UNIVERSITI PUTRA MALAYSIA

IMPROVEMENT ON ROOFTOP CLASSIFICATION OF WORLDVIEW-3 IMAGERY USING OBJECT-BASED IMAGE ANALYSIS

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By

MASAYU BINTI NORMAN

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

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IMPROVEMENT ON ROOFTOP CLASSIFICATION OF WORLDVIEW-3 IMAGERY USING OBJECT-BASED IMAGE ANALYSIS

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Chairman : Associate Professor Helmi Zulhaidi bin Mohd Shafri, PhD
Faculty : Engineering

Roof materials and roof surface conditions are the main factors that contribute to the determination of rooftop rainwater harvesting (RRWH) quality and quantity in an urban area. Therefore, these factors are required to be analyzed effectively. According to the previous study, the types of different roof materials and roof surface conditions that affected by aging and weathering effects, contribute to the spectral response variability of these features. Even though multispectral images have been used to map the roofing types previously, the characterization of roof surface conditions remains limited because of spectral, spatial, and textural limitations.

To overcome such challenges, this study attempts to comprehend and improve the remote sensing technology for rooftop classification using the Worldview-3 (WV-3) image and object-based image analysis (OBIA) method. The improvement process involved segmentation, feature selection and classification techniques.

A spatio-statistical optimization technique that combines the Taguchi statistical method and a spatial plateau objective function (POF) was presented to improve the segmentation procedures for building footprint extraction. The optimal scale, shape and compactness parameters of multi-resolution segmentation have been determined and the detection accuracy was evaluated based on receiver operating characteristics (ROC). The result shows the area under the ROC curve (AUC) of 0.804 with $p <$ 0.0001 at 95% confidence level.

Furthermore, a systematic feature selection approach was proposed in which search algorithms (Ant-Search, Best First-Search and Particle Swamp Optimization (PSO) - Search) performance were evaluated to select the most significant features. The

accuracy of each algorithm was evaluated using LibSVM, Bayes network, and Adaboost classifier. The result presents that the Ant-Search algorithm via LibSVM was determined as the best combination with 100% accuracy.

The accuracy of classification result using OBIA is insufficient to depend on the segmentation parameters, the selection of features, and the existence of spectrally mixed objects. An analysis of the choice of classification techniques is also required. Therefore, the LiDAR derived data were combined with WV-3 image using different fusion methods such as layer stacking (LS), Gram–Schmidt (GS), and PC spectral sharpening (PCSS). Then, the classifier (support vector machine (SVM) and data mining (DM) algorithm, decision tree (DT) were applied on each fusion image and their accuracy were evaluated. Generally, the generated DT classification presents a higher overall accuracy with 87%, 72%, and 66% for LS, GS, and PC Pan-Sharpening (PCSS), respectively. Meanwhile, the DT classification using the LS approach produced the highest overall accuracy of 87% and a kappa coefficient of 0.80.

Overall, this study offers new insights into remote sensing urban applications, specifically for roof-based mapping through the development of systematic improvement approach using OBIA. Interestingly, the degradation status of the roof in heterogenous urban environments can be determined and the quality of roof-based harvested rainwater affected by roofing materials and roofing conditions can be analyzed effectively.

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

PENAMBAHBAIKAN TEKNIK PENGELASAN BUMBUNG IMEJ WORLDVIEW-3 MENGGUNAKAN ANALISIS IMEJ BERASASKAN OBJEK

Oleh

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Bahan bumbung dan keadaan permukaan bumbung adalah faktor utama yang menyumbang kepada penentuan kualiti dan kuantiti penuaian air hujan di aras bumbung di kawasan bandar. Oleh itu, faktor-faktor ini diperlukan untuk dianalisis dengan berkesan. Mengikut kajian terdahulu, jenis bahan bumbung yang berbeza dan keadaan permukaan bumbung yang terjejas oleh kesan penuaan dan cuaca, menyumbang kepada kebolehubahan tindak balas spektrum ciri-ciri ini. Walaupun imej multispektral telah digunakan untuk memetakan jenis bumbung sebelum ini, pencirian keadaan permukaan bumbung masih terhad kerana batasan spektral, ruang dan tekstur.

Untuk mengatasi cabaran-cabaran sedemikian, kajian ini cuba memahami dan memperbaiki teknologi penginderaan jauh untuk pengelasan bumbung menggunakan imej Worldview-3 (WV-3) dan kaedah analisis imej berdasarkan objek (OBIA). Proses penambahbaikan melibatkan segmentasi, pemilihan ciri-ciri pengelasan yang sesuai dan teknik klasifikasi.

