SPECTRAL DISCRIMINATION AND INDEX DEVELOPMENT OF ROOFING MATERIALS AND CONDITIONS USING FIELD SPECTROSCOPY AND WORLDVIEW-3 SATELLITE IMAGE

SARAH HANIM BINTI SAMSUDIN

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By

SARAH HANIM BINTI SAMSUDIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

June 2016
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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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June 2016

Chairman: Assoc. Prof. Helmi Zulhaidi Mohd Shafri, PhD
Faculty: Engineering

Monitoring roofing materials and conditions are important to improve urban management and support the well-being of an urban environment. However, it is difficult to map the within-class roofing surfaces in the heterogeneous urban environment using multispectral remotely sensed data due to a wide-range of materials exist. Furthermore, restriction in multispectral bands has led to spectral confusions when mapping the within-class roofing types. Normal supervised pixel-based classification scheme is often applied to map urban land use and land cover which the accuracy is dependent on the training site information. Hence, the development of new approach is indispensable to improve the within-class roofing materials mapping. A technique combining the information of spectral and spatial characteristic could be considered as an effective way to improve urban analysis and overcome issues of limited spectral band and coarse spatial resolution of remote sensing data. Therefore, this study utilize the combination of field spectroscopy hyperspectral data and very high resolution multispectral data of WorldView-3 (WV-3) to map the roofing materials and conditions.

Hyperspectral data has the ability of providing adequate spectral information for discriminating within-class of roofing materials and conditions. This study utilizes field spectroscopy data as fundamental on analysing roofing spectral signature instead of using airborne hyperspectral data due to the expensive cost of data acquisition. However, handling hyperspectral data required effective method to reduce redundancy of data, yet maintaining the useful information. This research investigates a feature selection technique to discriminate between four different types of roof materials (i.e.: asbestos, concrete, clay and metal) and their conditions by using field spectroscopy within the range of 350 nm – 2500. Three feature selection algorithms of Genetic Algorithm (GA), Support Vector Machine (SVM) and Random Forest (RF) were used to select the most significant wavelengths since the algorithms works well with large size of data and widely applied for feature selection of hyperspectral remote sensing data. Results from feature selection
specify that visible, Shortwave Infrared-1 (SWIR-1) and SWIR-2 (SWIR-2) spectral regions are important for roof materials and conditions separation. Comparatively, overall accuracy obtained from GA, SVM and RF algorithms are fairly high in percentage with GA and SVM both produced 96.3%, while RF yield 97.53% accuracy. Generally, the highest accuracy is produced using RF feature selection (97.53%), hence, describe the efficiency of RF algorithm for feature selection task using field spectroscopy data. Accuracy of spectra without feature selection was also investigated and the result was lower compared with classification using significant wavelengths. Result using all wavelengths mostly recorded 44.44%, while result using significant wavelengths mostly produced 100% accuracy. Therefore, the findings described the importance of selecting significant wavelengths to improve the spectral classification accuracy.

Additionally, new spectral indices of Normalized Difference Concrete Condition Index (NDCCI) and Normalized Difference Metal Condition Index (NDMCI) have been developed in this study for detecting concrete and metal roofing condition status. Significant wavelengths located at visible to near infrared spectral region were used as basis for developing spectral indices to be applied onto very high resolution satellite imagery of WV-3 satellite data. The classification accuracy using spectral indices were compared with the normal supervised pixel-based classification of SVM. Results show that the spectral indices produce higher accuracy compared to SVM classification with NDCCI produced 84.44% compared to SVM classification of concrete condition accuracy by 73.06%. NDMCI produced 94.17% accuracy which is higher compared to SVM classification of metal condition accuracy of 62.5%. Therefore, the results indicate that the application of the developed spectral indices is effective for mapping roofing conditions in the heterogeneous urban environment. Feasibility of the spectral indices developed were assessed by validating the indices on second study area, generating results of 72.06 for NDMCI and 70.3% accuracy for NDCCI. Lower accuracy obtained could be due to different study areas; the first study area is residential and commercial area, meanwhile the second study area is university area. Generally, both spectral indices could be considered for roofing materials and conditions detection application, however NDMCI perform better than NDCCI.

