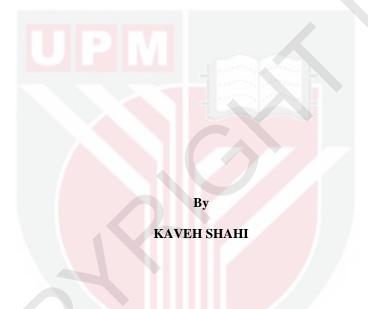**UNIVERSITI PUTRA MALAYSIA**

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

KAVEH SHAHI

FK 2017 30

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

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

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

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KAVEH SHAHI

February 2017

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.

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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

Februari 2017

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),

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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.

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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.

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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.

I certify that a Thesis Examination Committee has met on 24 February 2017 to conduct the final examination of Kaveh Shahi on his thesis entitled "Development of a New Technique for Road Extraction and Pavement Surface Condition Mapping at Primary Level using Worldview-2 Satellite Imagery" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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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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Declaration by graduate student

I hereby confirm that:
- this thesis is my original work;
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This is to confirm that:
- the research conducted and the writing of this thesis was under our supervision;
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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).

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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.

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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

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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.

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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.

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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.

REFERENCES

Adeline, K. R. M., Chen, M., Briottet, X., Pang, S. K., & Paparoditis, N. (2013). Shadow detection in very high spatial resolution aerial images: A comparative study. ISPRS *Journal of Photogrammetry and Remote Sensing*, 80, 21-38.

Aggarwal, M. & Prasad, A. (2013). Fusion of statistic, data mining and genetic algorithm for feature selection in intrusion detection. *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET),* 2**,** 1725-1731.

Rizvi, I. A. & Mohan, B. K. (2010). Object-oriented method for automatic extraction of road from High Resolution Satellite Images. *Iranian Journal of Earth Sciences*, *2*(1), 55-62.

Ambrosia, V. G., Wegener, S. S., Sullivan, D. V., Buechel, S. W., Dunagan, S. E., Brass, J. A., Stoneburner, J. & Schoenung, S. M. (2003). Demonstrating UAV-acquired real-time thermal data over fires. *Photogrammetric Engineering & Remote Sensing,* 69**,** 391-402.

Andreou, C., Karathanassi, V. & Kolokoussis, P. (2011). Investigation of hyperspectral remote sensing for mapping asphalt road conditions. *International Journal of Remote Sensing,* 32**,** 6315-6333.

Aplin, P., & Smith, G. M. (2008). Advances in object-based image classification. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37, 725-728.

Anil, P. & Natarajan, S. (2010). Automatic road extraction from high resolution imagery based on statistical region merging and skeletonization. *International Journal of Engineering Science and Technology,* 2**,** 165-171.

Anil, P. N. & Natarajan, S. (2013). Road extraction using topological derivative and mathematical morphology. *Journal of the Indian Society of Remote Sensing,* 41**,** 719-724.

Annadate, C. A. & Lobo, L. (2014). Road Extraction Using K-Means Clustering and Snakes Pattern. *International Journal of Application or Innovation in Engineering & Management (IJAIEM)*. ISSN 2319-4847.

Arnold Jr, C. L. & Gibbons, C. J. (1996). Impervious surface coverage: the emergence of a key environmental indicator. *Journal of the American planning Association,* 62**,** 243-258.

Bacher, U. & Mayer, H. (2005). Automatic road extraction from multispectral high resolution satellite images. *Proceedings of CMRT05*.

Barsi, A. & Heipke, C. (2003). Artificial neural networks for the detection of road junctions in aerial images. *International Archives Of Photogrammetry Remote Sensing And Spatial Information Sciences,* 34**,** 113-118.

Bell, C. A. (1989). Summary report on aging of asphalt-aggregate systems. *Strategic Highway Research Program*. Report No. SHRP-A-/IR-89-004 (SHRP-A-305).

Ben-Dor, E. (2001). Imaging spectrometry for urban applications. *Imaging Spectrometry* (pp. 243-281), Springer Netherlands.

Ben-Dor, E., Levin, N. & Saaroni, H. (2001). A spectral based recognition of the urban environment using the visible and near-infrared spectral region (0.4-1.1 µm). A case study over Tel-Aviv, Israel. *International Journal of Remote Sensing,* 22**,** 2193-2218.

Bendig, J., Bolten, A. & Bareth, G. (2012). Introducing a low-cost mini-UAV for thermal-and multispectral-imaging. *International Archives Of*

Photogrammetry Remote Sensing And Spatial Information Sciences, 39**,** 345-349.

Bhaskaran, S., Nez, E., Jimenez, K. & Bhatia, S. K. (2013). Rule-based classification of high-resolution imagery over urban areas in New York City. *Geocarto International,* 28**,** 527-545.

Bhatta, B. (2009). Analysis of urban growth pattern using remote sensing and GIS: a case study of Kolkata, India. *International Journal of Remote Sensing,* 30**,** 4733-4746.

