Detailed urban object-based classifications from WorldView-2 imagery and LiDAR data: supervised vs. fuzzy rule-based

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Key words: Object-based classification, LiDAR data, WorldView-2 imagery, urban area

SUMMARY

Detailed and small scale mapping of urban surface materials is challenging and difficult; due to spectral and spatial heterogeneity of pervious and impervious surfaces. This paper investigates the comparative assessment of object-based classifications including fuzzy rule-based and supervised Support Vector Machine (SVM) to perform detailed characterization of urban classes. In this study, image classifications were applied to combine the attributes of WorldView-2 (WV-2) imagery and LiDAR data. Image segmentation and merging objects was used for both classifiers to construct the spectral, spatial, textural, and elevation attributes. Classification result of supervised SVM contained mixed objects and misclassifications of impervious surfaces and other urban features. This classification achieved 85.02% overall accuracy. Rule-based classifier performed better than supervised SVM resulting in finer discrimination of spatially and spectrally similar objects. The overall accuracy of rule-based classification was 93.07%. This study showed that, rule-based feature extraction more accurately can characterize the heterogeneities and diversities of urban areas. This approach was flexible in extracting the urban targets from WV2 imagery and LiDAR data. Therefore, effective separation of urban surface materials was achieved by rule-based classifier.

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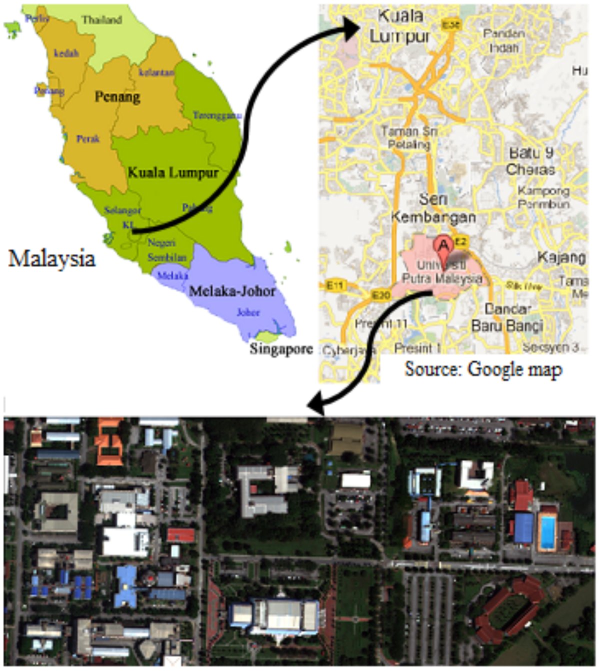
1. Introduction

Detailed and small scale mapping of urban surface materials is challenging and difficult, due to spectral and spatial heterogeneity of pervious and impervious surfaces. Although remote sensing imageries can successfully monitor these features, fine scale mapping of urban surface materials is a complicated task. Urban areas include a wide range of virtual and natural materials, which result in spectral and spatial diversity of surface materials (Herold et al 2003). Hyperspectral remote sensing obviously offers detailed urban infrastructure type mapping (Taherzadeh and Shafri 2011; Heiden et al 2012); however, the effective usage of such data is prohibitive due to their limited coverage and being expensive to be operationalized (Shafri et al 2012). Resolution improvement of Very High Resolution (VHR) multispectral imageries by WorldView-2 (WV-2) imagery provides the remarkable potential in detailed mapping of urban environment. WV-2 imagery with high spatial resolution and new spectral bands can effectively reduce the needs of utilizing hyperspectal data in detailed urban mapping. It should be noted that, although VHR imageries are limited in the number of spectral bands, but their higher coverage and cheaper price can be economically reasonable compared to hyperspectral data. While VHR imageries are able to identify small-scale features (such as rooftops and roads), heterogeneities of engineered and natural features contribute misclassifications in pixel-based land cover classifications.

