UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A NEW TECHNIQUE FOR ROAD EXTRACTION AND PAVEMENT SURFACE CONDITION MAPPING AT PRIMARY LEVEL USING WORLDVIEW-2 SATELLITE IMAGERY

KAVEH SHAHI

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By

KAVEH SHAHI

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

February 2017

In The Name of Allah

This thesis is dedicated to my parents

Haj Ahmad and Noushin Shahi

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

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

Road networks and their conditions hold fundamental meaning in development. Given the importance of these factors, accurate and comprehensive information on the condition of road infrastructures is necessary for effective pavement management, social network, and global economy.

The main objective of this study is to develop a new spectral index for road detection and new technique for mapping road conditions. Field spectral data were collected using field spectrometer to determine the best bands on WorldView-2 (WV-2). The bands were selected based on significant wavelengths from visible and near-infrared to develop a new spectral index for extracting road networks, namely, road extraction index (REI). The accuracy of in the two classes of roads, namely, roads and non-roads, were 88% and 86%, respectively. These roads were extracted using REI from the two selected areas. Nevertheless, the proposed method has limitation in extracting several asphalt roads covered by trees or shadow. A novel spectral index that can detect shadows, namely, shadow detection index (SDI), was developed to improve REI. Two road extraction test areas are conducted on WV-2 to evaluate the propose method. SDI results were used to detect and remove shadow from WV-2 images and improve the accuracy of road extraction. Results show that the accuracy of REI increased up to 5% in the main and validation areas from 90.75% and 91.80% to 95.15% and 95.10%.

Another main objective of this research is to extract road conditions using object-based image analysis (OBIA) and feature selection technique. Three different methods for feature selection, such as chi-square (CHI), random forest (RF), and support vector machine (SVM), were used. Results show that CHI, RF, and SVM respectively extracted 19, 17, and 20 out of 54 attributes of asphalt road condition using WV-2 satellite data. Results show that the accuracy of RF (71.06%) and SVM (75.75%) are less than the accuracy of CHI method at 83.79% in two different classes (i.e., High

deterioration detected and Low deterioration detected). Finally, the CHI method is used to extract road conditions in seven study areas because this method, which has an accuracy of up to 91%, can potentially detect road conditions in different study areas using high-resolution images such as WV-2 in the primary level.

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

PEMBANGUNAN TEKNIK BARU UNTUK PENGEKSTRAKAN JALAN DAN KAKI LIMA PERMUKAAN KEADAAN PEMETAAN DI PERINGKAT SEKOLAH RENDAH MENGGUNAKAN WORLDVIEW-2 IMEJAN SATELIT

Oleh

KAVEH SHAHI

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Pengerusi : Profesor Madya Helmi Zulhaidi Mohd Shafri, PhD
Fakuti : Kejuruteraan

Rangkaian jalan raya dan keadaan mereka memegang makna asas dalam pembangunan. Memandangkan kepentingan faktor-faktor ini, maklumat yang tepat dan menyeluruh kepada keadaan infrastruktur jalan raya adalah perlu bagi pengurusan yang berkesan turapan, pembangunan sosial, dan ekonomi global.

Objektif utama kajian ini adalah untuk membangunkan indeks spektrum baru untuk mengesan jalan dan teknik baru untuk keadaan jalan pemetaan. data spektrum Field telah dikumpulkan menggunakan medan spektrometer untuk menentukan band terbaik WorldView-2 (WV-2). The band dipilih berdasarkan panjang gelombang yang besar daripada yang boleh dilihat dan dekat inframerah untuk membangunkan indeks spektrum baru untuk mengeluarkan rangkaian jalan raya, iaitu, indeks pengekstrakan jalan (REI). Ketepatan dua kelas jalan raya, iaitu, jalan raya dan bukan jalan raya, masing-masing 88% dan 86%. Jalan-jalan ini telah diekstrak menggunakan REI dari kedua-dua kawasan terpilih. Walau bagaimanapun, kaedah yang dicadangkan mempunyai had dalam mendapatkan beberapa jalan asfalt dilindungi oleh pokok-pokok atau bayang-bayang. A indeks spektrum novel yang boleh mengesan bayang-bayang, iaitu bayangan indeks pengesanan (SDI), telah dibangunkan untuk meningkatkan REI. Dua kawasan ujian pengekstrakan jalan raya yang dijalankan ke atas WV-2 untuk menilai kaedah yang mencadangkan. keputusan SDI telah digunakan untuk mengesan dan menghapuskan bayang-bayang dari WV-2 imej dan meningkatkan ketepatan pengekstrakan jalan raya. Keputusan menunjukkan bahawa ketepatan REI meningkat sehingga 5% di kawasan-kawasan utama dan pengesahan dari 90,75% dan 91,80% kepada 95,15% dan 95,10%.