Teknik pengoptimuman spatio-statistik yang menggabungkan kaedah statistik Taguchi dan fungsi objektif dataran tinggi (POF) telah dipersembahkan untuk memperbaiki prosedur segmentasi bagi membina pengekstrakan tapak. Skala optimum, bentuk dan kepadatan parameter bagi segmen kepelbagaian resolusi telah ditentukan dan ketepatan pengesanan dinilai berdasarkan ciri-ciri operasi penerima (ROC). Hasilnya menunjukkan kawasan di bawah lengkok ROC (AUC) 0.804 dengan $p < 0.0001$ pada tahap keyakinan 95%.

Tambahan pula, pendekatan pemilihan ciri yang sistematik dicadangkan di mana algoritma carian (Pencarian-Ant, Pencarian-Best-First dan Pencarian-Partical Swamp Optimization (PSO)) dinilai untuk memilih ciri-ciri yang paling penting. Ketepatan setiap algoritma telah dinilai menggunakan LibSVM, rangkaian Bayes, dan pengelas Adaboost. Hasilnya menunjukkan bahawa algoritma Pencarian-Ant melalui LibSVM ditentukan sebagai gabungan terbaik dengan ketepatan 100%.

Ketepatan hasil klasifikasi menggunakan OBIA tidak mencukupi untuk bergantung pada parameter segmentasi, pemilihan ciri, dan keberadaan objek bercampur spektrum. Analisis pilihan teknik klasifikasi juga diperlukan. Oleh itu, data yang diperolehi daripada LiDAR telah digabungkan dengan imej WV-3 menggunakan kaedah gabungan yang berbeza seperti lapisan susun atur (LS), Gram-Schmidt (GS), dan PC spectral sharpening (PCSS). Kemudian, klasifikasi sokongan vektor mesin (SVM) dan algoritma perlombongan data (DM), keputusan pokok (DT) telah diaplikasi pada setiap imej gabungan dan ketepatan mereka dinilai. Secara umumnya, klasifikasi DT menghasilkan ketepatan keseluruhan yang lebih tinggi dengan 87%, 72%, dan 66% untuk LS, GS, dan PCSS. Sementara itu, klasifikasi DT menggunakan pendekatan LS menghasilkan ketepatan keseluruhan tertinggi 87% dan pekali kappa 0.80.

Secara keseluruhannya, kajian ini memberikan pandangan baru dalam aplikasi bandar penderiaan jarak jauh, khususnya untuk pemetaan berasaskan bumbung melalui pembangunan pendekatan peningkatan sistematik menggunakan OBIA. Menariknya, status degradasi bumbung di persekitaran bandar heterogen boleh ditentukan dan kualiti air hujan menuai berasaskan bumbung yang terjejas oleh bahan bumbung dan keadaan bumbung boleh dianalisis dengan berkesan.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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LIST OF ABBREVIATIONS

ABACO	Advanced BACO
AFI	User's coefficient
ANN	Artificial neural networks
AUC	Area under the ROC curve
BACO	Binary coded ant colony optimization
BDE	Binary coded differential evolution
BPSO	Binary coded particle swarm optimization
CFS	Correlation feature selection
CNN	Convolution neural network
D	Index combining US and OS
DID	Department of irrigation and drainage
DM	Data mining
DSM	Digital surface model
DT	Decision tree
DTM	Digital terrain model
FCBF	Fast correlation-based filter
GA	Genetic algorithm
GIS	Geographical information system
GPS	Global positioning system
GR	Gain ratio
GS	Gram-Schmidt
HRW	Harvested rainwater
IMUs	Inertial measurement units
KNN	K- nearest neighbor algorithm

LiDAR	Light detection and ranging
LS	Layer stacking
LSLB	Large scale with larger-is-better
LSSB	Large scale with smaller-is-better
LULC	Land use land cover
MBACO	Modified binary coded ant colony optimization algorithm
ML	Machine learning
mRMR	Minimum redundancy maximum relevance
MRS	Multi-resolution
NDCCI	Normalized difference concrete condition index
NDMCI	Normalized difference metal condition index
nDSM	Normalized digital surface model
OA	Overall accuracy
OBIA	Object-based image analysis
OS	Over-segmentation
PA	Producer accuracy
PCSS	Spectral pc sharpening
PMBACO	Pheromone density model
POF	Plateau objective function
PSO	Particle swarm optimization
QR	Quality rate
RF	Random forest
ROC	Receiver operating characteristics
RRWH	Rooftop rainwater harvesting
SAM	Spectral angle mapper
SAR	Synthetic aperture radar