Generally, the findings of this study describes the importance of applying feature selection as a preliminary process before developing a spectral index to eliminate uninformative data and enhance the separation between impervious surfaces. Spectral index of NDCCI and NDMCI found to be effective in providing roof degradation status map in effective time-manner and parameter-free algorithm compared to normal supervised classification scheme. However, the proposed technique has some limitations which the classification is depended on roof brightness, hence, lead to misclassification between new metal roofs and new concrete roofs. This approach also required removal of natural land cover such as vegetation and water bodies to provide better delineation of impervious surfaces. Therefore, further improvement is needed to provide better classification accuracy for delineation of roofing types. The output from this study could contribute into new insight of urban planning and monitoring and sensor development for urban mapping.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

DISKRIMINASI SPEKTRUM DAN PEMBINAAN INDEKS UNTUK JENIS DAN KEADAAN BUMBUNG MENGGUNAKAN SPEKTROSKOPI LAPANGAN DAN DATA SATELIT WORLDVIEW-3

Oleh

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Jun 2016

Pengerusi: Professor Madya Helmi Zulhaidi Mohd Shafri, PhD
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Pemantauan bahan dan keadaan bumbung adalah penting untuk meningkatkan pengurusan bandar dan membantu dalam memastikan kesejahteraan kawasan persekitaran bandar. Walau bagaimanapun, memetakan antara kelas permukaan berbumbung dalam persekitaran bandar yang heterogen menggunakan data penderiaan jauh adalah rumit kerana kepelbagaian bahan yang wujud. Tambah pula, limitasi jalur spectrum data multispectral telah menyebabkan kekeliruan spektrum apabila pemetaan antara kelas bahan dilakukan. Kaedah klasifikasi diselia normal berasaskan piksel sering digunakan untuk memetakan kawasan guna tanah bandar. Walaubagaimanapun, ketepatan menggunakan kaedah klasifikasi ini adalah bergantung kepada maklumat tapak latihan yang disediakan. Oleh itu, pembangunan teknik baru adalah amat diperlukan untuk meningkatkan pemetaan antara kelas bahan permukaan berbumbung. Teknik yang menggabungkan maklumat ciri spektrum dan spatial boleh dianggap sebagai cara yang berkesan untuk meningkatkan analisis bandar dan mengatasi masalah-masalah data penderiaan jauh seperti jalur spektrum yang terhad dan resolusi ruang kasar. Oleh itu, kajian ini menggunakan gabungan data hyperspectral spektroskopi lapangan dan imej satelit multispectral beresolusi yang sangat tinggi iaitu WorldView-3 (WV-3) untuk memeta bahan bumbung dan keadaannya.