Pixel-based classifiers ignore spatial and textural characteristics of urban features and produce mixed pixels as well as salt and pepper noise in image classification of VHR (Blaschke and Strobl2001). Hamedianfar and Shafri (2013) utilized WV-2 image to compare the accuracy and performance of per-pixel classifiers (such as Maximum Likelihood and Support Vector Machine) with object-based classifications. Their study showed that both parametric and non-parametric pixel-based classifiers resulted in many misclassifications and salt and pepper effects. Therefore, object-based image analysis can be used as an alternative technique to deal with spectral and spatial diversity of pervious and impervious features. This approach can be performed rule-based or supervised (ENVI-Zoom 2010). This classification performs image segmentation to split the image to homogenous image objects and integrate spectral, spatial, and textural information (Baatz and Schape 2000). Many studies have stated the potential and abilities of object-based classification to map urban features (Blaschke and Strobl 2001; Zhou and Troy 2008; Myint et al 2012; Hamedianfar and Shafri 2013). As it can handle ancillary data such as LiDAR products and vector layers, the classification accuracy can efficiently get enhanced (Zhou and Troy 2008; Hamedianfar et al 2014). The data integration of VHR imagery and LiDAR products can overcome the vertical and horizontal heterogeneities of urban environment (Chen et al 2009; Hodgson et al 2003). It should be noted that both supervised and rule-based classifiers can handle the combined image of VHR imagery and LiDAR. Supervised technique can be executed more quickly than rule-based approach. It should be noted that if supervised classifier can be performed similar or better than rule-based classifier, it is not meaningful to conduct rule-based classification. The objective of this study is to demonstrate a comparative assessment of object-based classifications including rule-based and supervised Support Vector Machine (SVM) classifiers to perform detailed characterization of urban areas by using a hybrid image from WV-2 and LiDAR data. In addition, this data integration was examined the potential object-based classifiers to utilize the new generation of VHR in combination with LiDAR data in accurate discriminating of concrete tile roofs, metal roofs, asbestos roofs, roads, sidewalks, pond, swimming pool, grass, tress, and shadow.

2. Study area and data

This study is conducted using WV-2 imagery and LiDAR data in a part of Universiti Putra Malaysia (ranged from upper left longitude 3°00’14.48”N and latitude 101°42’14.71”E, lower right longitude 3°00’00.71”N and latitude 101°42’44.12”E, of WGS84 coordinate system). Study area (Fig1) contains heterogeneous impervious surfaces.



Source: Google map

Figure 1 Study area

Rooftops vary in terms of shape, size and brightness. In addition, roads and sidewalks have serious spectral confusion with rooftops. LiDAR data was used as an ancillary data to reduce the spatial and spectral diversity of impervious surfaces. This data was created by 0.5m pixel size that can be matched by WV-2 spatial resolution. Digital Elevation Model (DEM) was subtracted from Digital Surface Model (DSM) to create normalized Digital Surface Model (nDSM). nDSM provides height information for urban features such as buildings, trees, etc. Fig 2 shows the nDSM image. Both WV-2 and nDSM are geometrically corrected to UTM projection, zone 47N and Kertau48. Pan-sharpening (Zhang 2002) of WV-2 image was performed to provide more de-tailed visualization about impervious features.

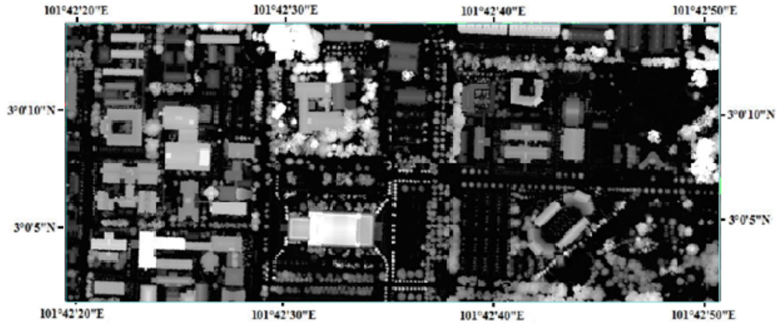


Figure 2 nDSM image

3. Object-based classifications

Object-based classifications based on fuzzy rule-based and supervised SVM classifiers were demonstrated in this paper. Hybrid image of WV-2 and nDSM was utilized to conduct the image analysis. Attributes (spatial, spectral, texture, and elevation) were computed for each segment using edge-based segmentation. In order to avoid over/under segmentation, merging object was used to improve the delineation of boundaries of features. As suitable and extra attributes can considerably improve the accuracy of image classification, a multi-band file was generated including WV-2, nDSM, Normalized Difference Vegetation Index (NDVI).

3.1 Supervised object-based classification by SVM

SVM is popular in remote sensing data analysis due to its ability to deal with small training data sets. It investigates and finds the hyperplanes within n-dimensional feature space that separate data set into classes in a consistent fashion with training sites resulting in reduction of misclassifications (Mountrakis et al. 2011). Supervised classification utilizes training data to allocate unknown objects to known classes. Radial Basis Function (RBF) was employed as a kernel for SVM. As recommended by Hsu et al. (2009), grid-search using cross-validation approach is the most effective method to optimize the RBF parameters. The cross validation determined the optimal parameter of $C = 0.5$ and $\gamma = 0.0078$ with 5-fold function rate = 99% (Hamedianfar and Shafri 2013).