Satu lagi objektif utama kajian ini adalah untuk mengeluarkan keadaan jalan raya yang menggunakan analisis berdasarkan objek-imej (OBIA) dan teknik pemilihan ciri. Tiga kaedah yang berbeza untuk pilihan ciri, seperti chi-square (CHI), hutan rawak (RF),

dan mesin sokongan vektor (SVM), telah digunakan. Keputusan menunjukkan bahawa CHI, RF, dan masing-masing SVM diekstrak 19, 17, dan 20 daripada 54 sifat-sifat keadaan jalan asfalt menggunakan WV-2 data satelit. Keputusan menunjukkan bahawa ketepatan RF (71,06%) dan SVM (75,75%) adalah kurang daripada ketepatan kaedah CHI pada 83,79% dalam dua kelas yang berbeza (iaitu, kemerosotan dikesan dan tiada kemerosotan dikesan). Akhir sekali, kaedah CHI yang digunakan untuk mengekstrak keadaan jalan raya di lima kawasan kajian kerana kaedah ini, yang mempunyai ketepatan sehingga 91%, yang berpotensi boleh mengesan keadaan jalan raya di kawasan kajian yang berbeza dengan menggunakan imej resolusi tinggi seperti WV-2 di peringkat rendah.

ACKNOWLEDGEMENTS

Though only my name appears on the cover of this thesis, a great many people have contributed to its production. I owe my gratitude to all those people who have made this thesis possible and because of whom my graduate experience has been one that I will cherish forever.

Firstly, I would like to express my sincere gratitude to my advisor Associate. Prof. Dr. Helmi Zulhaidi bin Mohd Shafri for the continuous support of my PhD study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my PhD study.

Special thanks are also extended to my committee member, Professor Dato' Dr. Shattri Mansor and Professor Dr. Ratnasamy Muniandy.

Many friends have helped me stay sane through these difficult years. Their support and care helped me overcome setbacks and stay focused on my graduate study. I greatly value their friendship: Ebrahim Taherzadeh, Dato' Ieman Shahi, Shahab Sabghi, Mahmud Ajel Loo, Dr. Pejman Hafez, Mohammad Sadeghi, Mojtaba Naghavian, Kamran Hosseinzadeh, Alireza Hamendianfar, Maryam Mazlomian, Reza Pishva, Keivan Kabiri and all my friends who helped me for their moral support during my study.

I am pleased to extend my gratitude to my uncle, Haj Mahmoud and my cousin Amir for his financial support and interest in my progress.

I must express my gratitude to my lovely wife Razieh Shojanoori, for her support and encouragement, quiet patience and unwavering love were undeniably the bedrock upon which the past few years of my life have been built.

Finally, I owe my success to my parents, Haj Ahmad and my mother Noushin and my brothers, Kamran, Kamyar, Kiarash and who have been helping me during my stay away from home, thanks for your patience, moral support and encouragement.

This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfillment of 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:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate studies) Rules 2003 (Revision 2012-2013) were adhered to.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation
ASD	Analytical Spectral Device
ARAN	Automatic Road analyzer
ANN	Artificial Neural Network
BPN	Back Propagation Network
BAI	Built-up Area Index
CHI	Chi-Square
CASI	Compact Airborne Spectrographic Imager
CSNN	Constraint Satisfaction Neural Network
DA	Discriminate Analysis
DSM	Dominant Singular Measure
GNL	General Public License
GIS	Geographic Information System
GPS	Global Positioning System
HSR	High Spatial Resolution
IG	Information Gain
IS	Impervious Surface
IRI	International Roughens Index
KL	Kuala Lumpur
MM	Mathematical Morphology
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
NN	Neural Network
OB	Object-Based
OBIA	Object-Based Images Analysis
PCI	Pavement Condition Index
PCR	Pavement Condition Rating
PSVM	Probabilistic Support Vector Machines
RBF	Radial Basis Function
RF	Random Forest
ROI	Region Of Interest