Data hyperspectral mempunyai keupayaan untuk menyediakan maklumat spektrum yang mencukupi untuk tujuan diskriminasi antara-kelas bahan bumbung dan keadaannya. Kajian ini menggunakan data spektroskopi lapangan sebagai asas untuk menganalisis karakter spektrum jenis-jenis bumbung, ini adalah kerana penggunaan data hyperspectral udara memerlukan kos yang mahal untuk proses pemerolehan data. Walau bagaimanapun, pengendalian data hyperspectral memperluakan kaedah yang berkesan untuk mengurangkan pertindikan data, tetapi masih mengekalkan maklumat yang berguna. Kajian ini menyiasat teknik pemilihan ciri untuk membezakan antara empat jenis bahan bumbung (iaitu: asbestos, konkrit, tanah liat dan logam) dan keadaan mereka dengan menggunakan alat spektroskopi lapangan dalam julat 350 nm - 2500. Tiga
Algoritma telah digunakan iaitu Genetic Algorithm (GA), Support Vector Machine (SVM) dan Random Forest (RF) untuk memilih panjang gelombang yang paling penting. Algoritma-algoritma ini digunakan kerana ianya mampu berfungsi dengan baik apabila mempunyai saiz data yang besar serta telah digunakan dengan meluas untuk pemilihan ciri data hyperspectral. Keputusan dari pemilihan ciri telah menentukan bahawa spectrum pada gelombang boleh nampak, gelombang infra merah pendek-1 (SWIR-1) dan gelombang infra merah pendek-2 (SWIR-2) adalah penting untuk membezakan bahan-bahan dan keadaan bumbung yang berlainan. Secara perbandingan, ketepatan keseluruhan yang diperolehi daripada algoritma GA, SVM dan RF adalah agak tinggi dengan peratusan menggunakan GA dan SVM adalah 96.3%, manakala RF menghasilkan ketepatan 97.53%. Oleh itu, keputusan menggunakan pemilihan ciri RF (97.53%) adalah yang paling tinggi, secara tidak langsung menggambarkan kecekapan algoritma RF untuk tugas pemilihan ciri menggunakan data spektroskopi lapangan. Ketepatan spektrum tanpa pemilihan ciri turut disiasat dan hasilnya adalah lebih rendah berbanding menggunakan klasiifikasi menggunakan panjang gelombang yang penting. Keputusan menggunakan semua panjang gelombang kebanyakannya mencatatkan 44.44%, manakala hasil menggunakan panjang gelombang yang penting kebanyakannya menghasilkan ketepatan 100%. Oleh itu, dapat disarankan kepada kajian ini menunjukkan kepentingan memilih panjang gelombang yang penting untuk meningkatkan klasifikasi ketepatan spektrum.

Di dalam kajian ini, indeks spektrum baru iaitu ‘Normalized Difference Concrete Condition Index’ (NDCCI) dan ‘Normalized Difference Metal Condition Index’ (NDMCI) telah dibangunkan untuk mengesan status keadaan bumbung konkrit dan keadaan bumbung logam. Panjang gelombang penting yang terletak di kawasan spektrum boleh nampak digunakan sebagai asas untuk membangunkan indeks spektrum yang akan digunakan ke imej satelit WV-3. Pengelasan ketepatan menggunakan indeks spektrum telah dibandingkan dengan klasiifikasi berdasarkan piksel-diselia biasa, iaitu SVM. Keputusan menunjukkan bahawa klasifikasi mengunakan indeks spektrum menghasilkan ketepatan yang lebih tinggi berbanding klasiifikasi menggunakan SVM dengan NDCCI dihasilkan 84.44% berbanding klasiifikasi SVM keadaan ketepatan konkrit sebanyak 73.06%. NDMCI pula menghasilkan ketepatan 94.17% iaitu lebih tinggi berbanding klasiifikasi SVM dengan 62.5%. Oleh itu, keputusan menunjukkan bahawa penggunaan indeks spektrum adalah berkesan untuk pemetaan keadaan permukaan bumbung di kawasan bandar yang heterogen. Ujian pengesahan telah dilaksanakan di kawasan kajian yang paling berbeza untuk mengesan keupayaan indeks menghasilkan peta status keadaan permukaan bumbung. NDMCI telah menunjukkan ketepatan sebanyak 72.06%, manakala NDCCI menghasilkan ketepatan sebanyak 70.3%. Ketepatan yang lebih rendah diperolehi mungkin disebabkan kawasan kajian yang berbeza; kawasan kajian yang pertama adalah kawasan perumahan dan komersil, sementara itu kawasan kajian yang kedua ialah kawasan universiti. Secara umumnya, kedua-dua indeks spektrum boleh dipertimbangkan untuk pemetaan bahan bumbung dan keadaannya, bagaimanapun prestasi NDCCI adalah lebih baik daripada NDMCI.