3.2 Rule-based object-based classification

Rule-based classification is a feature extraction approach that allows rule set creation to map particular features class based on its spectral, spatial and textural characteristics. Rules are created based on human knowledge and reasoning about specific land-cover types (ENVI-Zoom 2010). For example, dark building has a low NDVI, roads are elongated, buildings are rectangle in shape, water has a low mean value in NIR band, and vegetation has a high NDVI and trees are highly textured compared to grass. To extract spesific features, multiple rules can be defined to separate unwanted features from targeted features, and assigning wanted objects to desired feature class. Rule-based classifiers permit user to apply fuzzy membership function to characterize the degree that an object belongs to a specific land cover class. In this study, s-type membership function was employed to deal with fuzzy nature of urban environment (Jin & Paswaters 2007).

3.3 Accuracy assessment

Standard confusion matrix was used to perform the accuracy assessment of image classifications. Accuracy assessment is based comparing the classification results with true land cover condition or ground truth data (Congalton 1991). Ground truth data was collected by field survey. Stratified random sampling was used in accuracy assessment to distribute the ground truth samples on WV-2 imagery and classified images.

4. Results and Discussion

4.1 Supervised object-based classification by SVM

Figure 3 shows the classified image of supervised object-based by SVM classifier. This classification achieved the overall accuracy and kappa coefficient of 85.02% and 0.82, respectively (Table1). In this classification, it was tried to select sufficient numbers of training objects to carry out the classification. It is important to note that supervised object-based classification is underperformed with the large number of training samples (ENVI-Zoom 2010). Although feature height information was added to spectral, spatial and textural information; SVM classifier could not produce an accurate result from impervious surfaces.

This result exhibited the mixed objects between roofing materials and roads and sidewalks. Utilization of height information was useful to separate the heterogeneous spectra of rooftops from roads and sidewalks. The classes of grass and trees were well extracted by the classifier. Textural, spectral, and elevation attributes were useful to make the differentiation between grass and trees. Pond was classified with high user and producer accuracies, but its misclassification can be seen with dark metal roofs showing that classifier could not make use of elevation information to separate these two classes effectively. Finally this classifier showed the accurate characterization of swimming pool and shadows with high user and producer accuracy.

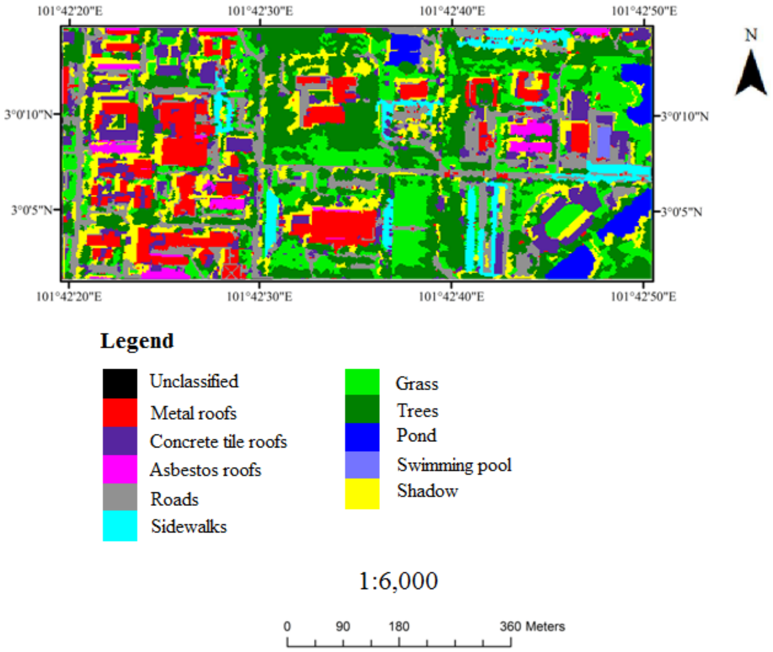


Figure 3 result of supervised SVM object-based classification

Table1 Accuracy assessment of supervised SVM object-based classification

class	Reference total	Classified total	Correct classified	Pa %	Ua %
Mr	80	58	58	72.50	100
Cr	58	57	47	81.03	82.46
Ar	24	40	24	100	60
R	61	43	41	67.21	95.35
S	10	24	10	100	41.67
G	52	52	51	98.08	98.08
T	72	83	71	98.61	85.54
P	33	38	33	100	86.84
Sp	5	5	5	100	100
Sh	39	34	29	74.36	85.29
Overall Accuracy = 85.02%			Kappa Coefficient = 0.82		

