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Using pan-sharpened high resolution satellite data to improve impervious surfaces estimation

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ABSTRACT

Impervious surface is an important environmental and socio-economic indicator for numerous urban studies. While a large number of researches have been conducted to estimate the area and distribution of impervious surface from satellite data, the accuracy for impervious surface estimation (ISE) is insufficient due to high diversity of urban land cover types. This study evaluated the use of panchromatic (PAN) data in very high resolution satellite image for improving the accuracy of ISE by various pan-sharpening approaches, with a further comprehensive analysis of its scale effects. Three benchmark pan-sharpening approaches, Gram-Schmidt (GS), PANSHARP and principal component analysis (PCA) were applied to WorldView-2 in three spots of Hong Kong. The on-screen digitization were carried out based on Google Map and the results were viewed as referenced impervious surfaces. The referenced impervious surfaces and the ISE results were then re-scaled to various spatial resolutions to obtain the percentage of impervious surfaces. The correlation coefficient (CC) and root mean square error (RMSE) were adopted as the quantitative indicator to assess the accuracy. The accuracy differences between three research areas were further illustrated by the average local variance (ALV) which was used for landscape pattern analysis. The experimental results suggested that 1) three research regions have various landscape patterns; 2) ISE accuracy extracted from pan-sharpened data was better than ISE from original multispectral (MS) data; and 3) this improvement has a noticeable scale effects with various resolutions. The improvement was reduced slightly as the resolution became coarser.

1. Introduction

With the expansion of urbanization, development of impervious surfaces has greatly boosted and become increasingly complicated. Previous researches have focused on impervious surfaces estimation (ISE) from different remote sensing images such as MODIS, TM, SPOT, IKONOS, WorldView-2, Quickbird (Yuan and Bauer, 2007; Schneider et al., 2009; Knight and Voth, 2011; Lu et al., 2011a,b; Im et al., 2012; Yang et al., 2012; Deng and Wu, 2013a,b; Hong et al., 2013; Xu, 2013; Lu et al., 2014; Zhang et al., 2014a), and a number of exemplary methods have been developed for ISE in the past decades, including linear spectral mixture analysis (LSMA) (Civco et al., 2002; Yang et al., 2003a,b; Lu and Weng, 2004; Deng and Wu, 2013a,b; Li et al., 2013a,b), artificial neural network (ANN) (Hu and Weng, 2010; Patel and Mukherjee, 2014); support vector machine (SVM) (Sun et al., 2011; Zhang et al., 2014b), regression tree model (CART) (Yang et al., 2003a,b; Shao et al., 2015). However, the accuracy of ISE may be inadequate due to mixed pixel problems caused by low spatial details of image data (Weng, 2012) and spectral confusion between different land cover types (Lu and Weng, 2004). Multisource data fusion used in land cover classification mainly included optical and optical data fusion (e.g. pan-sharpening), and optical and non-optical (e.g. SAR and LiDAR) data fusion. Data sets from different platforms have the ability to increase the accuracy of impervious surfaces estimation. Previous studies have shown the potential for extracting the impervious surface using fusion of optical and SAR data (Zhang et al., 2014b, 2015a). However, there is a few research related with pan-sharpening technique in impervious surface extraction. Although fusion of optical and SAR data and pan-sharpening all focuses on improve the accuracy of impervious surface extraction, there exist much difference between them. For instance, there is no medium product when using the optical and SAR data fusion, however, the pan-sharpening method provides

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new fused MS image for use. In other words, two products can be obtained through pan-sharpening method, including the original MS image and the sharpened images, but there is only one data set after adopting fusion of optical and SAR image. Pan-sharpening process provides two-resolutions (also means scales in this study) products, but the fusion of optical and SAR data only affords one-scale product. The intermediate products which come from the pan-sharpening can be used as input experiment data and allow us to compare the results of information extraction at different scales, which is insufficient in impervious surface extraction filed. Pan-sharpening technique has been widely studied to increase spatial resolution while maintaining spectral information of MS data by incorporating corresponding PAN data (Simone et al., 2002; Li et al., 2013a,b; Pohl and van Genderen, 2014). It aims to integrate the MS imagery with PAN imagery that has different spatial resolutions together (Pohl and van Genderen, 1998). A large number of pan-sharpened algorithms have been proposed in recent decades, such as: High-Pass Filtering (HPF) (Schowengerdt, 1980), Intensity-Hue-Saturation (IHS) (Haydn et al., 1982), Brovey (Hallda and Cox, 1983), Principal Component Analysis (PCA) (Chavez et al., 1991), Gram-Schmidt (GS) (Laben and Brower, 1998), PANSHARP (Zhang, 2004) etc. Although these typical pan-sharpened methods have certain low spectral fidelity problems, three of them are widely spread and adopted in commercial software – ENVI and PCI Geomatics: GS, PCA and PANSHARP. They are frequently used due to relative high-quality spectral fidelity and simple calculation principles. The pan-sharpened methods have shown their advantages in elevating classification accuracy (Palsson et al., 2012; Lwin and Murayama, 2013a,b; Johnson, 2015). However, the potential of pan-sharpened products for ISE improvement from VHR remote sensing data is still under-explored. With the availability of very high resolution (VHR) satellite data, such as WorldView-2 data, the accuracy and details have been dramatically increased in recent years. Unfortunately, high spatial resolution is always provided in panchromatic (PAN) band, while the spatial resolution for multispectral (MS) data is not high enough. For instance, the PAN data of WorldView-2 is 0.5 m, while the resolution for MS data is only 2m, there is a need to evaluate combining the spatial information from PAN data and spectral information of MS data for improving the accuracy of ISE.