Secara umumnya, hasil kajian ini telah menggambarkan kepentingan mengaplikasi pemilihan ciri sebagai proses awal sebelum membangunkan indeks spektrum untuk menghapuskannya data tidak bermaklumat dan meningkatkan pemisahan antara permukaan kedap. Selain itu, indeks spectrum NDCCI dan NDMCI juga didapati berkesan dalam menyediakan peta status degradasi bumbung dengan lebih cepat dan efektif kerana menggunakan indeks yang bebas dari parameter berbanding kaedah klasiifikasi diselia.
yang normal. Walau bagaimanapun, teknik yang dicadangkan mempunyai beberapa batasan seperti terpengaruh dengan kecerahan permukaan bumbung. Salah pengelasan juga cenderung terjadi antara bumbung logam baru dan bumbung konkrit baru. Tambahan pula, teknik spectrum indeks ini memerlukan penyingkiran kawasan guna tanah semula jadi seperti tumbuh-tumbuhan dan badan air untuk membezakan permukaan kedap dengan lebih berkesan. Oleh itu, penambahbaikan diperlukan untuk menyediakan klasifikasi perbezaan jenis-jenis bumbung dengan ketepatan yang lebih baik pada masa hadapan. Hasil dapatan daripada kajian ini boleh menyumbang kepada pengetahuan baru dalam bidang perancangan dan pemantauan bandar serta pembangunan sensor untuk pemetaan bandar.
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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

GA  Genetic Algorithm
SVM  Support Vector Machine
RF  Random Forest
NDCCI  Normalized Difference Concrete Condition Index
NDMCI  Normalized Difference Metal Condition Index
UAV  Unmanned Aerial Vehicle
VHR  Very High Resolution
NDVI  Normalized Difference Vegetation Index
GER  Geophysical Environmental Research
ASD  Analytical Spectral Device
PC  Personal Computer
SWIR  Shortwave Infrared
PE  Polyethylene
UHI  Urban Heat Island
LSMA  Linear Spectral Mixture Analysis
V-I-S  Vegetation-Impervious-Soil surfaces
MIVIS  Multispectral Infrared and Visible Imaging Spectrometer
RFE-SVM  Recursive Feature Elimination-Support Vector Machine
CFS  Correlation-based Feature Selection
mRMR  Minimum-Redundancy-Maximum-Relevance
EFS-SVM  Embedded Feature Selection-Support Vector Machine
MR-SVM  Modified Recursive-Support Vector Machine
TW-SVM  Twin-Support Vector Machine
NN  Neural Network
OOB  Out of Bag
DAIS  Digital Airborne Imaging Spectrometer
k-NN  k-Nearest Neighbour
REI  Road Extraction Index
NIR-2  Near Infrared-2
NDBI  Normalized Difference Built-up Index
BAEI  Built-up Area Extraction Index
NBAI  Normalized Built Up Area Index
BRBA  Band Ratio for Built-up Area
NDISI  Normalized Difference Impervious Surface Index
MNDISI  Modifies Normalized Difference Impervious Surface Index
ISD  Index of Surface Deterioration
WV-3  WorldView-3
SWIR-1  Shortwave Infrared-1
SWIR-2  Shortwave Infrared-1
VNIR  Visible-Near Infrared
WEKA  Waikato Environment for Knowledge Analysis
ENVI  Exelis Visual Information Solutions
DN  Digital Number
OIF  Optimum Index Factor
NDWI  Normalized Difference Water Index
WV-2  WorldView-2
OA  Overall Accuracy
CHAPTER 1

INTRODUCTION

1.1 Background of Study

The development of remote sensing technology has improved urban mapping tasks to provide essential information in urban monitoring and urban management. The motivation for improving within-class impervious surfaces mapping in urban area, arose from the worldwide demographic trends, indicating that half of the world’s population is living in cities, and is expected to increase into future decades, causing changes in spatial distribution of global population (United Nation, 2014). Hence, one of the effects of rapid urbanization phenomenon is the transformation of land use in urban areas, since pervious surfaces will be transformed into impervious surfaces to provide better infrastructures for urban citizens (Miller et al., 2014).

Impervious surface mapping is essential in urban studies since it is considered a key indicator of anthropogenic impact upon the urban environment (Weng, 2012). The characteristics of impervious surfaces, which prevent infiltration of water into the ground, have consequential effects on urban hydrological systems and ecology (Simonovic, 2012; Chithra et al., 2015). Therefore, detection of roofing materials and conditions over an area is very important, as some of the roofing materials, such as asbestos-cement roofs, are harmful to human health (Frassy et al., 2014; Cilia et al., 2015). Besides, some of the roofing materials are constructed from non-reflective material, which releases a high amount of heat into the environment, thereby causes Urban Heat Island phenomenon (Yu and Lu, 2014; Li et al., 2014; Cilia et al., 2015).