RS	Remote Sensing
REI	Road Extraction Index
SDI	Shadow Detection Index
SVM	Support Vector Machine
SVM–RFE	SVM Recursive Feature Elimination
SAM	Spectral Angle Mapper
SI	Structural Index
TS	Tern Strength
UPM	Universiti Putra Malaysia
UAVs	Unmanned Aerial Vehicles
VHR	Very High Resolution
WV-2	WorldView-2
WV-3	WorldView-3

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Urban areas are categorized by an extensive difference of natural and artificial surface materials that effect the ecology (Arnold Jr and Gibbons, 1996), energy condition, and climate (Oke, 2002). The United Nations reported that the world population will increase and live in cities, from 30% in 1950 to 60% by 2030 (Rajeswari et al., 2011). Given the quick development and growth of cities, several new approaches to update the database are necessary, which will replace the traditional method that is typically implemented by visual interpretation of aerial photographs and field investigation.

Remote sensing (RS) is renowned as a beneficial tool for extracting urban features, and its use has been increasing in recent years. However, road extraction and condition mapping are still a challenging RS application. Information on road network is also important in urban planning, transportation engineering, and social network. Thus, updating and ensuring the accuracy of information are important (Rajeswari et al., 2011). Given the rapid technological development of very high-resolution (VHR) satellite sensors in the past decades, greater spectral, spatial, and temporal characteristics can be used for urban mapping applications (Kavzoglu et al., 2009; Ma et al., 2013; Wang et al., 2014). Therefore, optimal methods should be designed to efficiently provide updated and cost-effective maps (Hamedianfar et al., 2014).

Impervious surfaces (IS), such as sidewalks, rooftops, parking lots, roads, etc., have been known as important components of urban environmental conditions (Conway, 2007; Hu and Weng, 2009) and are identified for their entireness features, that is, water cannot pierce into the soil (Arnold Jr and Gibbons, 1996). Hence, the detection and assessment of IS, such as roads, are important and challenging tasks in urban RS; this field of study has been expanding as well (Wang and Zhang, 2004).

The current study proposes the detection of IS, particularly road based on extraction and condition, using multispectral RS data. Detection of road condition is important because roads have been the basis for transportation planning and management; road structure is also among the most critical elements for road safety and often affects the quality of life (Mohammadi, 2011; Wang et al., 2008). Hence, road networks should be constantly repaired and maintained to reduce mishaps; however, repair and maintenance are highly expensive, time consuming, and labor intensive (Mohammadi, 2011; Schnebele et al., 2015). Given that concerns on pavement type condition and road surface material are essential in urban areas to retrieve road information, road network information can be obtained either through traditional surveying or RS technology (Zhang and Couloigner, 2004).

RS plays a significant role in providing information on the spatial distribution of IS in urban areas because traditional methods, which are generally based on field survey, are highly time consuming and costly. However, data collection in several segments of roads and highways is a highly difficult task, although the road can be surveyed using a Roadware Aran survey vehicle (Herold and Roberts, 2005b). Nevertheless, RS images provide a synoptic view of land cover, which is highly significant (Bhatta, 2009; Griffiths et al., 2010).

Generally, road extraction is divided into semi- and fully automatic approaches, which are critical and challenging tasks in urban RS because of the necessity to update the GIS database. Accordingly, developing fully automated algorithms to determine road network information is difficult (Chaudhuri et al., 2012; Tupin et al., 2002). However, all existing indices are based on Landsat TM or SPOT imageries (He et al., 2010; Varshney, 2013; Xu, 2008). Thus, detecting and extracting urban land cover, particularly roads, require VHR imagery (Zhou and Troy, 2008).

Several studies have been conducted to extract the road network from high spatial satellite imagery. Maboudi et al., 2016 used a multi-stage approach to create novel linearity index for road networks extraction from VHR satellite images. however the accuracy of the extraction was high, nonetheless; it require different information such as spatial, spectral and texture and furthermore the result is depend on segmentation scale level. As a result this approach is complex and not fast and commercialize. Some study applied morphology approach to extract road from VHR such as Chinnathevar, S. and Dharmar, S. 2016. These researchers used morphology approach but it should be mentioned the results are depend on type and size of structure of elements that will be used for extraction and directly effect to the final result.

With advent of very high spatial satellite remote sensing data such as WorldView-2 (WV-2), which contain eight spectral bands, road network can be extracted (Digital-Globe, 2009). Several indices have been developed for built-up areas; however, a lack of a suitable asphalt road extraction index as well as an automated method for road detection and extraction from WV-2 imagery is still a major setback.