Breiman, L. (2001). Random forests. *Machine learning,* 45**,** 5-32.

Bughrara, N. F. (2008). Evaluation of road pavement cracks in Malaysia. PhD Dissertation, Universiti Putra Malaysia.

Chaudhuri, D., Kushwaha, N. & Samal, A. (2012). Semi-automated road detection from high resolution satellite images by directional morphological enhancement and segmentation techniques. *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of,* 5**,** 1538-1544.

Chen, Y., Su, W., Li, J. & Sun, Z. (2009). Hierarchical object oriented classification using very high resolution imagery and LIDAR data over urban areas. *Advances in Space Research,* 43**,** 1101-1110.

Chen, X., Dong, Q., Zhu, H., & Huang, B. (2016). Development of distress condition index of asphalt pavements using LTPP data through structural equation modeling. Transportation Research Part C: Emerging Technologies, 68, 58-69.

Chen, C., Zhang, S., Zhang, G., Bogus, S. M., & Valentin, V. (2014). Discovering temporal and spatial patterns and characteristics of pavement distress condition data on major corridors in New Mexico. Journal of Transport Geography, 38, 148-158.

Chen, D., Stow, D. & Gong, P. (2004). Examining the effect of spatial resolution and texture window size on classification accuracy: an urban environment case. *International Journal of Remote Sensing,* 25**,** 2177-2192.

Chiang, T., Hsieh, Y. & Lau, W. (2001). Automatic road extraction from aerial images. Stanford education.

Chiang, Y. Y. & Knoblock, C. (2009). A method for automatically extracting road layers from raster maps. *Document Analysis and Recognition.* ICDAR'09. 10th International Conference on, 2009. IEEE, 838-842.

Clark, R. N. (1999). Spectroscopy of rocks and minerals, and principles of spectroscopy. *Manual of remote sensing,* 3**,** 3-58.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment,* 37**,** 35-46.

Conway, T. M. (2007). Impervious surface as an indicator of PH and specific conductance in the urbanizing coastal zone of New Jersey, USA. *Journal of Environmental Management,* 85**,** 308-316.

Costa, F. G., Ueyama, J., Braun, T., Pessin, G., Osório, F. S. & Vargas, P. (2012). The use of unmanned aerial vehicles and wireless sensor network in agricultural applications. *Geoscience and Remote Sensing Symposium (IGARSS)*, IEEE, 5045-5048.

Dalla Mura, M., Atli Benediktsson, J., Waske, B. & Bruzzone, L. (2010). Extended profiles with morphological attribute filters for the analysis of hyperspectral data. *International Journal of Remote Sensing,* 31**,** 5975-5991.

Das, S., Mirnalinee, T. & Varghese, K. (2011). Use of salient features for the design of a multistage framework to extract roads from high-resolution multispectral satellite images. *Geoscience and Remote Sensing, IEEE Transactions on,* 49**,** 3906-3931.

Debba, P., Cho, M. & Mathieu, R. (2009). Optimal individual supervised hyperspectral band selection distinguishing savannah trees at leaf level. *Hyperspectral Image and Signal Processing: Evolution in Remote Sensing.* WHISPERS'09. First Workshop on, 2009. IEEE, 1-4.

ENVI-Zoom tutorial 2010. ENVI user guide. Colorado (CO): ITT.

Egbert, J. & Beard, R. W. (2007). Low altitude road following constraints using strap-down EO cameras on miniature air vehicles. *American Control Conference*, ACC'07, 2007. IEEE, 353-358.

Egmont-Petersen, M., De Ridder, D. & Handels, H. (2002). Image processing with neural networks—a review. *Pattern Recognition,* 35**,** 2279-2301.

Elkaim, G. H., Lie, F. A. P. & Gebre-Egziabher, D. (2015). Principles of guidance, navigation, and control of UAVs. *Handbook of Unmanned Aerial Vehicles.* Springer.

Elsharkawy, A., Elhabiby, M. & El-Sheimy, N. (2012). New combined pixel/object-based technique for efficient urban classification using WorldView-2 data. *Proceedings of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* 39**,** B7.

Flora, W. F., Ong, G. P. R. & Sinha, K. C. (2010). Development of a structural index as an integral part of the overall pavement quality in the INDOT PMS. *Joint Transportation Research Program*, Purdue University, 2010.

Feng, W., Yundong, W., & Qiang, Z. (2009). UAV borne real-time road mapping system. In 2009 J*oint Urban Remote Sensing Event* (pp. 1-7).

Forestry Department Peninsular Malaysia. (1999). Specification of Forest Roads for Peninsular Malaysia. Kuala Lumpur: Forestry Department Peninsular Malaysia.

Foody, G. M. (2004). Thematic map comparison. *Photogrammetric Engineering & Remote Sensing,* 70**,** 627-633.