Remote sensing has been introduced as an efficient tool to map roof surfaces at a large scale compared to the conventional method, which is through ground survey and manual inspection (Cilia et al., 2015; Swanson & Helmlinger, 2014). In the early usage of the remote sensing technology, identification of urban features was done by utilizing pixel-based supervised classification. However, heterogeneity of features and different surface materials available in urban environments has created a challenge in the urban remote sensing application to discriminate between land cover classes due to the wide range of materials used for manmade surfaces (Chisense, 2012; Taherzadeh and Shafri, 2013; Fiumi et al., 2012; Lu and Moran, 2010). Traditional supervised classification techniques often result in poor classification and a salt-and-pepper effect; this could be due to mixed land cover components in urban areas (Hamedianfar and Shafri, 2014). Apart from that, similarity in colour for certain types of roofs and similar spectral information (i.e.: clay roofs, steel roofs and road) also led to confusion when interpreting the impervious surfaces (Hamedianfar and Shafri, 2014; Herold et al., 2004; Taherzadeh and Shafri, 2013). Therefore, applying this technique required adequate information on the training site to classify the within-class of roofing types.
Recently, knowledge of detecting within-class roofing types up to parcel level is required to improve inter-class and intra-class of urban classification. Therefore, very high resolution (VHR) satellite imagery, such as WorldView, IKONOS and Quickbird (Taherzadeh et al., 2014) is suitable to be used due to high spatial resolution specification. Although VHR could provide sufficient spatial resolution to extract detailed information of land cover, a suitable classification method is required to provide good classification accuracy, especially when classifying a high-spectral variety of urban land cover classes (Lu et al., 2010). Currently, object-based image analysis (OBIA) was introduced to be used with VHR imagery to improve the within-class roofing type’s classification. OBIA technique has advantages of providing high accuracy classification for within-class detection and could differentiate roofing materials from other urban land covers (Hamedianfar and Shafri, 2015; Hamedianfar and Shafri, 2016). However, OBIA techniques involve complex processing and long computation time to produce classification results (McMahon, 2007; Deng and Wu, 2012). Apart from that, the limitation of spectral bands of multispectral imagery has also led to misclassification error when applying OBIA classification on VHR satellite imagery (Taherzadeh and Shafri, 2013; Hamedianfar and Shafri, 2014).

The introduction of hyperspectral technology in remote sensing has provided new insights in urban mapping, since it is equipped with hundreds and contiguous spectral bands that make it efficient for materials detection (Liciardi, 2014). The exploitation of this technology in urban environmental study is still being investigated for impervious surface materials characterization in current research (Taherzadeh and Shafri, 2013; Weng, 2012). Hyperspectral technology could be useful for inter-class material detection since roofing materials spectral are mostly influenced by material, aging and weathering factors (Lacherade et al., 2005). Thus, it has the advantage of supplying sufficient information to improve material and surface condition detection compared to multispectral data. Nevertheless, the abundance of hyperspectral data is highly correlated with each other and are redundant, which consequently leads to complexity of processing. Hence, selecting only suitable wavelengths or bands for discrimination of roofing material is vital to improve the urban materials classification (Weng, 2012; Le Bris et al., 2016).

Machine learning algorithms have recently been used as a tool to select suitable wavelengths discriminating between materials as well as reducing the redundancy of data (Pal, 2010; Kumar and Minz, 2014). Although there are many machine learning algorithms that are developed for feature selection tasks, the most common algorithms used for hyperspectral remote sensing are the Genetic Algorithm (GA) (Pal, 2013; Ullah et al., 2012) and modern algorithms such as Random Forest (RF) and Support Vector Machine (SVM) (Archibald and Fann, 2007; Pal and Foody, 2010; Abdel-Rahman et al., 2013). GA feature selection algorithm has been widely used for remote sensing application due to the simplicity and effective computation time (Yu and Liu, 2003). RF and SVM, on the other hand, are mostly used, since they are efficient when working with large size of data, hence describing its suitability to work with hyperspectral data application (Pal, 2006; Zhang and Ma, 2009; Genuer et al., 2010).