SNR	Signal-to-noise ratios
SSLB	Small scale with larger-is-better
SSSB	Small scale with smaller-is-better
SVM	Support vector machines
SWIR	Short-waved infrared imagery
UAV	Unmanned aerial vehicle
UC	User’s coefficient
US	Under-segmentation
VHR	Very high resolution
VMBACO	Visibility density model
WV-2	Worldview-2
WV-3	Worldview-3

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

This study is motivated by the development of rooftop rainwater harvesting (RRWH) system, one of the water sources in urban areas. The implementation of the system requires some improvement in terms of the roof detection techniques to ensure the selected roof of the building is appropriate regarding the quality and quantity of the rainwater harvesting. Therefore, the basic techniques for roof classification have been optimized for obtaining detailed roof classification with high accuracy.

Water is the most important natural resources for human and it covers 70% of the earth's surface. However, water scarcity is a worldwide problem due to enormous amounts of demand for personal and industrial uses. In some African and Asian countries, such as South Africa, Algeria, Saudi Arabia, India, Pakistan, Iran, and Iraq, it is estimated that more than 40% of the water available will be withdrawn by the year in focus. Meanwhile, for the United States of America, Sudan, and China, it is estimated that water withdrawal will be at 20% (UN-HABITAT, 2003). This will invariably result in difficulty for these countries in supplying the needed quantity of water to fulfill basic societal needs or ensure equal access to water. Currently, drinking water is becoming contaminated due to the pollution of fresh water sources. This phenomenon caused a limitation of water sources.

Accordingly, rainwater harvesting technology was introduced and it has been practiced for more than four thousand years (UN-HABITAT, 2003). Later, it becomes a popular means of conserving potable water and develop a sustainable water cycle particularly in an urban area (Zhang et al., 2014). Interestingly, the technique of rainwater harvesting involves the collection, storage, and subsequent use of rainwater for domestic, industrial, and livelihood activities, such as irrigation, vehicle washing, toilet flushing, and other non-potable (nondrinking) uses of water.

Nowadays, the rainwater harvesting system in an urban area is improved by introducing RRWH system. It is because roofs represent approximately half of the total sealed surface in urban and roofs are suitable as a catchment area for rainwater (Ugai, 2016). Nevertheless, previous study (Zhang et al., 2014; Huston et al., 2011; Farreny et al.; 2011) stated that several factors have been recognized as the main contributor to the determination of RRWH quality, such as roofing materials, roofing conditions, roofing geometry, weather conditions, and land use/land cover (LULC) conditions. Therefore, a comprehensive analyzation is required in order to evaluate the impact of above-mentioned factors on RRWH quality.

This research determines the research gaps in the use of remote sensing technology in discriminating roof materials and roof surface conditions for estimating RRWH quality and quantity for future research. An approach for the technique's improvement in image segmentation, feature selection, and classification was proposed.

Remote sensing technology provides the opportunity to obtain data from an urban surface without direct contact with the features (Kadhim et al., 2016). This technology is also considered as an alternative approach instead of traditional field survey. The ability and development of very high resolution (VHR) sensors have opened a new prospect in the remote sensing community to monitor imperviousness and natural features effectively at the fine and detailed scale. Nowadays, detail and small sizes of land cover such as the roof of buildings, buildings, and pavements are possible to identify due to the advancement in sensor technology from QuickBird, Worldview 2 (WV-2), and WV-3 images (Hamedianfar & Shafri, 2015).

Remote sensing and GIS have been widely used in urban environmental analysis (Hari et al., 2018; Gaikwad, 2015; Lee et al., 2012). However, these technologies have never been used to analyze, map, and model the effect of various factors on harvested rainwater quality. Thus, the application of geospatial technologies in estimating harvested rainwater quality and assessment of rooftop harvested rainwater can be proposed with the integration of remote sensing and GIS approach.

Remote sensing technique is useful in extracting various determinants of harvested rainwater quality. Such information can then be compiled, mapped, and modelled in GIS to generate a spatial model. The resulting map and model can help to identify potential rainwater harvesting sites and model predicted quality over large areas (Dadhich & Mathur, 2016). Besides, information from the maps can be used to identify suitable sites for RRWH. Furthermore, the information on various characteristics of roofs can be explored further and the GIS model can simulate harvested rainwater quality.