Gini, R., Pagliari, D., Passoni, D., Pinto, L., Sona, G., Dosso, P., Grenzdörffer, G. & Bill, R. (2013). UAV photogrammetry: Block triangulation comparisons. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.*

Globe, D. (2009). The benefits of the 8 spectral bands of WorldView-2. White Paper.

Gomez, R. B. (2002). Hyperspectral imaging: a useful technology for transportation analysis. *Optical Engineering,* 41**,** 2137-2143.

Greenacre, M. (2008). Measures of distance between samples: Euclidean. *URL http://www. econ. upf. edu/~ michael/stanford/maeb4. pdf*.

Gruen, A., & Li, H. (1995). Road extraction from aerial and satellite images by dynamic programming. *ISPRS Journal of Photogrammetry and Remote Sensing*, 50(4), 11-20.

Griffiths, P., Hostert, P., Gruebner, O. & Van Der Linden, S. (2010). Mapping megacity growth with multi-sensor data. *Remote Sensing of Environment,* 114**,** 426-439.

Grote, A., Heipke, C. & Rottensteiner, F. (2012). Road Network Extraction in Suburban Areas. *The Photogrammetric Record,* 27**,** 8-28.

Hamedianfar, A., Shafri, H. Z. M., Mansor, S. & Ahmad, N. (2014). Improving detailed rule-based feature extraction of urban areas from WorldView-2 image and lidar data. *International Journal of Remote Sensing,* 35**,** 1876-1899.

He, C., Shi, P., Xie, D. & Zhao, Y. (2010). Improving the normalized difference built-up index to map urban built-up areas using a semiautomatic segmentation approach. *Remote Sensing Letters,* 1**,** 213-221.

Heiden, U., Roessner, S., Segl, K. & Kaufmann, H. (2001). Potential of hyperspectral HyMap data for material oriented identification of urban surfaces. *Remote Sensing of Urban Areas*, 69-77.

Heiden, U., Segl, K., Roessner, S. & Kaufmann, H. (2007). Determination of robust spectral features for identification of urban surface materials in hyperspectral remote sensing data. *Remote Sensing of Environment,* 111, 537-552.

Hepner, G. F., Houshmand, B., Kulikov, I. & Bryant, N. (1998). Investigation of the integration of AVIRIS and IFSAR for urban analysis. *Photogrammetric Engineering and Remote Sensing,* 64, 813-820.

Herold, M., Gardner, M., Hadley, B. & Roberts, D. (2002). The spectral dimension in urban land cover mapping from high-resolution optical remote sensing data. *Proceedings of the 3rd Symposium on Remote Sensing of Urban Areas*.

Herold, M., Gardner, M., Noronha, V. & Roberts, D. (2003). Spectrometry and hyperspectral remote sensing of urban road infrastructure. *Online Journal of Space Communications,* 3.

Herold, M. & Roberts, D. (2005a). Spectral characteristics of asphalt road aging and deterioration: implications for remote-sensing applications. *Applied Optics,* 44, 4327-4334.

Herold, M. & Roberts, D. A. (2005b). Mapping asphalt road conditins with hyperspectral remote sensing. *5th International Symposium Remote Sensing of Urban Areas* (URS 2005), Tempe, AZ, USA.

Herold, M., Roberts, D. A., Gardner, M. E. & Dennison, P. E. (2004). Spectrometry for urban area remote sensing—Development and analysis of a spectral library from 350 to 2400 nm. *Remote Sensing of Environment,* 91, 304-319.

Herumurti, D., Uchimura, K., Koutaki, G. & Uemura, T. (2013). Urban road extraction based on hough transform and region growing. *Frontiers of Computer Vision*,(FCV), 2013 19th Korea-Japan Joint Workshop on. IEEE, 220-224.

Hsu, C. W., Chang, C. C. & Lin, C. J. (2003). A practical guide to support vector classification. http://www.csie.ntu.edu.tw/~cjlin/papers/guide/guide.pdf.

Hu, X. & Weng, Q. (2009). Estimating impervious surfaces from medium spatial resolution imagery using the self-organizing map and multi-layer perceptron neural networks. *Remote Sensing of Environment,* 113, 2089-2102.

Hui, Z., Hu, Y., Jin, S., & Yevenyo, Y. Z. (2016). Road centerline extraction from airborne LiDAR point cloud based on hierarchical fusion and optimization. ISPRS Journal of Photogrammetry and Remote Sensing, 118, 22-36.

Hu, X. & Weng, Q. (2011). Impervious surface area extraction from IKONOS imagery using an object-based fuzzy method. *Geocarto International,* 26, 3-20.

Jensen, J. R. (2005). Introductory digital image processing: A remote sensing perspective. Univ. of South Carolina, Columbus.

Jensen, J. R. & Cowen, D. C. (1999). Remote sensing of urban/suburban infrastructure and socio-economic attributes. *Photogrammetric engineering and remote sensing,* 65, 611-622.

