number of sample spectra while the right y-axis is the percentage of sample spectra from each data set

In this study, spectral angle metric also was applied to measure inter-species spectral variability among mean reference spectra of 20 tree species in a pair-wise way. Out of all tree species, Table 2 has only displayed ten tree species and the top five species which have largest inter-species spectral variation in spectral angle with respect to other tree species at different spectral ranges. Across the five spectral ranges analyzed, different tree species has significant spectral angle difference with respect to other tree species. This means that each spectral range was sensitive to discriminate specific tree species from other species. Unlike other previous studies which selected a set of important wavelengths or spectral features to classify all target tree species, there are potentials to apply specific species sensitive wavelengths or spectral features extracted from specific spectral range in hyperspectral remote sensing data to achieve promising accuracy in tree species classification.

Table 2 Top five tree species with the largest spectral angle difference with respect to other species at spectral ranges

Species Name	The top five largest spectral difference tree species (Measured by spectra angle metric, θ)				
	Full Spectral Range	**Visible Range**	**Red Edge Range**	**Near Infrared Range**	**Short-wave Infrared Range**
Alstonia Angostiloba (Pulai)	SG, MB, AL, PP, AM	MB, SS, EO, PP, SR	MB, EO, FF, SG, PG	MB, CA, SG, EO, SS	SG, AM, AL, PP, EO
Calophyllum Spp. (Bintagor)	AM, KF, SG, MB, SH	SSI, AA, MB, PG, DO	MB, EO, FF, PG, SG	MB, KF, AM, EO, AA	SG, AM, PP, AL, KF
Dyera Costulata (Jelutong)	AM, KF, SG, MB, AL	MB, EO, SS, PP, PG	MB, EO, PG, FF, KF	MB, CA, KF, AA, SS	AM, KF, EO, SG, FF
Hopea Odorata (Merawan Siput Jantan)	AM, SG, KF, MB, PP	MB, EO, SS, PG, PP	MB, EO, PG, AA, FF	MB, KF, AM, EO, AA	SG, AM, PP, MB, AL
Pterygota Alata (Kasah)	AM, KF, SG, MB, EO	MB, EO, PG, SS, PP	MB, EO, PG, FF, KF	MB, CA, KF, AA, SS	AM, KF, EO, FF, DO
Palouium Gutta (Nyatoh Taban)	SG, MB, PP, AL, SS	MB, SS, PP, EO, SR	MB, SS, AA, CA, PP	MB, SH, SS, CA, AM	SG, PP, AL, MB, SS
Peltophorum Pterocarpum (Jemerlang)	AM, KF, SH, DO, SSI	MB, EO, PG, SS, PP	MB, EO, PG, FF, KF	MB, KF, CA, AM, AA	AM, KF, EO, DO, SH
Shorea spp. (Meranti)	SG, MB, PP, AL, SS	MB, EO, SS, PP, PG	MB, EO, FF, PG, SG	MB, CA, SG, SS, HO	SG, PP, AL, MB, SS
Shorea Roxburghii (Meranti Temak Nipis)	AM, KF, SH, DO, SSI	PG, AA, SSI, KF, DC	MB, EO, PG, FF, SG	MB, KF, AM, EO, AA	AM, KF, EO, DO, FF
Shorea Singkawang (Meranti Sekawang Merah)	SG, MB, PP, AL, SS	MB, SS, EO, PP, SR	MB, EO, FF, PG, SG	MB, CA, SG, SS, HO	SG, PP, AL, MB, SS

■4.0 CONCLUSIONS

Spectral variability analysis has been carried out on in-situ hyperspectral remote sensing data for 20 tree species in tropical urban forest. From the results and analysis carried out in this study, several findings could be highlighted as follow:

a) The degree of intra-species spectral variability was not constant across the visible, red edge, near infrared and shortwave infrared spectral ranges for 20 tree species in this study.
b) In general, the influence of spatial scale towards intra-species spectral variability at different spectral ranges was found increasing from leaf to branch scale. Due to mixture of leaves and non-photosynthetic tissues at branch scale, the ratio of leaves to non-photosynthetic tissues (serve as the main factor control on spectral reflectance) has made branch scale significantly influent the intra-species spectral variability.
c) The red edge spectral range was found very sensitive towards spectral difference among sample spectra as the intra-species spectral variation at this spectral range was evenly influenced by leaf and branch scales.
d) In this study, spectral angle and spectral amplitude have shown that a specific spectral range was species sensitive on both the intra-species and inter-species spectral variability. In this context, a spectral range has significant intra-species spectral variability for certain tree species meanwhile gave good spectral separability (inter-species spectral variability) among some specific tree species. Thus, there are potentials to use species sensitive wavelengths or spectral features extracted from specific spectral range in hyperspectral remote sensing data to achieve promising accuracy in tree species classification.

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References

[1] M. L. Clark, D. A. Roberts, D. B. Clark. 2005. *Remote Sens. Environ.* 96: 375.
[2] M. L. Clark, D. A. Roberts. 2012. *Remote Sens.* 4: 1820.
[3] E. M. Adam, O. Mutanga, D. Rugege, R. Ismail. 2012. *Int. J. Remote Sens.* 33: 552.
[4] J. B. Féret, G. P. Asner. 2013. *IEEE T. Geosci. Remote.* 51: 73.
[5] M. A. Cochrane. 2000. *Int. J. Remote Sens.* 21: 2075.
[6] K. L. Castro-Esau, G. A. Sánchez-Azofeifa, B. Rivard, S. J. Wright, M. Quesada. 2006. *Am. J. Bot.* 93: 517.

[7] A. Ghiyamat, H. Z. M. Shafri, G. A. Mahdiraji, A. R. M. Shariff, S. Mansor. 2013. *Int. J. Appl. Earth Obs.* 23: 177.

[8] J. C. Price. 1994. *Remote Sens. Environ.* 49: 181.