Note: Mr =metal, Cr: concrete tile roofs, Ar: asbestos roofs, R= roads, S=sidewalks, G=grass, T=trees, P=pond, Sp= swimming pool, Sh=shadow, Pa= producer accuracy, and Ua= user accuracy

4.2 Rule-based object-based classification

After performing segmentation and merging steps, fuzzy rule-based classifier with S type membership function was utilized to build the optimal rule-sets. These rule-sets of object-based classification were developed to cope with spatial and spectral diversity of urban features. Fuzzy logic allows well approximation of human reasoning as well as the probabilities to assign image objects to their related feature classes.

As mentioned earlier, urban surface material characterization is a challenging task, mainly due to spectral and spatial diversities of urban surface materials. The classification result (Figure 4) shows that rule-based object-based classification of WV-2 imagery and LiDAR data can effectively alleviate the aforementioned heterogeneities. Figure 4 shows the better discrimination of impervious surface compared to supervised SVM. Bering in mind that, some parts of roads were not extracted due to: (1) being covered by trees, (2) being colored by road marking.

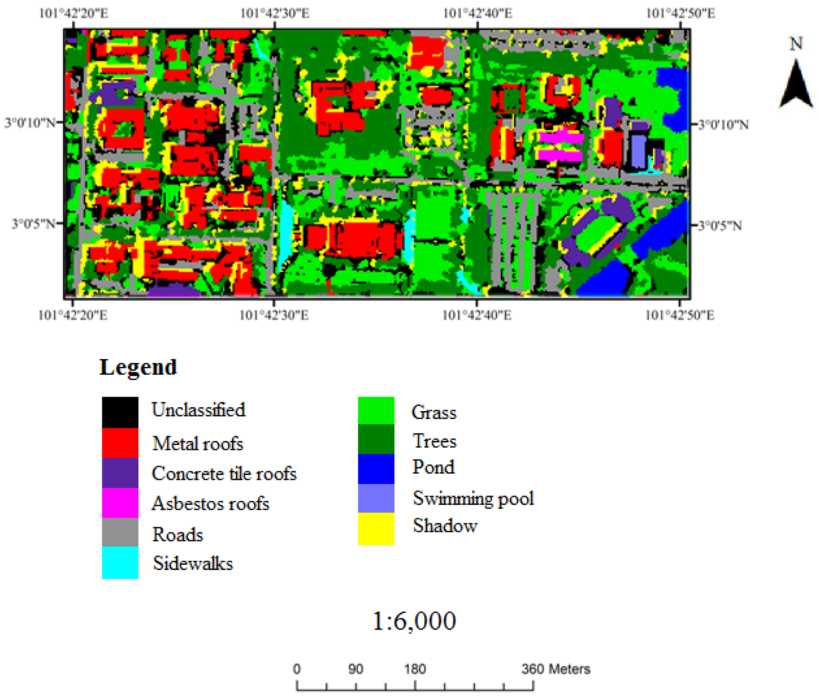


Figure 4 result of rule-based object-based classification

The overall accuracy and Kappa coefficient were reported to be 93.07% and 92%, respectively (Table 2). Several attributes were used to differentiate metal roofs from other features. Firstly, nDSM applied to discriminate metal roofs from low elevated features such as roads and grass. Concrete tile roofs showed to be the most heterogeneous impervious surface. Different spatial, spectral, texture and elevation were used to extract these rooftops. Then, attributes from nDSM, costal blue band, blue band and yellow band were used to discriminate concrete tile roofs from other unwanted features. Figure4 and table 2 show the improvement made in mapping of concrete tile roofs compared to supervised SVM classifier result. To extract asbestos roofs, NDVI was assisted in elimination of spectrally and spatially similar features as well as vegetated areas. Then, tx-entropy was applied to differentiate asbestos roofs from roads. The rule sets of asbestos roofs overcome the mixed object of this class with concrete tile roofs and roads classes. In order to discriminate roads, NDVI was used to remove the vegetations. Then, nDSM was applied to differentiate road from elevated features. After that, costal band was useful to get rid of spectrally similar features such as dark roof tops and water bodies. To extract sidewalks, different attributes were tested. Firstly, NDVI was used to remove building and vegetation. Then, NIR2 and mindir were used to differentiate sidewalks from dark rooftops and roads. Classification result of pervious classes was achieved high producer and user accuracies, due to less spatial and spectral diversities between these materials. Textural, spectral and elevation attributes were so effective to map these feature classes. Descriptions of mentioned attributes are available in ENVI-Zoom (2010).