Application of hyperspectral data for urban mapping in the early stage has involved the use of airborne hyperspectral data, which is able to cover large areas and provide adequate spectral information. Previous studies have explored the use of airborne hyperspectral
data to map roof material, particularly asbestos-cement roofing material (Cilia et al., 2016; Frassy et al., 2014). Although the findings from the studies visualize the ability of utilizing high spectral resolution of hyperspectral data for roof detection, the cost of obtaining airborne hyperspectral data is expensive. Satellite-based hyperspectral data could be used as an alternative data; however, the coarse spatial resolution of the data – for instance, Hyperion data by 30-meter spatial resolution – makes it difficult to produce parcel-level urban materials map (Chakravortty et al., 2015). Hence, exploitation of the spatial and spectral advantages of hyperspectral data and VHR satellite data could be investigated to contribute knowledge towards improving the within-class mapping of roof surfaces in the heterogeneous urban environment.

Previously, field spectroscopy was used to investigate the spectral characteristics of urban materials through the development of urban impervious surfaces spectral library (Nasarudin and Shafri, 2011; Ferbern, 2013, Khottaus et al., 2014). However, knowledge of spectral properties useful for urban mapping is still lacking (Deshpane et al., 2013). Hence, the combination of information from field spectroscopy and high spatial resolution of VHR multispectral satellite imagery was explored in this study. The significant wavelengths obtained for roofing class discrimination were utilized by developing them into a new spectral index for mapping application on WorldView-3 satellite imagery. In this way, the technique used in this study could overcome the issue of selecting suitable classification algorithms and image processing methods due to limitations of spectral and spatial resolution of remote sensing data (Lu et al., 2010). This technique was explored to provide an efficient technique of mapping the roof degradation status and contributes to new insight of urban study through spectral index application. This study focuses on concrete and metal roofing materials since concrete roofs are commonly used in Malaysia (Taherzadeh et al., 2014), whereas metal roofs are mostly used for commercial and residential areas (Kriner et al., 2010).

1.2 Problem Statements

Mapping impervious surfaces in urban environments is a challenging task due to the heterogeneity of features, high variation of materials used, and different conditions due to aging and weathering factors. First, the separating impervious surfaces with pervious surfaces is challenging since the urban environment has intense heterogeneity of land covers (Hamedianfar and Shafri, 2015). Besides, the problem of high within-class variations makes it difficult to identify intra-class of impervious surfaces as different materials and surfaces could poses similar spectral information. Hence, using normal pixel-based classification upon multispectral satellite imagery is difficult, as the result will be influenced by inadequate spectral information and textural information (Myint et al., 2011). The pixel-based classification results also often depend on the spatial resolution of remote sensing imagery used. Thus, the technique required proper training site and knowledge on the study area to produce good results of classification.

Secondly, due to the heterogeneity of features that exist in urban environment, mixture of different land cover could present in a single pixel of the image (Du et al., 2014). The mix of land cover in a single pixel will consequently result in the salt-and-pepper effect and misclassification during classification. Therefore, sub-pixel classification analysis was
introduced to resolve the issue of finding endmembers that could represent urban surfaces class based on homogeneity of pixels over the image (Zhang et al., 2014). Still, the technique is not suitable to be used for urban area, due to the difficulty of identifying pure endmembers for within-class materials classification. Thus, classification will likely be influenced by the presence of unidentified classes resulting in degradation of classification accuracy (Myint et al., 2013). Furthermore, restriction of endmember identified could not be greater than number of spectral bands has limit the material mapping (Deng and Wu, 2013).

