**UNIVERSITI PUTRA MALAYSIA**

# *DETECTION OF ROOF MATERIALS BASED ON AN OBJECT-ORIENTED APPROACH USING WORLDVIEW-2 SATELLITE IMAGERY*

***EBRAHIM TAHERZADEH MOBARAKEH***

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**By**

**EBRAHIM TAHERZADEH MOBARAKEH**

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

**February 2013**

**In The Name of Allah, the Most Gracious and the Most Merciful**

**Specially Dedicated**

**To**

**My parents**

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

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**February 2014**

**Chairman: Assoc. Prof. Helmi Zulhaidi bin Mohd Shafri-PhD**
**Faculty: Engineering**

One of the most challenging tasks in urban remote sensing is detection of impervious surface (IS) which plays an important role in assessing urban environmental conditions. However, accurate impervious surface extraction is still a challenge.

New methods are needed due to the rapid expansion and development of urban centers which are able to do more frequent updating of existing databases instead of traditional methods. In this study, detection of the IS especially the roof surfaces based on their materials is proposed. Detection of roof types and conditions are important and the information on the roof material types can be useful for different applications such as disaster preparedness, urban heat island assessment and runoff quality.

Due to the limitations of airborne hyperspectral data in which data acquisition is normally expensive, the coverage area is limited, and the analysis can be too complex, very-high-resolution (VHR) imagery, such as Worldview-2 (WV-2) image was used. In order to do supervised classification and extract the IS at the parcel level, especially roof materials, adequate training data are needed, but lack of sufficient training data is one of the limitations, due to the security of buildings, permission to access the roof could not be obtained or access was impossible.

The Object-oriented (OO) approach was used in order to utilize the spectral, spatial and textural information which are inherent in VHR imagery. In order to define the objects based on OO approach, certain rules should be defined. This

is a difficult task due to the requirement of the prior knowledge about the objects. Lack of generic rule to extract the IS is another limitation in urban remote sensing.

The main goal of this research is to build the generic rules based on the spectral, spatial and textural information to predict roof materials in WV-2 images without using training data.

A generic model is proposed that is based on spectral, spatial and textural information which were extracted from available training data. Furthermore, discriminant analysis (DA) is used for dimensionality reduction and to discriminate between different spatial, spectral and textural attributes. The generic model consists of a discriminant function based on linear combinations of the predictor variables that provide the best discrimination between the groups. The DA result shows that of the 54 attributes extracted, only 13 attributes related to spatial, spectral and textural information are useful for discriminating different roof materials. Finally, this model was applied to different WV-2 images from different areas and proved that this model has a good potential to predict roof materials in different study areas with more than 81% accuracy. This is performed on WV-2 images without using training data.

Abstrak thesis yang diserahkan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PEMBANGUNAN MODEL GENERIK UNTUK PENGESANAN BAHAN BUMBUNG BERDASARKAN PENDEKATAN BERORIENTASIKAN OBJEK MENGGUNKAN IMEJ SATELIT WORLDVIEW-2**

Oleh

**EBRAHIM TAHERZADEH MOBARAKEH**

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Salah satu aplikasi yang amat mencabar di dalam penderiaan jauh bagi kawasan bandar adalah pengesanan permukaan kedap air yang mana memainkan peranan yang ber penting dalam menilai keadaan persekitaran bandar.

Kaedah baru untuk pengesanan permukaan tersebut adalah diperlukan bagi mengemaskini pangkalan data sedia dengan lebih cepat berbanding kaedah tradisional memandangkan perkembangan dan pembangunan pusat-pusat bandar yang pesat. Dalam kajian ini, pengesanan IS terutamanya permukaan bumbung berdasarkan bahan pembuatannya adalah dicadangkan. Pengesanan jenis dan keadaan bumbung adalah penting dan maklumat berkenaan jenis bahan binaan bumbung berguna untuk pelbagai aplikasi seperti persiapan menghadapi bencana, penilaian pulau haba bandar dan kualiti air larian.

Oleh kerana keterbatasan perolehan data hiperspektral udarayang kebiasaannya mahal, kawasan liputan yang terhad dan analisis boleh menjadi terlalu kompleks ; imej yang beresolusi tinggi seperti Worldview-2 (WV-2) telah digunakan. Dalam usaha untuk melakukan pengkelasan secara berselia dan mengekstrak maklumat IS data latihan yang mencukupi adalah diperlukan. Namun begitu, kekangan yang dihadapi adalah dari segi kekurangan data latihan kerana isu keselamatan bangunan dan kebenaran untuk mengakses bumbung bangunan  agak sukar dan mustahil.