Shadow is also one of the main sources of misclassification in high-resolution imagery (Saha et al., 2005); therefore, a new spectral index for shadow detection was developed to avoid the effect of the shadow on the results of road extraction index, as well as enhance the spectral index in terms of visual interpretation and accuracy assessment.

In terms of road condition mapping, several traditional road assessment methods determine the road condition through visual examination (Tiong et al., 2012). However, recent approaches on road condition are based on in situ observation, and use indices, namely, structural index (SI) , pavement condition index (PCI) and the International Roughness Index (IRI), (Kavzoglu et al., 2009). In addition, in recent years for evaluation of road condition road scanner with high-speed motion video camera, laser and ultrasonic sensor is available to collect a range of data about the geometry and information for evaluating the amount of crack and surface deformation of road.

Road conditions can be recognized using hyperspectral imagery at less cost compared to a field survey, recently several attempts have been completed to develop an automatic procedure for extracting road information using remotely sensed hyperspectral data (Bacher and Mayer, 2005; Kirthika and Mookambiga, 2011; Mohammadi, 2011). Thus, a few studies have been conducted to demonstrate the potential of hyperspectral data for spectral identification and detecting urban surface material (Ben-Dor et al., 2001; Herold et al., 2004). These types of data are able to detect the material better than traditional multispectral imagery because of high spectral resolution. Despite such potential, several limitations to the acquisition of hyperspectral data result from the inadequacy of coverage and high cost of collecting hyperspectral data; analyzing such data is also highly complex compared with multispectral imagery (Shafri et al., 2012).

In the current research, two types of data were employed: ASD hand-held spectroradiometer, which detects reflectance within the wavelength range of 350–2500 nm to select and discriminate the best bands to develop a novel spectral index; and multispectral data to detect the road condition over wide area. Therefore, the WV–2 VHR imagery was used because it can extract road network information. Unlike other commercial satellites, the WV–2 satellite imagery comprises eight bands with high spatial resolution. Moreover, WV–2 can be highly beneficial in extracting information more effectively than other high spatial resolution imagery because of the former's new bands. However, several studies used Landsat or SPOT images, although the low spatial resolution of these types of data is unsuitable for urban areas (He et al., 2010; Sheng et al., 2013). In addition, high spatial resolution satellites, such as IKONOS and QuickBird, have been significantly used for extracting IS in urban areas (Lu and Weng, 2009; Wu, 2009). However, these satellites are limited in their spectral resolution and several misclassifications still occur in the process of discriminating and classifying different materials (Herold et al., 2002).

The literature focuses on the traditional RS classification, such as supervised classification, because only spectral information is used, which could not be highly effective owing to the spectral similarity of different urban land covers or sharing the similar or having same spectral responses (Chen et al., 2004; Myint et al., 2011). Therefore, many researchers have used object-based image analysis (OBIA) to classify pixels appropriately to overcome the problem (Elsharkawy et al., 2012). Given that spatial information can be useful for discriminating between different classes in classification tasks (Dalla Mura et al., 2010), such information should be integrated with high spatial and spectral information, as well as textural information, to achieve accurate mapping that can enhance the classification accuracy.

OBIA is used when integrating and extracting different information, such as spatial, spectral, and textural information. These types of information facilitate discrimination between different land covers in urban areas even though spectral similarity is present (Wang et al., 2007 and 2012). OBIA has been utilized extensively in mapping VHR imagery to address the complexities induced by the spectral and spatial heterogeneity of urban areas (Bhaskaran et al., 2013; Taubenböck et al., 2010). Rule-based classification is one of the methods for classifying image subjects; however, traditional rules may be inappropriate for categorizing objects since the features of different attributes may overlap (Hu and Weng, 2011; Jin and Paswaters, 2007). Therefore, feature selection in VHR imagery is valuable because such process reduces the dimensionality of data and the number of attributes essential to detect and categorize objects, as well as increases the efficiency of the algorithm. Consequently, the accuracy of classification in several applications can be improved (Raghavendra and Simha, 2010; Taherzadeh and Shafri, 2013).