Table2 Accuracy assessment of rule-based object-based classification

class	Reference total	Classified total	Correct classified	Pa %	Ua %
Mr	80	80	78	97.50	97.50
Cr	58	58	52	89.66	100
Ar	24	24	24	100	100
R	61	61	51	83.61	91.07
S	10	10	10	100	100
G	52	52	51	98.08	89.47
T	72	72	71	98.61	92.21
P	33	33	33	100	100
Sp	5	5	5	100	100
Sh	39	39	30	76.92	96.77
Overall Accuracy = 93.07%			Kappa Coefficient = 0.92		

Note: Mr =metal, Cr: concrete tile roofs, Ar: asbestos roofs, R= roads, S=sidewalks, G=grass, T=trees, P=pond, Sp= swimming pool, Sh=shadow, Pa= producer accuracy, and Ua= user accuracy

5. Conclusion

This paper investigated the technical performance of fuzzy rule-based and supervised SVM classifications to utilize the attributes of VHR imagery of WV-2 and LiDAR data. Supervised SVM resulted 85% overall accuracy. Although it was tried to select sufficient number of training objects for this classification, classified output showed the misclassification between impervious surfaces. It could be due to supervised nature of this classification which cannot effectively differentiate the spatial and spectral diversity of roof types, roads and sidewalks through supervised characterization. Developed object-based rule-sets produced better classified image compared to supervised SVM. Urban surface materials were approximately well delineated by rule-based classifier. As this rule-sets are generated with respect to human knowledge and reasoning, better result can be seen in classification output. This classification achieved the overall accuracy and kappa coefficient of 93.02% and 92%, respectively. In addition, this study showed the significant potential of LiDAR and WV-2 data fusion to extract urban classes. LiDAR data assisted in reduction of vertical and horizontal heterogeneities. Combining attributes of WV-2 with nDSM provided an effective separation of spectrally similar image objects. This data fusion helped to make an adequate distinction between urban surface materials. Rule-based object-based classification provided the accurate classified map, since it efficiently utilized spectral, spatial, texture and elevation information. Future study can be done to explore the transferability of rule-sets of rule-based classification to another study region. At the same time supervised object-based classification with K Nearest Neighbor and SVM can be performed to indicate their capability for classify bigger and different scenes of VHR imageries.

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BIOGRAPHICAL NOTES

Alireza Hamedianfar is a PhD candidate in the field of Remote Sensing at Uiniversiti Putra Malaysia (UPM). His research focused on urban mapping, feature extraction, and expanding the scope of urban remote sensing applications with the use of Object Based Image Analysis (OBIA). He holds a Msc in Remote Sensing and GIS from UPM and BSc degree in Surveying Engineering from IAU in Iran.

Helmi Z. M. Shafri received his BSc in Surveying degree from RMIT University, Melbourne, Australia in 1998. He obtained his PhD in remote sensing from the University of Nottingham, UK in 2003 and is now the Head of Department of Civil Engineering, Universiti Putra Malaysia (UPM). His major research interests are hyperspectral and hyperspatial remote sensing data analysis and algorithm development especially for urban and engineering applications.

Shattri Mansor, is curently a Professor in Remote Sensing at Faculty of Engineering, Universiti Putra Malaysia. His major research effort includes feature extraction from satellite imagery, spatial decision support system, fish forecasting, oil spill detection and monitoring system, UAV-based remote imaging, disaster management and early warning system. He has published over 300 articles in and conference proceedings. In tandem with his expertise, Dr. Shattri has also supervised and co-supervised a total of *22 MS students, 24 PhD students and 6 post doctorates*. Dr. Shattri holds membership to various organizations and institutions. He has served as a *councilor* for the Institution of Surveyors Malaysia (ISM), an *Editor* of the Journal of the Malaysian Surveyor and an executive committee for Malaysian Remote Sensing Society and an *executive committee* for the Royal Institution of Surveyors Malaysia (ISM Geomatics and Land Surveying Division). He is currently the Editorial Board member of Disaster Advances Journal and International Journal of Geoinformatics.

Dr. Noordin Ahmad has been an academician, practitioner and holding respected government post. He has been involved in the Geospatial industry since late 80's and has carried out many GIS and GNSS consultancy works. He is also involved in various researches in the Geospatial field mainly focusing on Optimization using GIS and LBS applications with GNSS.

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