Pendekatan berorientasikan objek (OO) telah digunakan untuk menggunakan,. maklumat spektral, spatial dan tekstur yang sememangnya wujud dalam imej VHR. Untuk menentukan objek berdasarkan pendekatan OO, peraturan tertentu perlu ditakrifkan dan merupakan satu tugas yang sukar kerana memerlukan pengetahuan sebelum berkenaan objek. Kekurangan peraturan generik untuk mengesan IS adalah satu lagi limitasi penderiaan jauh bandar.

Matlamat utama kajian ini adalah untuk membina kaedah-kaedah generik berdasarkan, maklumat spektral, spatial dan tekstur untuk meramalkan bahan bumbung didalam imej WV-2 tanpa menggunakan data latihan.

Satu model generik adalah dicadangkan berdasarkan maklumat spektral, spatial dan tekstur yang diekstrak daripada data latihan yang sedia ada. Tambahan pula, analisis diskriminan (discriminant analysis - DA) digunakan untuk mengurangkan dimensionaliti dan membezakan antara sifat-sifat spatial, spektral dan tekstur yang berbeza. Model generik terdiri daripada fungsi diskriminan berdasarkan gabungan linear bagi pemboleh ubah ramalan yang memberikan diskriminasi yang terbaik di antara kumpulan. Hasil DA menunjukkan bahawa daripada 54 sifat-sifat dikeluarkan, hanya 13 sifat-sifat yang berkaitan dengan maklumat spektral, spatial dan tekstur yang berguna untuk membezakan bahan-bahan bumbung yang berbeza. Akhir sekali, model ini telah digunakan untuk memberbezakan imej WV-2 dari daripada kawasan yang berlainan dan terbukti bahawa model ini berpotensi untuk menjangkakan bahan bumbung di kawasan kajian yang berlainan seperti Kuala Lumpur dan dua bahagian di Universiti Putra Malaysia dengan ketepatan melebihi 81% daripada kawasan-kawasan yang berbeza dan membuktikan bahawa model ini mempunyai potensi yang baik untuk meramalkan bahan-bahan bumbung dari WV-2 imej tanpa menggunakan data latihan.

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I certify that a Thesis Examination Committee has met on (7/02/2014) to conduct the final examination of Ebrahim Taherzadeh Mobarakeh on his thesis entitled "Dete" 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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| | |
|---|---|
| °C | Celsius degree |
| ASTER | Advanced space-borne thermal emission and reflection radiometer |
| CASI | Compact airborne spectrographic imager |
| CV | Cross-validation |
| DA | Discriminate analysis |
| *et al.* | et alia |
| etc. | et cetera |
| ETM+ | Landsat enhanced thematic mapper plus |
| g/l | Gram per liter |
| HSI | Hue, saturation, and intensity |
| KL | Kuala Lumpur |
| LDA | linear discriminant analysis |
| LST | land surface temperature |
| M | Meter |
| Mg | Milligram |
| mg/l | milligram per liter |
| MLH | Maximum likelihood |
| MM | Mathematical morphology |
| MNF | Minimum noise fraction |
| MP | Morphological profile |
| MTMF | Mixture tuned matched filtering |
| NIR | Near infrared |
| NN | Neural Network |

| | |
|---|---|
| OO | Object oriented |
| PCA | Principle component analysis |
| PPI | Pixel purity index |
| QUAC | Quick atmospheric correction |
| RBF | Radial basis function |
| ROI | Region of interest |
| RS | Remote sensing |
| SAM | Spectral angle mapper |
| SWIR | Shortwave infrared |
| TIR | Thermal infrared |
| TM | Thematic mapper |
| UHI | Urban heat island |
| UPM | University Putra Malaysia |
| VHR | Very high resolution |
| V-I-S | Vegetation-Impervious surface–Soil |
| WV-2 | Worldview-2 |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Almost half of the world population lives in urban areas and this proportion will be increased to 60% by 2030 (United Nations, 2001). Over the last few decades, urban area has been growing very fast, although this area occupies the small fraction of the earth's land surface (5% of the earth's surface). The large diversity of man-made and natural surface materials in the urban area can affect the ecological (Arnold and Gibbons, 1996), climatic and energetic (Oke, 1987) conditions. The centers of human activity are cities, and because of the boom of cities, urban mapping is becoming more significant. Due to the rapid expansion and development of urban centers and cities, new methods are needed in order to update the databases instead of traditional methods, which are typically based on field investigations and the visual interpretation of aerial photographs.