Therefore, in order to produce a high accurate classification result, VHR multispectral satellite imagery is often used to provide parcel-level classification for urban mapping. In recent years, object-based classification was utilized to improve the classification of impervious surfaces mapping using VHR multispectral satellite images (Hamedianfar and Shafri, 2014; Lu et al., 2011; Taherzadeh and Shafri, 2013). The advantage of applying segmentation-based classification is one of the ways that could reduce the salt-and-pepper effect, and at the same time, overcome high spectral variations issue in the scene. Despite the advantages offered, the technique has shortcomings: it is time consuming and requires effort to develop proper rule-set for delineation between land covers and within-class features (Lu et al., 2011; Myint et al., 2011). Since pixel-based, sub-pixel based and object-based techniques are highly dependant upon training samples, the techniques are computationally intensive, which makes it less efficient for fast and efficient mapping of roofing types, especially for large geographic area.

Lastly, the suitability of data used is also important to improve roof surface detection. Multispectral VHR satellite data has broad and limited number of bands that are commonly equipped with visible-NIR bands. Subsequently, the spectral band restriction will limit the spectral characterization of heterogeneous features in urban environments (Heldens et al., 2011; Mohammadi, 2011; Van der Linden, Waske, et al., 2007). Therefore, new methods are required to solve the challenges initiated by VHR data. Spectral index techniques have the advantage of producing easy implementation and parameter-free classification schemes. However, limitations in terms of spatial and spectral information of the data used need to be considered to improve the classification result. Previously, field spectroscopy data was used as a basis to characterize impervious surfaces materials and conditions for spectral index implementation on multispectral or airborne hyperspectral, since it offers sufficient spectral information (Shahi et al., 2015; Cilia et al., 2016). Hence, spectral analysis from field spectroscopy data could be considered to support limited spectral information of VHR multispectral satellite data with the aim of improving classification output.

1.3 Significance of Study

Roof mapping is very important for urban monitoring, analysis, and planning. However, the current classification scheme applied for roofing detection through pixel-based, sub pixel-based or object-based methods involving complex processing and not efficient for fast computation of a large area. Hence, this study exploits the usage of field spectroscopy data and WorldView-3 satellite data to overcome the difficulties in discriminating between impervious surfaces through the development of spectral indices, namely
Normalized Difference Concrete Condition Index (NDCCI) and Normalized Difference Metal Condition Index (NDMCI). Since information on spectral properties for urban material spectra using ground-based spectroradiometers is still limited, the information on spectral characterization of roofing materials could contribute to new knowledge in roof materials mapping (Khottaus et al., 2014). The development of the spectral indices for roof degradation status mapping is significant to efficiently classify the roofing materials and condition. Producing parcel-level roof degradation status map using conventional pixel-based and object-based required an intensive effort. Therefore, the establishment of the spectral indices of NDCCI and NDMCI helps to reduce the complexity of existing classification schemes through exploitation of field spectroscopy and VHR satellite image. Therefore, the findings from this study could also be used as the basis for large-scale assessment using airborne, satellite imagery or unmanned aerial vehicle (UAV) by applying the new indices developed for comprehensive mapping of roofing types instead of using census data and manual inspection. Furthermore, the information of roof materials and conditions is also essential for assessment of urban heat and energy consumption in the city especially for rapid urbanization in South East Asian countries, such as Malaysia, Singapore, and Indonesia (Al-Obaidi et al., 2014).

1.4 Research Objectives

The main aim of this research is to evaluate the ability of field spectroscopy and WorldView-3 data to effectively discriminate between different types of roof materials (inter-class) and roof conditions (intra-class). The specific objectives to be achieved in this study are as follows:

i. To determine the significant spectral wavelengths and significant spectral regions for discrimination of roofing materials and conditions using field spectroscopy data.

ii. To compare the performance of Support Vector Machine (SVM), Random Forest (RF) and Genetic Algorithm (GA) feature selection algorithms in discriminating and classifying roof materials and conditions.

iii. To develop and apply spectra indices for roofing conditions detection of roofing material condition from very high resolution (VHR) satellite data.

