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A spectral index ratio-based Antarctic land-cover mapping using hyperspatial 8-band WorldView-2 imagery

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Abstract

This study evaluates the potential of 8-band high resolution WorldView-2 (WV-2) panchromatic (PAN) and multispectral image (MSI) data for the extraction of polar geospatial information. We introduce a novel method based on a customized set of normalized difference Spectral Index Ratios (SIRs), incorporating multiple bands, to improve the accuracy of land-cover mapping in the Antarctic. Most recently available WV-2 data are classified into land-cover surfaces such as snow/ice, water bodies, and landmass using the customized normalized difference SIRs. A novel multi-fold methodology is used to evaluate the effect of pan-sharpening algorithms on spectral characteristics of satellite data, and on subsequent land-cover mapping using an array of SIRs. A set of existing pan-sharpening algorithms was implemented in order to fuse PAN with MSI data, followed by estimation of multiple SIRs to extract target land-cover classes. These algorithms were compared on the basis of their effectiveness in extracting target classes using a defined set of SIRs. Our results indicate that the use of 8-band WV-2, customized SIRs, and appropriate pan-sharpening can greatly improve the extraction of land-cover information.

Keywords: Pan-sharpening; WorldView-2; Index ratios; Land-cover

1. Introduction

WorldView-2 (WV-2) is the first hyperspatial satellite that offers eight multispectral (MS) bands along with a panchromatic (PAN) band using imaging MS radiometers (VIS/IR) and a WV110 camera. The satellite, launched in October 2009, provides images at a spatial resolution of 0.50 m in the PAN band and 2 m in the MS bands. The Ground Sampling Distance (GSD) for the PAN band is about 0.46 m at nadir and 0.52 m at 20° off-nadir. For the eight MS bands, the GSD is about 1.80 m at nadir and 2.40 m at 20° off-nadir. The spatial resolution difference between PAN and MS modes can be measured by the ratio of their respective GSDs, which generally varies between 1:2 and 1:5; the GSD ratio for WV-2 is 1:4. The MS bands include four conventional visible and near-infrared bands common to multispectral satellites: Band 2, Blue (450–510 nm); Band 3, Green (510–580 nm); Band 5, Red (630–690 nm); and Band 7, Near-IR1 (NIR1) (770–895 nm), and four new bands: Band 1, Coastal (400–450 nm); Band 4, Yellow (585–625 nm); Band 6, RedEdge (705–745 nm); and

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Band 8, Near-IR2 (NIR2) (860–1040 nm). These new channels enable access to spectral regions where distinguishable differences exist between multiple classifications within the scene, which may be overlooked by traditional MS systems such as Landsat 7.

The Spectral Index Ratio (SIR), which is used to classify a particular target or feature, is proportional to the difference in reflectance values of the bands used in the ratio. Traditionally, water and vegetation (Rouse et al., 1974) have been the primary focus of normalized difference SIRs, since water and vegetation are easy to discriminate on the basis of the difference in reflectance values in the range 450–750 nm.

Preliminary investigation on the bundled 8-band WV-2 imagery reveals a significant difference between the SIR images created using the 'traditional' spectral bands, equivalent to QuickBird's four spectral bands (Blue, Green, Red, and NIR1), and the 'new' WV-2 spectral bands. The existing SIRs used for effective land-cover mapping with WV-2 imagery are listed in Table 1. However, it is practically impossible to differentiate polar land-cover using just these two SIRs, as the landscape is very dynamic and consists of snow/ice of varying extent, texture, and morphology; landmasses of varying texture; and water bodies ranging from small ponds to large lakes. Also, the use of two simple SIRs underutilizes the 8-band capability of WV-2 data. We designed a novel set of normalized difference SIRs for WV-2 to fully exploit the 8-band capability. Each SIR includes at least one unique band from the set of newly available wavelengths. We focus our research efforts on designing new SIRs using the WV-2 acquisitions for Antarctic land-cover mapping.

The goal of the present paper is to demonstrate a new and simple method for mapping land-cover classes rapidly and accurately. Our study focuses on the following objectives: (a) to evaluate traditional pan-sharpening methods for WV-2 data on the basis of quality indices, (b) to design a "customized SIR" approach for 8-band WV-2 data to extract Antarctic land-cover and compare its performance with manually digitized land-cover map, and (c) to assess the unique 8-band characteristics of WV-2 data by employing multiple pan-sharpening algorithms coupled with multiple SIRs.

Table 1
List of existing normalized difference spectral index ratios (SIR).

Spectral index ratio	Spatial rationale	Mathematical expression	Reference
NDVI (Normalized Difference Vegetation index)	To extract vegetation	$\frac{NIR - Red}{NIR + Red}$	Rouse et al. (1974)
NDWI (Normalized Difference Water index)	To extract standing water	$\frac{Blue - NIR}{Blue + NIR}$	Gao (1996)

2. Literature review

Extensive research on image fusion techniques in Remote Sensing (RS) started in the late 1980s and early 1990s (Chavez et al., 1991; Cliche et al., 1985; Ehlers, 1991; Welch and Ehlers, 1987) and concentrated on pixel level fusion (pan-sharpening) in the late 1990s. Image fusion is the process of combining images of different resolution to increase the spectral and/or spatial quality of the fused image compared with the original (Pohl and Van Genderen, 1998; Wald et al., 1997). The fusion of RS images can assimilate the spectral information of a single sensor (Wang et al., 2005) or different sensors (Moser and Serpico, 2009). Fusion of the PAN and MS bands is classically referred to as pan-sharpening. Currently, pixel level image fusion is used as synonymous with pan-sharpening, resolution merge, image integration, or multi-sensor data fusion (Kumar et al., 2009; Vijayaraj et al., 2006). Today, a variety of airborne as well as space-borne sensors have produced image datasets of varying spatial, spectral and temporal resolution. Most of the Earth Observation (EO) satellites in operation, such as WorldView, Landsat, IRS-P5 (Cartosat), IRS 1C/1D, SAC-C, CBERS, SPOT, IKONOS, Quickbird, Formosat, and GeoEye, provide PAN images at a higher spatial resolution than in their MS mode. With the launch of these very high-resolution satellite sensors, the interest in pan-sharpening techniques has significantly increased. Much research has focused on preserving the spectral characteristics of the multispectral data after pan-sharpening (Alparone et al., 2007; Thomas et al., 2008).

Pan-sharpening techniques have become very important for RS applications such as enhancement of image classification, temporal change detection studies, object identification and selection, image segmentation, map updating, and enhanced visualization (Yuhendra et al., 2012). Various pan-sharpening algorithms have been developed (Ranchin and Wald, 2000; Ranchin et al., 2003; Wang et al., 2005), and some have been incorporated in commercial RS software packages such as ERDAS 9.3 and ENVI 4.8 (Ehlers et al., 2010; Shah et al., 2008). Most of these methods work well with images that were acquired at