Remote sensing (RS) refers to the technology that is able to collect the data from the object without direct contact with it. Using RS technology and RS data for urban areas applications is relatively new topic and becoming one of the interesting topics in the RS community. With the advent of high resolution imagery and new sensors the new opportunities are opened to the RS community for different urban application.

Impervious surface (IS) is defined as the entirety of surfaces through where the water cannot penetrate the soil, including roads, sidewalks, parking lots, rooftops, and so on (Arnold and Gibbons, 1996). It has been known as an important indicator in urban environmental conditions (Conway, 2007; Hu and Weng, 2009; Weber and Bannerman, 2004). One of the sources of pollution in the rivers and lakes is runoff in the urban area that mostly created through the IS (Arnold and Gibbons, 1996; Booth and Jackson, 1997).

Detection and assessment of the percentage of IS in the heterogeneous urban area are one of the challenging and important tasks in urban RS. Due to the impact of the IS on the environment the concentration in this field of study has been growing (Weng, 2001; Civco *et al*., 2002; Dougherty *et al*., 2004; Wang and Zhang, 2004).

In this study, detection of the IS especially the roof of buildings based on their materials using multispectral RS data is proposed. Detection of the roof types and conditions are important; knowledge about the roof material types can assist applications such as disaster preparedness (Bhaskaran *et al.,* 2001), urban heat island assessment (Ben-Dor *et al.,* 2001) runoff quality (Paul and Meyer 2001; Birs and Robert- Sainte 2009,; Clark *et al.,*2008).

Traditional methods which are based on field survey is very time consuming and costly, additionally in some part of the urban area collection of the data is very difficult tasks due to the security of the building. RS data can play the critical role in order to provide the information about the spatial distribution of IS in the urban area.

Still, there is a lack of suitable methods to quantify and assess IS in an accurate, quick and economical way. In order to update the information about the cities new methods are needed instead of the existing and traditional methods.

In order to assess and classify the urban land cover at the material level, very high resolution (VHR) imagery is required (Zhou and Troy, 2008). For supervised classification of IS at material level, such as roofing materials, the adequate training data is needed. Lack of sufficient training data is one of the limitations, due to the security of buildings, permission to access the roof could not be obtained, or access was impossible. Based on the literature, several studies have been done to illustrate the potential of hyperspectral data to discriminate the urban surface materials (Ben-Dor *et al.,* 2001; Heiden *et al.*, 2001; Heiden *et al.,* 2007; Herold *et al.,* 2004) because of its high spectral resolution able to detect, classifying, and disseminate materials on the earth more than the traditional multispectral imagery with only several wideband spectral channels (Platt and Goetz, 2004).

In this research, two types of RS data were employed such as hyperspectral and multispectral data to detect the different roof types in Malaysia. Despite the availability of space-borne hyperspectral systems (Shafri *et al*., 2012) data acquisition is normally expensive, the coverage area is limited and the analysis can be too complex compared to the multispectral imagery. In this study VHR imagery such as Worldview-2 (WV-2) image was used which, unlike other commercial sensors, contains 8 spectral bands high spatial resolution (0.5 m pan sharpened). Some studies employed Landsat or SPOT image, but these images are not recommended for an urban study because of the low spatial resolution. It should be mentioned that despite the fact that VHR imagery provides more information about an object, but once spatial resolution increases, discrimination between classes is reduced because of increased internal variability of objects (Thomas *et al.,* 2003; Kumar and Castro, 2001). Some studies have used the VHR satellite image such as Ikonos or Quickbird; they are relatively limited in their spectral resolution and these types of data are employed to discriminate between significant land cover in urban areas such as road, building and water body and still there are some misclassification in order to discriminate and classifying the residential and non-built up materials (Herold *et al.,* 2002).

Studies show that the traditional RS classification methods such as Maximum Likelihood (MLH) and Parallelepiped which are only based on the spectral information are insufficient for classifying the VHR imagery in urban area (Cushnie, 1987; Thomas *et al.,* 2003, Chen *et al.,* 2004). Recent research shows that using the spectral information only is not sufficient for urban area mapping up to materials level and integration of high spectral and spatial information is necessary to achieve accurate mapping output.