Most studies on road condition mapping except traditional method which is based on different indices and high speed scanner vehicle have been conducted using hyperspectral imagery and spectrometry of urban materials and road surfaces. Accordingly, road condition maps and automatic model based on multispectral imagery are evidently lacking. The main goal of the current study is to develop a model based on OBIA and the feature selection technique for road condition mapping using the available training data. Thereafter, in order to validate the rule the model will be applied in different WV-2 images which were obtained on different dates and locations without using training data featuring WV–2 images. By utilizing all information, this method can be highly beneficial compared with traditional road assessments in terms of saving time and resources.

1.2 Problem Statement

The objective of this research is divided in two parts. First road network extraction and second detecting and tracking deterioration in primary level in pavement surface while maintains the lowest cost possible in large area in little time. At the moment the current technique to do the primary level mapping using traditional survey technique can be slow and cannot cover a large area quickly, in addition; it can be inaccurate. However, there are few spectral indices have been developed for man-made detection based on satellite imagery, nonetheless, still the lack of a suitable spectral index for asphalt road extraction from VHR imagery. thus in order to updating and mapping the road network we require the novel technique that able extract the road network frequently and accurately in cost effective manner.

Retrieving road information, such as road surface material and pavement-type condition, is essential in urban areas. In recent years, remote sensing techniques have allowed for non-destructive road condition mapping in large spatial coverage (Schnebele et al. 2015). Over the past decade, several attempts have been made to develop an automatic procedure for road condition mapping from hyperspectral remotely sensed images (Bacher & Mayer 2005; Kirthika & Mookambiga 2011). Thus due to limitation of hyperspectral data such as coverage, high data acquisition cost in this study WV-2 satellite image was used.

OBIA approach is considered as powerful method to extract the information from VHR but still lack of specific rule-based parameter for road condition mapping from WV-2 satellite imagery is obvious.

1.3 Objectives

1.3.1 General Objectives

In general, this study will determine the applicability of WV–2 satellite imagery for road network analysis and developing a new spectral index for road extraction and mapping technique for road condition based on all information inherent in the image.

1.3.2 Specific Objectives

- To determine the significant bands to extract road network and develop a new spectral index following the significant bands for road network extraction automatically.

- To develop a shadow detection index and examine the improvement on road extraction index.

- To develop a new rule-based parameter for road condition mapping based on OBIA approach and validate the rule parameter in different study areas using WV–2 images.

1.4 Scope of Study

The research study is expected to produce suitable map for road extraction and condition using very high resolution imagery WV-2 data. The information generated by this study is believed to provide useful information for urban planners and transportation engineering. Traditional methods of road assessment involve time consuming and expensive ground survey, which can take long time to complete in order to arrive at an acceptable alignment. With the help of GIS and remote sensed data it is hoped that specific assessment tasks can be identified on large-scale assessment where in the use of spatial data, tools, and technologies reduce costs, decrease time and provide better solution.

Nonetheless, the types of surface distress are not considered in this study and only deterioration at primary level is considered. The primary evaluation is defined as the only surface of asphalt which trend to deterioration and relate to quality, responsiveness, maintenance and rehabilitation quickly. The classifications of road deterioration are divided into two classes; first High deterioration detected which are road needed to consider as a damage and rehabilitation and second; Low deterioration detected which are road still in good condition. All classification is based on primary level, which is considered only at the surface of asphalt. Therefore, for the types of damages need further assessment with other sources of data such as hyperspectral which is not considered in this research.

1.5 Organization of Thesis

Chapter 2 reviews the literature related to RS and detecting IS particularly road extraction and condition. In this chapter, several methods of semi-automatic and automatic road extraction and different types of classification approaches in road extraction, such as spectral-based and OBIA, will be reviewed. In the last section of this chapter, all existing road condition methods will be reviewed and the gaps in the previous research will be explained.

Chapter 3 explains the materials and methods utilized in this research to achieve the objectives of this study. The first section of this chapter is related to band selection and the development of novel spectral index to extract the roads. The succeeding sections focus on the applied and produced methods related to WV–2 image, such as spectral-based classification and shadow detection, as well as developing techniques to extract roads, and map their conditions using the newly proposed methodology.

Chapter 4 includes the results of this thesis after applying different methods. Two types of data have been used: the first is related to hand-held spectroradiometer for band selection and discriminating the best bands for developing a road extraction index; the second uses WV–2 images, which utilizes spectral-based, OBIA, and feature selection techniques for road network and condition mapping. The findings and results are presented in the last section of this chapter.

Chapter 5 presents the conclusion and recommendations. The results, limitation of the study, and benefits of this thesis are explained in this chapter. Several recommendations to improve this study in the future will also be presented.

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