Jeon, B. K., Jang, J. H. & Hong, K. S. (2000). Map-based road detection in spaceborne synthetic aperture radar images based on curvilinear structure extraction. *Optical Engineering,* 39, 2413-2421.

Ji, X. & Niu, X. (2014). The attribute accuracy assessment of land cover data in the national geographic conditions survey. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* 2, 35.

Jimenez, L. O. & Landgrebe, D. (1999). Hyperspectral data analysis and supervised feature reduction via projection pursuit. *Geoscience and Remote Sensing, IEEE Transactions on,* 37**,** 2653-2667.

Jin, C., Ma, T., Hou, R., Tang, M., Tian, Y., Al-Dhelaan, A. & Al-Rodhaan, M. (2015). Chi-square statistics feature selection based on term frequency and distribution for text categorization. *IETE Journal of Research***,** 1-12.

Jin, X. & Davis, C. H. (2005). An integrated system for automatic road mapping from high-resolution multi-spectral satellite imagery by information fusion. *Information Fusion,* 6**,** 257-273.

Jin, X. & Paswaters, S. (2007). A fuzzy rule base system for object-based feature extraction and classification. *Defense and Security Symposium.* International Society for Optics and Photonics, 65671H-65671H-12.

Kass, M., Witkin, A. and Terzopoulos, D. (1988). Snakes: Active contour models. *International Journal of Computer Vision,* 1**,** 321-331.

Kaur, S. and Baghla, S. (2013). Automatic road detection of satellite images—A survey. *International Journal of Computer Applications and Information Technology (IJCAIT),* 3**,** 32-34.

Kavzoglu, T., Sen, Y. E. & Cetin, M. (2009). Mapping urban road infrastructure using remotely sensed images. *International Journal of Remote Sensing,* 30**,** 1759-1769.

Kirthika, A. & Mookambiga, A. (2011). Automated road network extraction using artificial neural network. *Recent Trends in Information Technology* (ICRTIT), International Conference on, IEEE, 1061-1065.

Kim, S. H., & Kim, N. (2006). Development of performance prediction models in flexible pavement using regression analysis method. KSCE Journal of Civil Engineering, 10(2), 91-96.

Kobayashi, K., Do, M., & Han, D. (2010). Estimation of Markovian transition probabilities for pavement deterioration forecasting. *KSCE Journal of Civil Engineering*, 14(3), 343-351.

Li, H. (1997). Semi-automatic road extraction from satellite and aerial images. Diss. Techn. Wiss. ETH Zürich, Nr. 12101, 1997. Ref.: Armin Gruen; Korref.: Pascal Fua; Korref.: Zuxun Zhang.

Latif, A. B. (2009). Relationship between International Roughness Index (IRI) and Present Serviceability Index (PSI). *Unpublished Thesis) Universiti Teknologi Malaysia*.

Lian, L. & Chen, J. (2011). Research on segmentation scale of multi-resources remote sensing data based on object-oriented. *Procedia Earth and Planetary Science,* 2**,** 352-357.

Lin, P. (2009). A framework for consistency based feature selection. *Masters Theses***,** 62.

Lin, Y., Hyyppä, J. & Jaakkola, A. (2011). Mini-UAV-borne LIDAR for fine-scale mapping. *Geoscience and Remote Sensing Letters, IEEE,* 8**,** 426-430.

Lu, B., Ku, Y. & Wang, H. (2009). Automatic road extraction method based on level set and shape analysis. *In 2009 Second International Conference on Intelligent Computation Technology and Automation*.

Lu, D. & Weng, Q. (2009). Extraction of urban impervious surfaces from an IKONOS image. *International Journal of Remote Sensing,* 30**,** 1297-1311.

Ma, H., Cheng, X., Wang, X. & Yuan, J. (2013). Road information extraction from high resolution remote sensing images based on threshold segmentation and mathematical morphology. *Image and Signal Processing* (CISP), 6th International Congress on, 2013. IEEE, 626-630.

Mäkisara, K., Simula, O., Kangas, J. & Kohonen, T. (2014). *Artificial neural networks*, Elsevier.

Masahiko, N. (2007). UAV borne mapping system for river environment. *Proc. of 28th Asian Association of Remote Sensing* Conf., ACRS, Kuala Lumpur, Malaysia (12–16 November 2007).

Maurya, R., Gupta, P. & Shukla, A. S. (2011). Road extraction using k-means clustering and morphological operations. *Image Information Processing* (ICIIP), International Conference on, 2011. IEEE, 1-6.

Mayer, H., Hinz, S., Bacher, U. & Baltsavias, E. (2006). A test of automatic road extraction approaches. *International Archives of Photogrammetry, Remote Sensing, and Spatial Information Sciences,* 36**,** 209-214.

Mcinerney, T. & Terzopoulos, D. (2000). T-snakes: Topology adaptive snakes. *Medical image analysis,* 4**,** 73-91.

Mena, J. B. (2003). State of the art on automatic road extraction for GIS update: a novel classification. *Pattern Recognition Letters,* 24**,** 3037-3058.