1.5 Scope of the Study

This study aimed to characterize and discriminate within-class roofing spectral for mapping purposes. Being aware of the rapid development of built-up areas in the city, this research focuses on the different materials of rooftops used in Malaysia, which include asbestos, concrete, clay and metal roofing types. This study, too, includes the different status of rooftop conditions, which is categorized as new and weathered conditions to provide detailed mapping of roof surfaces. Weathered condition roof surfaces are often covered with lichen and has faded paint. As for metal roofing material, weathered metal roof could be described by rusty condition on the roof surfaces. As for new roofing material, the physical surface of the roof are represent by new and bright paint coat.
Field spectroscopy data was used in this study to discriminate the roofing materials and conditions through significant wavelengths selection using SVM, RF and GA feature selection algorithms. The algorithms were also used as a way to reduce the dimensional size of the hyperspectral data. Spectral index derived from field spectroscopy data was used as alternative for efficient roofing conditions detection, which could be applied on low-cost VHR satellite imagery such as WorldView-3 data. The constraint of the study was the limited roofing materials available in the study area, which the roofing materials are dominated by concrete and metal roofs only. Therefore, this study excludes the spectral index development for clay and asbestos roof, as the materials are hard to be found in the study area.

1.6 Research Gap

Urban environments are commonly composed of various types of features made from different materials respectively. Therefore, spectral confusion between different impervious surfaces often happen due to heterogeneity of features in urban area (Moreira and Galvão, 2010; Weng, 2012). Apart from that, the physical conditions and surface roughness of impervious surfaces through aging and weathering process also contribute to high variation of within-class (Herold et al., 2006; Shaban and Dikshit, 2001). Hyperspectral remote sensing data was proposed as suitable tool for material delineation since it could provide detail spectral information. Nevertheless, the development of optimal methods for analysing hyperspectral data, however, is still limited since there is no standard approach suggested yet for material classification (Chisense, 2012).

Since less research has been done in investigating the spectral diversity and spectral requirements for the impervious surfaces using remote sensing technology (Weng, 2012), optimum application using hyperspectral data for urban application has become difficult. Furthermore, the issue of difficulties in mapping variations of the impervious surfaces in large-scale assessment still exist due to the lack of a standard approach for that kind of purpose. Therefore, Deshpande et al. (2013) in their study have proposed the need of developing the indices on urban materials to provide new insight in urban mapping. Limitation of spectral and spatial information of remote sensing data also has been mentioned by Weng (2007), suggesting the development of algorithms that could combine spectral and spatial information for effective impervious surfaces extraction in urban areas. Spectral index techniques have been suggested as method for mapping roofing conditions with the use of airborne hyperspectral data to overcome uncertainties of conventional method (Cilia, 2015). However, no spectral indices on roofing materials and conditions have been developed for multispectral VHR satellite data yet. Therefore, this study was conducted to design an effective technique of extracting significant spectral wavelengths that have higher possibility of discriminating and enhancing classification of roof materials and condition. It could also contribute new insights of impervious surfaces study in the remote sensing field through development of relevant spectral indices.
1.7 Thesis Organization

This thesis was organized into five chapters. Chapter 1 introduces this thesis through an explanation of the following: the background of the research, problem statements, research justification, and the objectives of doing this research.

In chapter 2, the literature review explains topics related to this research in detail. This includes the fundamental of remote sensing technology, background of urban spectral characterization, justification and explanation on operation of the feature selection algorithms and related indices developed for impervious surfaces.

Chapter 3 presents the research methodology, which includes the pre-processing, processing and accuracy assessment. The relevant information and the explanation of data collection, algorithms involves, parameter setting and software used for the processing are stated in this chapter.

Chapter 4 presents the results obtained in this study. The first stage in this chapter consists of results of spectral reflectance of the materials and the location of the significant wavelengths in discriminating between the different types of roofing materials and conditions. The second stage focuses on the results of spectral indices development and the indices assessment. A detailed discussion of the results obtained is provided in this chapter.

Chapter 5 is the conclusion of this research. It discusses the overall conclusion based on the objectives and the results achieved. The recommendations for further research are also included.
REFERENCES