Moreover, to investigate the potential of pan-sharpened data for ISE improving, the scales effects of this improvement were further analyzed. The concept of scale has many definitions, including geographical or observation scale, cartographical or map scale and operational scale (Lam and Quattrochi, 1992). When refers to remote sensing application, the mainly frequently used meaning of scale is means observation scale, in other word, the spatial resolution, and it mainly refers to spatial resolution, which is significant in remote sensing society (Moody and Woodcock, 1995; Treitz and Howarth, 2000; Ju et al., 2005; Johnson, 2015). Many studies have carried out which related to the idea of scale issues, even though the author did not clearly mention they are belongs to scale issue. Among the scale issues in remote sensing research, someone mentioned that with the spatial resolution change, the accuracy of information extraction has change (Marceau, 1999; Hsieh et al., 2001). This simple but promising result laid a foundation of scale research. From this concept, we can do many researches related with scales. For remote sensing classification, we can analyze the scale issues using different resolutions, since we can get many data types with varied resolution simultaneously. We can also analyze the scale issues in multisource data fusion. Hence, the objective of this research is to analyze the potential of pan-sharpened method in impervious surface accuracy elevation. In this paper, we assessed the performance of ISE under different scales by simulating various spatial scenes and made further analysis on the result.

Table 1
Detailed information of the datasets for three selected regions.

Research region	Band Name	Band Width(μm)	Obtained time
Yuen Long	Coastal	0.40–0.45	2014–01-16
	Blue	0.45–0.51	
	Green	0.51–0.58	
	Yellow	0.58–0.62	
	Red	0.63–0.69	
	Red edge	0.70–0.74	
	NIR1	0.77–0.89	
	NIR2	0.86–1.04	
	PAN	0.45–0.8	
Sha Tin/Central	Blue	0.45–0.51	2013-12-29(Sha Tin)
	Green	0.51–0.58	2014-01-30 (Central)
	Red	0.63–0.69	
	NIR	0.77–0.89	

2. Study areas and data sets

Three regions located in the urban area of Hong Kong were selected as the study areas, including Yuen Long, Sha Tin and Central. These three regions distributed in different part of Hong Kong as shown in Fig. 1. Fig. 2(a)–(c) display the false color composite of the research areas Yuen Long district is located in Northwest of Hong Kong, and the region is labeled as an industrial zone. Sha Tin district is mainly composed of residential areas, whereas Central is Central Business District (CBD) area full of skyscrapers. The landscape features in these areas mainly include grassland, man-made constructions (buildings, pavement, etc.), water, shadow (which should be considered in high resolution images) etc. Typical terrain types, rich space details and sufficient mixed pixels make the test images very suitable to evaluate the pan-sharpening and classification results (Aiazzi et al., 2007; Alparone et al., 2007). The WorldView-2 images were collected for mapping the impervious surfaces. The spatial resolutions of the MS and PAN images of WorldView-2 are 2 and 0.5 m, respectively. Table 1 displays the detailed information of the datasets for three selected regions, including the spectral information of WorldView-2 and data acquisition time.

Note: although the WorldView-2 has 8 bands in general, but only 4 bands of Sha Tin and Central regions could be obtained for data acquisition reasons.

3. Methodology

The methodological framework is shown in Fig. 3. The MS and PAN images with different spatial resolutions are pan-sharpened into new image with more spatial details and spectral information using GS, PCA and PANSHARP methods. Then SVM (Vapnik, 1979) is adopted for obtaining initial classification results and the referenced impervious surfaces are acquired through visual interpretation. The interpretation has been carefully conducted on the basis of the PAN image and Google Map (Lu and Weng, 2006) which could be treated as the most reliable reference. Percentage of impervious surfaces in each scale is obtained by overlaying different scales on referenced impervious surfaces and impervious surfaces extraction results. Then calculate the correlation coefficient (CC) (Wald et al., 1997) and root mean square error (RMSE) (Deng and Wu, 2013a,b) between the referenced and calculated impervious surfaces to evaluate the accuracy of ISE under various scales. More important, the average local variance (ALV) (Drăguţ et al., 2011; Ming et al., 2013; Woodcock and Strahler, 1987) was introduced to analyze the landscape patterns which influenced the classification results