Mhangara, P., Odindi, J., Kleyn, L. & Remas, H. (2011). Road extraction using object oriented classification.

Miao, Z., Wang, B., Shi, W. & Wu, H. (2014). A method for accurate road centerline extraction from a classified image. *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of,* 7**,** 4762-4771.

Miao, Z., Shi, W., Gamba, P., & Li, Z. (2015). An Object-Based Method for Road Network Extraction in VHR Satellite Images. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 8(10), 4853-4862.

Mirnalinee, T., Das, S. & Varghese, K. (2011). An integrated multistage framework for automatic road extraction from high resolution satellite imagery. *Journal of the Indian Society of Remote Sensing,* 39**,** 1-25.

Mnih, V. & Hinton, G. E. (2010). Learning to detect roads in high-resolution aerial images. *Computer Vision–ECCV 2010.* Springer.

Mohammadi, M. (2011). Road classification and condition determination using hyperspectral imagery. *Unpublished Master thesis, University of Applied Sciences Stuttgart, Germany*.

Mokhtarzade, M. & Zoej, M. J. V. (2007). Road detection from high-resolution satellite images using artificial neural networks. *International Journal of Applied Earth Observation and Geoinformation,* 9**,** 32-40.

Mohammadzadeh, A., Zoej, M. V., & Tavakoli, A. (2009). Automatic main road extraction from high resolution satellite imageries by means of particle swarm optimization applied to a fuzzy-based mean calculation approach. Journal of the Indian society of remote sensing, 37(2), 173-184.

Mokhtarzade, M., Zoej, M. V., & Ebadi, H. (2008). Automatic road extraction from high resolution satellite images using neural networks, texture analysis, fuzzy clustering and genetic algorithms. In The international archives of the photogrammetry remote sensing and spatial information sciences 2008 Proceedings ISPRS Congress Beijing, B3b (Vol. 549).

Mountrakis, G., Im, J. & Ogole, C. (2011). Support vector machines in remote sensing: A review. *ISPRS Journal of Photogrammetry and Remote Sensing,* 66**,** 247-259.

Myint, S. W., Gober, P., Brazel, A., Grossman-Clarke, S. & Weng, Q. (2011). Per-pixel vs. object-based classification of urban land cover extraction using high spatial resolution imagery. *Remote Sensing of Environment,* 115**,** 1145-1161.

Miller, J. S., & Bellinger, W. Y. (2003). Distress identification manual for the long-term pavement performance program (No. FHWA-RD-03-031).

Neuenschwander, W. M., Fua, P., Iverson, L., Székely, G. & Kübler, O. (1997). Ziplock snakes. *International Journal of Computer Vision,* 25**,** 191-201.

Noronha, V., Herold, M., Roberts, D. & Gardner, M. (2002). Spectrometry and Hyperspectral Remote Sensing for Road Centerline Extraction and Evaluation of Pavement Condition. Proceedings of the Pecora Conference.

Oke, T. R. (2002). *Boundary layer climates*, Routledge, London and New York.

Pal, M. and Mather, P. 2005. Support vector machines for classification in remote sensing. *International Journal of Remote Sensing,* 26**,** 1007-1011.

Peng, B., Xu, A., Li, H. & Han, Y. (2011). Road extraction based on object-oriented from high-resolution remote sensing images. *Image and Data Fusion* (ISIDF), 2011 International Symposium on, 2011. IEEE, 1-4.

Pierce, L. M., Mcgovern, G. & Zimmerman, K. A. (2013). Practical Guide for Quality Management of Pavement Condition Data Collection. US Department of Transportation, Federal Highway Administration, February 2013.

Prozzi, J. A., & Madanat, S. M. (2004). Development of pavement performance models by combining experimental and field data. Journal of Infrastructure Systems, 10(1), 9-22.

Price, J. (1995). Examples of high resolution visible to near-infrared reflectance spectra and a standardized collection for remote sensing studies. *Remote Sensing,* 16**,** 993-1000.

Pu, R., Landry, S. & Yu, Q. (2011). Object-based urban detailed land cover classification with high spatial resolution IKONOS imagery. *International Journal of Remote Sensing,* 32**,** 3285-3308.

Quackenbush, L. J. (2004). A review of techniques for extracting linear features from imagery. *Photogrammetric Engineering & Remote Sensing,* 70**,** 1383-1392.

Quackenbush, L. J., Im, I., & Zuo, Y. (2013). Road extraction: a review of LiDAR-focused studies. *Remote Sensing of Natural Resources*, 155-169.

Radopoulou, S. C. & Brilakis, I. (2015). Patch detection for pavement assessment. *Automation in Construction,* 53**,** 95-104.

Raghavendra, B. & Simha, J. B. (2010). Evaluation of Feature Selection Methods for Predictive Modeling Using Neural Networks in Credits Scoring. *Int. J. Advanced Networking and Applications,* 2**,** 714-718.

