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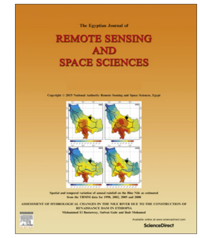

RESEARCH PAPER

A novel spectral index to automatically extract road networks from WorldView-2 satellite imagery

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Abstract This research develops a spectral index to automatically extract asphalt road networks named road extraction index (REI). This index uses WorldView-2 (WV-2) imagery, which has high spatial resolution and is multispectral. To determine the best bands for WV-2, field spectral data using a field spectroradiometer were collected. These data were then analyzed statistically. The bands were selected through the methodology of stepwise discriminant analysis. The appropriate WV-2 bands were distinguished from one another as per significant wavelengths. The proposed index is based on this classification. By applying REI to WV-2 imagery, we can extract asphalt roads accurately. Results demonstrate that REI is automated, transferable, and efficient in asphalt road extraction from high-resolution satellite imagery.

1. Introduction

Remote sensing can monitor built-up areas because it can detect the growth and spatial distribution of urban built-up, such as roads. Furthermore, remote sensing images provide a synoptic view of land cover (Xu, 2008; Bhatta, 2009; Griffiths et al., 2010).

In remote sensing applications, road extraction is challenging. Moreover, information on road networks is important in urban planning and transportation engineering. Thus, this information must be accurate and updated (Rajeswari et al., 2011). Local communities must monitor urban road extraction in a timely and cost-effective manner (Xu, 2008). Through this monitoring process, the monitoring time of automatic road extraction can be reduced and the spatial databases of some applications can be updated. In applications requiring precision, developing fully automated algorithms to determine road network information is difficult (Tupin et al., 2002; Chaudhuri et al., 2012).

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To identify built-up land features through unsupervised classification, Masek et al. (2000) established a technique based on a normalized difference vegetation index (NDVI). To automate the mapping process of built-up areas and to accurately extract urban features, Zha et al. (2001) developed the novel normalised difference built-up index (NDBI). Moreover, Zha et al. (2003) automatically mapped urban built-up areas by arithmetically manipulating NDBI and NDVI. However, this method is ineffective because the extracted features did not differentiate built-up areas from bare land successfully. He et al. (2010) improved the accuracy of the original approach using the automatic segmentation method. Varshney (2013) enhanced this method further by setting an optimal threshold value. This value allocates the improved positive difference values of continuous NDBI and NDVI to built-up areas. To enhance the efficiency of the detection process of built-up change in both built-up and bare areas, a thresholding algorithm based on automated kernels is utilized. This algorithm also classifies the difference values of multi-temporal images. To map urban areas, Xu (2008) developed the index-based built-up index. This index is derived from three different indices, namely, the soil adjusted vegetation index, modified normalized built-up index, and NDBI. To detect asphalt and concrete surfaces, Mhangara et al. (2011) established a new spectral index called the built-up area index (BAI) for SPOT imagery. Furthermore, several previous studies focused on spectral indices for Landsat TM imagery. Despite the effectiveness of these indices on such data, they may be difficult to apply to novel imagery with high spatial resolution.

Several studies have attempted to develop fully automated procedures to extract roads from remotely sensed images with high resolution (Bacher and Mayer, 2005; Kirthika and Mookambiga, 2011; Karaman et al., 2012; Zarrinpanjeh et al., 2013). Given road map limitations such as time-consuming field surveys, accurate and timely road network information is detected using high resolution imagery (Resende et al., 2008; Hu et al., 2007; Valero et al., 2010; Das and Mirnalinee, 2011; Xinpeng et al., 2014). Hence, high spatial resolution satellites such as IKONOS and QuickBird mainly extract impervious surfaces (Cablk and Minor, 2003; Lu and Weng, 2009; Wu 2009).

Some methods integrate hyperspectral field spectroradiometry with multispectral imagery to extract roads and conditions simultaneously (Herold and Roberts, 2005; Kavzoglu et al., 2009; Mohammadi, 2012; Andreou et al., 2011). Road network information can be extracted from WorldView-2 (WV-2) satellite imagery (DigitalGlobe, 2009). Unlike other commercial satellites, the WV-2 satellite imagery contains eight bands with high spatial resolution. These new features can help to extract information more effectively than other images with high spatial resolution. 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.

Hence, we develop an automated technique based on spectral index, using a field spectroradiometer to identify the significant bands. These bands are selected through stepwise discriminant analysis (DA). This method distinguishes useful bands for asphalt road extraction. The selected significant bands are matched on the WV-2 range to establish a new spectral index and assess asphalt road extraction.

2. Materials and methods

2.1. Study area

The selected study area is a section of Universiti Putra Malaysia (UPM) in Serdang, Selangor. This area is located between 3°00′34.05″N,101°43′19.77″E and 3°00′01.21″N, 101°42′35.63″E (Fig. 1a) and is surrounded by approximately 10 km^2 of residences and nature. The study area is also bordered by numerous tall trees and various buildings, as well as pervious and impervious surface materials.

2.2. Data acquisition

The information obtained by the field spectroradiometer were used as spectral reflectance. Data were obtained by an ASD hand-held spectroradiometer (Fig. 2a), which detects reflectance within the wavelength range of 350–2500 nm. Sampling was conducted in clear weather when illumination was stable. To determine the exact location of roads on the images, a Garmin handheld global positioning system (GPS) device was used during field observation (Fig. 2b).

In this study, we utilized a WV-2 satellite image. This satellite was launched in October 2009 as the first multispectral high-resolution system with eight bands. WV-2 has eight spectral sensors in the visible to near-infrared regions and provides 1.85 m and 46 cm multispectral and panchromatic resolutions, respectively. The high spatial resolution discriminates between various fine details, and the spectral resolution provides details on road surface quality, as shown in Fig. 1c and d.

2.3. Data pre-processing

To generate accurate results with WV-2 images, the data were preprocessed. The geometries were corrected based on points collected from Google Earth. The images were selected to generate a spectral index for road extraction using WV-2 images. To refine the results and maintain the sharpness of the images, the data were passed through Lee filters (Taherzadeh and Shafri, 2011).

2.4. Data processing and analysis

Significant data bands were identified using the band selection method. This method can extract asphalt roads and quality. The selected bands are then compared to discriminate the important ones on WV-2. To develop the new index, we identified significant bands through stepwise DA.

Stepwise DA was mainly applied to examine the differences between groups. It effectively discriminates among classes and generates the quantitative variable that reduces data dimensionality. Subsequently, different parts of the image are validated under the novel spectral index based on WV-2 imagery to assess its accuracy. The stepwise DA method was applied to the reflectance given a significance level of 0.05. This band selection method was also used by Fung et al. (2003), Clark et al. (2005), Debba et al. (2009), and Pu et al. (2011).

In DA, all independent variables can be simultaneously entered into the equation. Moreover, stepwise DA can eliminate insignificant independent variables when the number of