These results have an important significance for local governments and urban planners in the design and planning of cities. Redesigning the building and cities is very important for sustainable rainwater management. The information related to the roof such as roof slope and roughness in city planning will be useful to promote rainwater as an alternative water supply while preventing flooding and water scarcity.

Additionally, RRWH strategies are part of storm water management in Malaysia, which conducted by Department of Irrigation and Drainage (DID) (Lani et al., 2018). This approach helps the nation in managing water quantity and quality control. In line with the National Storm Water Management goal, storm water shall be managed so that it contributes towards sustainable development of the country. Although this study examined the effect of roofing material on harvested rainwater quality specifically in Malaysia, but it might be more useful for other countries because roofing materials, coatings, and building practices are almost similar globally.

Therefore, in this study, VHR multispectral WV-3 image and LiDAR data were utilized to classify roof in an urban area. This study is focusing on RRWH system due to its capability to provide more opportunity for collecting water from a larger surface area, besides building rooftops is the most important land cover types. Consequently, it is compulsory to extract the building footprint prior to roofing information to identify and discriminate buildings from other land cover classes. Hence, a spatio-statistical optimization technique for building footprint extraction with a high level of accuracy from the image that will allow future work to focus on distinguishing different roof materials have been developed, to produce segmentation with optimal parameters due to the sensitivity of image objects and their spatial relationship. Optimum parameters which consist of scale, shape, and compactness for suitable segmentation is desired for accurate building identification because the quality of segmentation will influence the classification accuracy.

Nevertheless, using only spectral information could not be helpful to alleviate the classification errors due to the spectral similarity of impervious surfaces. Shape and texture attributes play an important role as well to discriminate different classes and alleviate the lack of using spatial information. For object-oriented classification, usually it will combine spectral information with spatial and texture information to overcome problems associated with traditional per-pixel classifiers resulting in supervised approach or knowledge-based rule-sets to extract specific features from VHR satellite image (Zhou & Troy, 2008). Accordingly, accurate feature selection is also required instead of segmentation quality, to improve the accuracy of roof materials classification, which is known as the main factor of harvested rainwater quality. Only the most important feature will be selected by using GR algorithm, and thus the computing requirements can be minimized, while the quality of a subset of features were measured using CFS.

Apart from optimal segmentation and feature selection, a systematic classification approach also has an impact on the characterization of roof materials and roof surface conditions. In this study, roof surface conditions are categorized as new and old roof. Optimization of different fusion methods (LS, GS, and PCSS) yielded information of maximum benefit of using WV-3 data and LiDAR height information in classifying roof materials and roof surface conditions.

The capability of remote sensing in detecting roofing materials and surface conditions is extensively explained by passive and active remote sensing. Characterization of roof surface conditions whether the new or old roof condition affects the quality of harvested rainwater. Noteworthy that, acquiring roof surface conditions also depends on the capability of different classification and object identification algorithms. Besides, fusion and classification are important techniques in feature extraction from remotely sensed data, which optimization of various fusion method (LS, GS, and PCSS) produced the information of maximum benefit of using WV-3 data and LiDAR derived images: digital terrain model (DTM), digital surface model (DSM), normalized digital surface model (nDSM), slope, and intensity information. Next, an appropriate and suitable classification classifier provides a reliable roof materials and roof surface conditions map with high accuracy. Additionally, by employing DM classifier, numerous spatial, spectral, and textural attributes were explored and suitable rule-sets were provided.

The novelty of the entire study is related to the fundamental steps in the production of roof material and roof surface conditions map with high classification accuracy. The optimization approaches which consist of segmentation, feature selection, and classification process can be developed systematically, and processing time can be reduced. Besides, the feature selection technique to solve the roof materials and roof surface conditions classification separability problem has also been enhanced. In addition, by employing an optimal fusion method and DM classifier, numerous spatial, spectral, and textural attributes were explored and suitable rule-sets were provided.