Rajeswari, M., Gurumurthy, K., Reddy, L. P., Omkar, S. & Senthilnath, J. (2011). Automatic road extraction based on level set, normalized cuts and mean shift methods. *IJCSI Int. J. Comput. Sci. Issues,* 8.

Rango, A., Laliberte, A., Steele, C., Herrick, J. E., Bestelmeyer, B., Schmugge, T., Roanhorse, A. & Jenkins, V. (2006). Using unmanned aerial vehicles for rangelands: current applications and future potentials. *Environmental Practice,* 8**,** 159-168.

Remondino, F., Barazzetti, L., Nex, F., Scaioni, M. & Sarazzi, D. (2011). UAV photogrammetry for mapping and 3d modeling–current status and future perspectives. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* 38**,** C22.

Resende, M., Jorge, S., Longhitano, G. & Quintanilha, J. A. (2008). Use of hyperspectral and high spatial resolution image data in an asphalted urban road extraction. *Geoscience and Remote Sensing Symposium*, IGARSS 2008. IEEE International, 2008. IEEE, III-1323-III-1325.

Roadware, F. (2010). Pavement Condition Assessment. *Data sheets [Online] Available at:* http://www. *fugroroadware. com/related/english-alldatasheets [Accessed: 1 June 2013]*.

Rathinam, S., Kim, Z. W., & Sengupta, R. (2008). Vision-based monitoring of locally linear structures using an unmanned aerial vehicle 1. Journal of Infrastructure Systems, 14(1), 52-63.

Roberts, D. A., Gardner, M., Church, R., Ustin, S., Scheer, G. & Green, R. (1998). Mapping chaparral in the Santa Monica Mountains using multiple endmember spectral mixture models. *Remote Sensing of Environment,* 65**,** 267-279.

Saha, A., Arora, M., Csaplovics, E. & Gupta, R. (2005). Land cover classification using IRS LISS III image and DEM in a rugged terrain: a case study in Himalayas. *Geocarto International,* 20**,** 33-40.

Sun, L., & Qian, Z. (2016). Multi-scale wavelet transform filtering of non-uniform pavement surface image background for automated pavement distress identification. Measurement, 86, 26-40.

Salari, E., & Bao, G. (2011). Pavement distress detection and severity analysis. In IS&T/SPIE Electronic Imaging (pp. 78770C-78770C). *International Society for Optics and Photonics.*

Sirvio, K., & Hollmén, J. (2011, June). Forecasting road condition after maintenance works by linear methods and radial basis function networks. In International Conference on Artificial Neural Networks (pp. 405-412). Springer Berlin Heidelberg.

Santos, A., Celes, C. D. S., Araújo, A. D. A. & Menotti, D. (2012). Feature selection for classification of remote sensed hyperspectral images: A filter approach using genetic algorithm and cluster validity. The 2012 International Conference on Image Processing, Computer Vision, and Pattern Recognition (IPCV'12), 2012. 675-681.

Schnebele, E., Tanyu, B. F., Cervone, G. & Waters, N. (2015). Review of remote sensing methodologies for pavement management and assessment. *European Transport Research Review,* 7.

Segl, K., Heiden, U., Mueller, M. and Kaufmann, H. (2003). Endmember detection in urban environments using hyperspectral HyMap data. Third EARSeL Workshop on Imaging Spectroscopy.

Senthilnath, J., Rajeshwari, M. & Omkar, S. (2009). Automatic road extraction using high resolution satellite image based on texture progressive analysis and normalized cut method. *Journal of the Indian Society of Remote Sensing,* 37**,** 351-361.

Serra, J. (1983). Image analysis and mathematical morphology. *Academic Press*, Inc.

Shafri, H. Z., Taherzadeh, E., Mansor, S. and Ashurov, R. (2012). Hyperspectral remote sensing of urban areas: an overview of techniques and applications. *Research Journal of Applied Sciences, Engineering and Technology,* 4**,** 1557-1565.

Shen, Z., Luo, J. & Gao, L. (2010). Road extraction from high-resolution remotely sensed panchromatic image in different research scales. Geoscience and Remote Sensing Symposium (IGARSS), IEEE International, 2010. 453-456.

Sheng, Q., Zhu, F., Chen, S., Wang, H., & Xiao, H. (2013). Automatic Road Extraction from Remote Sensing Images Based on Fuzzy Connectedness. In *Geo-Information Technologies for Natural Disaster Management (GiT4NDM), 2013 Fifth International Conference on* (pp. 143-146). IEEE

Simler, C. & Beumier, C. (2010). Building and Road Extraction on Urban VHR Images using SVM Combinations and Mean Shift Segmentation. VISAPP (2), 2010. 451-457.

Singh, M. & Misal, A. (2013). A Survey Paper on Various Visual Image Segmentation Techniques. *International Journal of Computer Science and Management Research,* 2**,** 1282-1288.