Spatial information is valuable and significant when analyzing very high spatial resolution RS data and utilizing this type of information can be directly exploited for modeling the objects in the scene, especially to detect and extract the objects and in addition this can be increased the discriminability between different classes in classification tasks (Dalla Mira *et al.,* 2010). It is very important to combine the spectral information with another source of information which is inherent in an image such as spatial information (Gong *et al.,* 1992; Pesaresi and Benediktsson, 2001; Shackelford and Davis, 2003a; Chen *et al.,* 2004) and texture information for land use and land cover classification that can improve the classification accuracy.

One of the successful techniques in order to utilize the spectral and spatial information by Pesaresi and Benediktsson (2001) was presented. They presented a technique based on morphological profiles (MPs), which was carried out with opening and closing transformations that are defined in mathematical morphology (MM) based on the geodesic reconstruction.

With the aim of extracting and integrating spatial, spectral and textural information, the object-oriented (OO) approach is used. Studies show the discrimination between different land cover in the urban area is increased with spectral similarity when these types of information are employed (Wang *et al.*, 2007; Gong *et al.*, 1992; Shackelford and Davis, 2003b; Wang *et al.*, 2012; Goetz *et al.*, 2003). The OO classification approaches, in general, show better results compared with pixel-based approaches when mapping individual landscape features (Lu and Weng, 2007).

Nevertheless, to define objects in terms of certain rules based on extracted information, a priori knowledge is needed which is a difficult task. Generally, the relevant information is not well formalized, and it is difficult to directly obtain such implicit knowledge, which is ordinarily held only by domain experts (Sheeren *et al.*, 2006). Previous studies, such as (Hamedianfar and Shafri, 2013) have defined the optimal rule sets for a limited coverage urban area, but the rules are not transferable and generic for other different areas.

According to some limitations of urban RS in order to extract the IS at material level, it should be mentioned that most of the studies employed airborne hyperspectral data due to high spectral resolution of this data which enable us to extract more information about the IS up to the material level. However, there is a lack of studies that used multispectral satellite data to extract the IS at the material level. In addition, collecting adequate training data is very time consuming and costly, thus inadequate training data and lack of generic and transferable model that utilized the spectral, spatial and textural information inherent in the VHR data are other challenging tasks in urban RS context.

Thus the main goal of this research is to build a generic model to map roof materials based on the OO approach and available training data and finally apply this generic model to predict and detect the spatial distribution of the roof materials in different areas without using training data using WV-2 images. The proposed technique has the potential to be economically and technically superior; for example there is no need to use the training data and utilize all the information that are inherent in the WV-2 image thus leads to savings in time and money.

As an added motivation of this research, determination of housing assessment in Malaysia is now a controversial issue. The use of the proposed technique can help with not only identifying the roof material, but also helps to determine the illegal extension or renovation of housing blocks.

## 1.2 Research Objectives

In general, this study will investigate the applicability of VHR satellite RS data in mapping urban features, especially roof materials and build a generic model based on spectral, spatial and texture information.

The specific objectives of this study are:

- To investigate the performance of hyperspectral and high spatial resolution multispectral data for their suitability and effectiveness in urban mapping.
- To design a new approach based on generic rules for extracting the roof materials based on spectral, spatial, texture and color combination in order to improve urban area classification accuracy and better discrimination of urban roof materials.
- To validate the generic model in different study areas in order to test the transferability of the proposed technique.

## 1.2 Organization of Remaining Chapters

Chapter 2 reviews the literatures related to definition of RS, urban RS, IS and later on the application of RS including the multispectral and hyperspectral data in order to detect the IS. The next part of this chapter, some important types of classification approaches such as spectral-based and OO will be reviewed. In the last part of this chapter the summary and the gaps of the previous researches will be explained.

Chapter 3 includes the materials and methods utilized in this research to achieve the objectives of this study. The first of this chapter is related to hyperspectral data analysis in order to extract the roof materials. The next part of this chapter assigns to the procedure and methods applied to WV-2 image such as the spectral-based classification approaches (MLH, Support vector machine) and the developed techniques to extract the roof materials that include MM and generic model.

Chapter 4 includes the results of this research after applying the different methods. As mentioned before, two types of data were used in this study thus the first part of this chapter is related to the experimental result of hyperspectral data using spectral-based approach and the second part is related to multispectral data which is divided to three parts including the spectral-based, OO using MM and finally the generic model result. At the end of this chapter the findings and results will be interpreted.

In chapter 5, conclusions and recommendations are presented. Overview of the findings, limitations and the benefits of this research are explained and furthermore some recommendations for future studies are given in the recommendation part of this chapter.

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