1.2 Problem Statement

Roofing materials, roofing surface conditions, roofing geometry, weather conditions, and LULC conditions are identified as main factors that can significantly affect the quality of RRWH. Nevertheless, roofing materials and roofing age (surface conditions) have been categorized as factors that become priorities in RRWH quality study, considering that almost every year the research is made on that factor. Figure 1.1 demonstrated the frequency of studies based on a factor which affected RRWH quality. It is obviously indicated that roofing materials and roofing surface conditions have a high number of studies in 2012, 2014 and 2015. Thus, the effects of these factors on RRWH quality must be analyzed accordingly and it is significant to present the results obtained in the form of spatial data compared to tabular data. The spatial data are able to convey the RRWH quality information quickly and effectively.

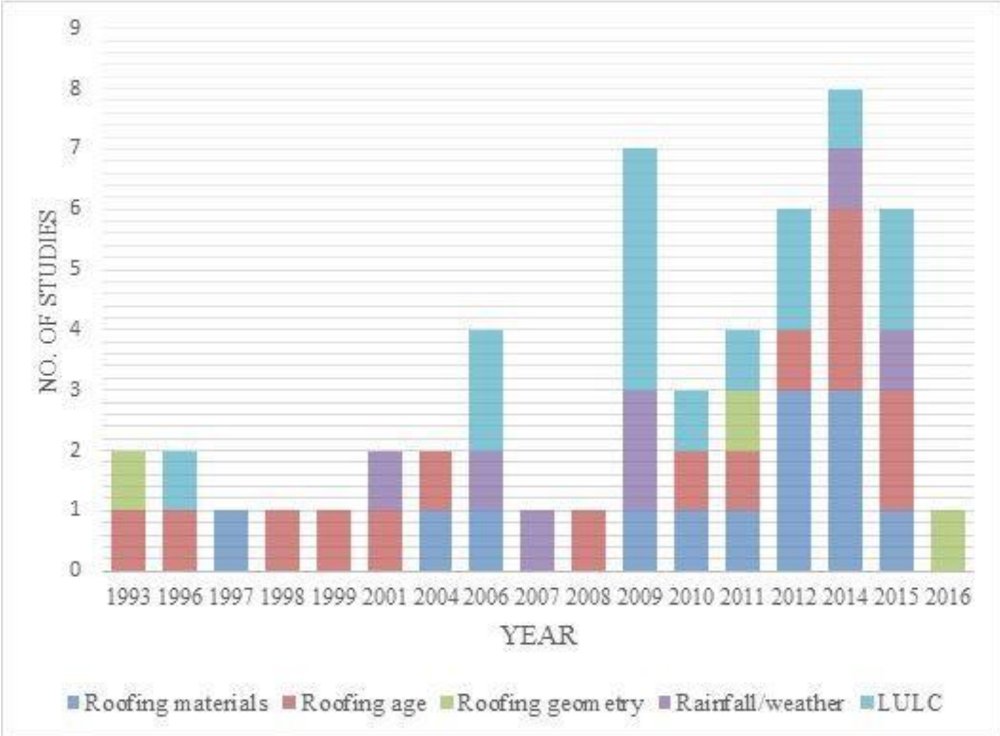

Figure 1.1 : Frequency of Studies Based on a Factor which Affected RRWH Quality

Segmentation process in building footprint extraction using object-based image analysis (OBIA) is crucial due to several factors, such as the spatial and spectral resolution of remote sensing images and the complexity of geo-objects. Consequently, the selection of suitable parameters to ensure the best segmentation quality remains a challenge. Although OBIA has been accepted as a standard remote sensing technique for feature extraction (Sameen & Pradhan, 2017; Ma et al., 2017; Wan et al., 2016), the extraction of buildings using satellite imagery is time-consuming and costly (Gavankar & Ghosh, 2018). In addition, misclassification remains a concern in buildings classification considering that classification accuracy is directly dependent upon the segmentation quality, which is controlled by the fitness of the defined parameters (Martha et al., 2011). Though the development of segmentation algorithms is continuously advancing, the segmentation process remains challenging (Arvor et al., 2013) due to its sensitivity to the characteristics of digital images, such as image resolution and scene density (Dragut et al., 2014). This study attempts to improve the segmentation quality by controlling the fitness of scale, shape and compactness and select the ideal parameter.

Feature selection is an important step when improving the accuracy and efficiency of classification and features attributes selection depends on the number of feature attributes obtainable for the interactive synthesis of common characteristics that differentiate different features. The high number of features also complicates the construction of a classifier and it leads to the curse of dimensionality or Hughes phenomenon (Pal & Foody, 2010). Feature analysis based on pixels is performed more frequently compared to OBIA (Novack et al., 2011). There have been no previous evaluations on the performance of these methods with OBIA, except a comparison of three unrepresentative feature selection methods reported by (Laliberte et al., 2012). Notable that, optimal and suitable features attributes are required to produce roof materials and roof surface conditions classification with high precision. Therefore, systematic strategies for efficient feature selection technique should be considered.