Singh, P. P. & Garg, R. (2013). Automatic road extraction from high resolution satellite image using adaptive global thresholding and morphological operations. *Journal of the Indian Society of Remote Sensing,* 41**,** 631-640.

Solomon, J. & Rock, B. (1985). Imaging spectrometry for earth remote sensing. *Science,* 228**,** 1147-1152.

Stoeckeler, E. (1970). Use of aerial color photography for pavement evaluation studies. *Highway Research Record,* 319**,** 40-57.

Tahar, K. N. & Ahmad, A. (2012). A simulation study on the capabilities of rotor wing unmanned aerial vehicle in aerial terrain mapping. *International Journal of Physical Sciences,* 7**,** 1300-1306.

Tawalare, A., & Raju, K. V. (2016). Pavement Performance Index for Indian rural roads. Perspectives in Science.

Taherzadeh, E. & Shafri, H. Z. (2011). Using hyperspectral remote sensing data in urban mapping over Kuala Lumpur. *Urban Remote Sensing Event* (JURSE), 2011 Joint, 2011. IEEE, 405-408.

Taherzadeh, E. & Shafri, H. Z. M. (2013). Development of a Generic Model for the Detection of Roof Materials Based on an Object-Based Approach Using WorldView-2 Satellite Imagery. *Advances in Remote Sensing,* 02**,** 312-321.

Taşcı, Ş. & Güngör, T. (2013). Comparison of text feature selection policies and using an adaptive framework. *Expert Systems with Applications,* 40**,** 4871-4886.

Taubenböck, H., Esch, T., Wurm, M., Roth, A. & Dech, S. (2010). Object-based feature extraction using high spatial resolution satellite data of urban areas. *Journal of Spatial Science,* 55**,** 117-132.

Tiong, P. L. Y., Mustaffar, M. & Hainin, M. R. (2012). Road surface assessment of pothole severity by close range digital photogrammetry method. *World Applied Sciences Journal,* 19**,** 867-873.

Tiwari, P. S., Pande, H. & Aye, M. N. (2010). Exploiting IKONOS and Hyperion data fusion for automated road extraction. *Geocarto International,* 25**,** 123-131.

Tupin, F., Houshmand, B. & Datcu, M. (2002). Road detection in dense urban areas using SAR imagery and the usefulness of multiple views. *Geoscience and Remote Sensing, IEEE Transactions on,* 40**,** 2405-2414.

Thang, H. C., & Chappell, N. A. (2005). 36 Minimising the hydrological impact of forest harvesting in Malaysia's rainforests. This page intentionally left blank, 852.

Usher, J. & Truax, D. (2001). Exploration of remote sensing applicability within transportation. *final projects rep.(Remote Sensing Technologies Center, Mississippi State University, 2001), http://www. rstc. msstate. edu/publications/99-01/rstcofr01-005b. pdf (access: March 2004)*

Van Der Meer, F. & De Jong, S. M. (2001). Imaging Spectrometry: basic principles and prospective applications. *Springer Science & Business Media.*

Vapnik, V. (2013). The nature of statistical learning theory. *Springer Science & Business Media.*

Varshney, A. (2013). Improved NDBI differencing algorithm for built-up regions change detection from remote-sensing data: an automated approach. *Remote Sensing Letters,* 4**,** 504-512.

Wang, J., Qin, Q., Yang, X., Wang, J., Ye, X. & Qin, X. (2014). Automated road extraction from multi-resolution images using spectral information and

texture. *Geoscience and Remote Sensing Symposium* (IGARSS), IEEE International, 2014. IEEE, 533-536.

Wang, L., Dai, Q., Hong, L. & Liu, G. (2012). Adaptive regional feature extraction for very high spatial resolution image classification. *Journal of Applied Remote Sensing,* 6**,** 063506-1-063506-16.

Wang, Y., Tian, Y., Tai, X., & Shu, L. (2006). Extraction of main urban roads from high resolution satellite images by machine learning. In Asian Conference on Computer Vision (pp. 236-245). Springer Berlin Heidelberg.

Wang, M. & Zhang, S. (2011). Road extraction from high-spatial-resolution remotely sensed imagery by combining multi-profile analysis and extended Snakes model. *International Journal of Remote Sensing,* 32**,** 6349-6365.

Wang, P., Feng, X., Zhao, S., Xiao, P. & Xu, C. (2007). Comparison of object-oriented with pixel-based classification techniques on urban classification using TM and IKONOS imagery. *Geoinformatics* 2007. International Society for Optics and Photonics, 67522J-67522J-8.

Wang, Y., Li, X., Zhang, L. & Zhang, W. (2008). Automatic road extraction of urban area from high spatial resolution remotely sensed imagery. *Int. Arch. Photogrammetry, Remote Sen. Spatial Inform. Sci,* 86.

Wang, J., Qin, Q., Gao, Z., Zhao, J., & Ye, X. (2016). A New Approach to Urban Road Extraction Using High-Resolution Aerial Image. ISPRS International Journal of Geo-Information, 5(7), 114.