Building tops in an urban area do not have similar shape, size, and texture. However, these buildings have certain common characteristics, such as, their bright appearance and high contrast to the surrounding features. Additionally, few building rooftops revealing similar reflectance value to that of the road and other surrounding features in the image which causes difficulty in discriminating between them. Extracting features from images acquired using different sensors are not only dependent upon the sensor characteristics, but to a greater extent on the capability of different classification and object identification algorithms (Lu et al., 2007). However, fusion does not really translate to better accuracy over using optical sensor alone. Therefore, satellite image and LiDAR data fusion are shown to provide greater classification accuracy than using either data type alone.

1.3 Research Objectives

In general, the main objective of this study is to improve the detection of roof materials and roof surface conditions approach using OBIA.

Meanwhile, the specific objectives of this research are as follows:

1. To improve image segmentation procedure for detailed building and rooftop information extraction from high-resolution remote sensing data.
2. To propose a systematic feature selection techniques of roof materials using feature selection algorithms.
3. To improve the classification technique by exploring the capability of different fusion methods and classifiers algorithms to discriminate roof materials and roof surface conditions.

1.4 Scope and Limitation of the Study

This study aims to classify detailed roofing information at material and surface conditions level, according to optimization approaches of segmentation, feature selection, and classification. Roof materials only consider metal, concrete, and asbestos, since these roof types are the most common in the study area and suitable for harvested rainwater applications. The optimal combination of segmentation parameters: scale, shape, and compactness were developed via a spatio-statistical optimization technique that combines the Taguchi statistical method and a POF to extract building footprint from high-resolution WV-3 satellite data. This proposed technique is required to ensure segmentation quality. The optimization process is only considering scale, shape, and compactness parameters since multi-resolution (MRS) segmentation in eCognition is only considering those parameters as an algorithm.

WV-3 image and LiDAR derived images such as DTM, DSM, nDSM, slope, and intensity were combined separately to enhance the visualization for image analysis purposes. A systematic feature selection technique was generated, whereby the most suitable attributes that represent spatial, shape, and texture to identify different roofing materials and their surface conditions were provided. For this study, not all features in the higher ranking were imported into the optimal feature subset. Only features that have a lower correlation with features that were preferable will be considered.

Enhancement of the classification result was performed by the fusion of WV-3 and LiDAR data. Roof surface conditions (old or new roof) were considered. For this study, only roof materials and roof surface conditions discriminations were tested, particularly on the tested area, because if other landcover types were tested, the data will be massive. Furthermore, the main objective of the research is to extract detailed building information specifically for RRWH system applications.

1.5 Organization of the Chapters

The second chapter provides the overview of remote sensing techniques to discriminate and map detailed roof materials and roof surface conditions classes in urban area, which later can be utilized in assessing water quality and water quantity for RRWH system. This chapter also discusses the importance of RRWH, the factors determined for harvested rainwater quality, the applications of remote sensing technology in roof material mapping, and the process involved to accomplish the classification. The gaps in the research are also discussed in the last part of the chapter.

The third chapter provides the materials and methods utilized to ensure the objectives of this research are achievable. The first section of this chapter discusses the overall methodologies involved in the optimization approaches development using WV-3 and LiDAR data, including their characteristics, spatio-statistical optimization of image segmentation, optimal feature attributes selection, and identification of roof materials and roof surface conditions using different classification techniques. The last part of this chapter discusses on hyperspectral data analysis using OBIA to obtain roof materials and roof surface conditions information.

The fourth chapter presents the results and discussion of the study. The results and discussion including the optimal combination of segmentation parameters used to segment WV-3 image, the most suitable features attributes utilized for roof materials classification, and the improvement of the OBIA result when LiDAR derived images, the selected fusion method algorithms, and the classification classifier were applied for roof materials and roof surface conditions discriminations. The last section of this chapter discusses the application of proposed techniques on roof materials and roof surface conditions applications for RRWH quality assessment.

The fifth chapter discusses the conclusion and recommendations for future research. The overview and benefits from the findings of this research are discussed. Lastly, the future research direction and application are explained in the last section of this chapter.

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