Wang, Y. & Zhang, X. (2004). A SPLIT model for extraction of subpixel impervious surface information. *Photogrammetric Engineering & Remote Sensing,* 70**,** 821-828.

Weng, Q. (2012). Remote sensing of impervious surfaces in the urban areas: Requirements, methods, and trends. *Remote Sensing of Environment,* 117**,** 34-49.

Wenxia, W., Chen, X. & Ma, A. (2005). Object-oriented information extraction and application in high-resolution remote sensing image. IGARSS, 2005. 3803-3806.

Wu, C. (2009). Quantifying high- resolution impervious surfaces using spectral mixture analysis. *International Journal of Remote Sensing,* 30**,** 2915-2932.

Xiang, H. & Tian, L. (2011). Method for automatic georeferencing aerial remote sensing (RS) images from an unmanned aerial vehicle (UAV) platform. *Biosystems Engineering,* 108**,** 104-113.

Xiao-gu, S., Man-chun, L., Yong-xue, L., Wei, L. & Lu, T. (2009). A semi-automation road extraction approach based on fast marching method and mean shift algorithm. GCIS'09 Proceedings of the 2009 WRI Global Congress on Intelligent Systems-Volume 04 IEEE Computer Society Washington. DC, USA.

Xinpeng, T., Shunlin, S. & Yongzhao, Z. (2014a). A Novel Road Extraction Algorithm for High Resolution Remote Sensing Images. *Applied Mathematics & Information Sciences,* 8**,** 1435-1443.

Xinpeng, T., Shunlin, S. & Yongzhao, Z. (2014b). A novel road extraction algorithm for high resolution remote sensing images. *Applied Mathematics,* 8**,** 1435-1443.

Xu, G., Yang, L., Liu, X. & Li, R. (2012). Research of Road Extraction Based on Hough Transformation and Morphology. In *Computer Science & Service System (CSSS), 2012 International Conference on* (pp. 2261-2264). IEEE.

Xu, H. (2008). A new index for delineating built- up land features in satellite imagery. *International Journal of Remote Sensing,* 29**,** 4269-4276.

Yang, H. & Ke-Ju, Z. (2009). Road extraction from remote sensing imagery based on road tracking and ribbon snake. *Knowledge Engineering and Software Engineering*, 2009. KESE'09. Pacific-Asia Conference on, 2009. IEEE, 201-204.

Yang, J., Liu, Y., Zhu, X., Liu, Z. & Zhang, X. (2012). A new feature selection based on comprehensive measurement both in inter-category and intra-category for text categorization. *Information Processing & Management,* 48**,** 741-754.

Yong, B., Ai-Gong, X., Quan-Hua, Z. & Zhan-You, Z. (2009). Urban road network extraction based on multi-resolution template matching and double-snake model. *Urban Remote Sensing Event*, 2009 Joint, 2009. IEEE, 1-6.

Yang, B., Fang, L., & Li, J. (2013). Semi-automated extraction and delineation of 3D roads of street scene from mobile laser scanning point clouds. ISPRS Journal of Photogrammetry and Remote Sensing, 79, 80-93.

Zhang, C. & Elaksher, A. (2012). An Unmanned Aerial Vehicle- Based Imaging System for 3D Measurement of Unpaved Road Surface Distresses1. *Computer- Aided Civil and Infrastructure Engineering,* 27**,** 118-129.

Zhang, Q. & Couloigner, I. (2004). A framework for road change detection and map updating. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* 35**,** 720-734.

Zakeri, H., Nejad, F. M., & Fahimifar, A. (2016). Image Based Techniques for Crack Detection, Classification and Quantification in Asphalt Pavement: A Review. Archives of Computational Methods in Engineering, 1-43.

Zhou, W. & Troy, A. (2008). An object- oriented approach for analysing and characterizing urban landscape at the parcel level. *International Journal of Remote Sensing,* 29**,** 3119-3135.

Zhou, H., Kong, H., Wei, L., Creighton, D., & Nahavandi, S. (2015). Efficient road detection and tracking for unmanned aerial vehicle. I*EEE Transactions on Intelligent Transportation Systems*, 16(1), 297-309

Zhu, C., Shi, W., Pesaresi, M., Liu, L., Chen, X. & King, B. (2005). The recognition of road network from high- resolution satellite remotely sensed data using image morphological characteristics. *International Journal of Remote Sensing,* 26**,** 5493-5508.

Zhu, Q. & Mordohai, P. (2009). A minimum cover approach for extracting the road network from airborne lidar data. *Computer Vision Workshops* (ICCV Workshops), IEEE 12th International Conference on, 2009. IEEE, 1582-1589.

Zongjian, L. (2008). UAV for mapping—low altitude photogrammetric survey. *International Archives of Photogrammetry and Remote Sensing, Beijing, China,* 37**,** 1183-1186.