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Image data fusion for the remote sensing of freshwater environments

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ABSTRACT

Remote sensing based mapping of diverse and heterogeneous freshwater environments requires high-resolution images. Data fusion is a useful technique for producing a high-resolution multispectral image from the merging of a high-resolution panchromatic image with a low-resolution multispectral image. Given the increasing availability of images from different satellite sensors that have different spectral and spatial resolutions, data fusion techniques that combine the strengths of different images will be increasingly important to Geography for land-cover mapping. Different data fusion methods however, add spectral and spatial distortions to the resultant data depending on the geographical context; therefore a careful selection of the fusion method is required. This paper compares a technique called subtractive resolution merge, which has not previously been formally tested, with conventional techniques such as Brovey transformation, principal component substitution, local mean and variance matching, and optimised high pass filter addition. Data fusion techniques are grouped into spectral and spatial centric methods. Subtractive resolution merge belongs to a new class of data fusion techniques that uses a mix of both spatial and spectral centric approaches. The different data fusion techniques were applied to a QuickBird image of a semi-aquatic freshwater environment in New Zealand. The results were compared both qualitatively and quantitatively using spectral and spatial error metrics. This research concludes that subtractive resolution merge performed better than all the other techniques and will be a valuable technique for enhancing images for freshwater land-cover mapping.

Introduction

The role of remote sensing has been pivotal for accurately mapping land cover and monitoring environmental changes in different habitats. This has been demonstrated by Melendez-Pastor, Navarro-Pedreño, Gómez, and Koch (2010) who used remote sensing to compare wetlands inside and outside a protected park using Landsat-5 TM and Landsat-7 ETM+. Remote sensing is often combined with standard Geographical data such as elevation to extract detailed features such as hedgerows (Tansey, Chambers, Anstee, Denniss, & Lamb, 2009) and other agricultural features that are an important part of landscape character. In developing countries, remote sensing is particularly valuable because it is a cost effective mapping tool and these countries often have very few base maps (Shalaby & Tateishi, 2007). A common technique used in enhancing images for land-cover mapping is to sharpen multi-spectral bands with panchromatic images. Mallinis, Emmanoloudis, Giannakopoulos, Maris, and Koutsias (2011) used such a technique prior to classifying land-cover/land-use changes in the Nestos Delta, Greece.

Remote sensing is rapidly advancing with the increasing availability of satellite images, and improved image enhancement and analysis techniques. Many remote satellites do not capture both high spatial and spectral images at the same time due to their technical limitations. Instead, dual images are often captured; one is a high (spatial) resolution panchromatic image (HRPI), which is good for identifying spatial details, and the other is a low (spatial) resolution multispectral image (LRMI), which is suitable for detecting features based on their spectral properties. Examples of these dual resolution satellites are; Landsat-7, SPOT 1-5, EO-1, IKONOS, QuickBird-2, WorldView-2, GeoEye-1 and FormoSat. There is considerable benefit from integrating HRPI and LRMI to produce a high-resolution multispectral image (HRMI) for further image analysis. This process is commonly labelled data fusion, pan sharpening, or resolution merging (de Béthune, Muller, & Binard, 1998; Wang, Ziou, Armenakis, Li, & Li, 2005), and is a common image enhancement process used in many land-cover mapping applications (FoxIII, Garrett, Heasty, & Torres, 2002; Mallinis et al., 2011; Midwood & Chow-Fraser, 2010; Munechika, Warnick, Salvaggio, & Schott, 1993).

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The choice of data fusion technique is dependent on the application of the image analysis because the reflectance varies with different environmental features. In a freshwater environment there is a high reflectance of blue light compared to the infra-red. When there is a high amount of vegetation, the infra-red intensity is high compared to the blue light. These variabilities make it difficult to use data fusion techniques. In freshwater environments that have submerged and emergent vegetation, the choice of data fusion method becomes critical. This paper therefore focuses on a freshwater environment to compare data fusion techniques. Freshwater environments are highly diverse, heterogeneous, and widely distributed due to the elongated and sinuous nature of water and land interaction zones. Access for ground surveys of freshwater environments are logistically difficult making remote sensing a preferred option. To map large scale freshwater environments, it is desirable to use images with a combination of high spatial, spectral, radiometric and temporal resolutions with large spatial extents (Ashraf, Brabyn, Hicks, & Collier, 2010).

A technique known as subtractive resolution merge (SRM) is a recent addition to existing data fusion algorithms that is in use by image processing software (ERDAS Imagine ver. 9.2). This paper reviews this technique and quantifiably compares its performance with standard techniques, such as Brovey transformation (BT), principal component substitution (PCS), local mean and variance matching (LMVM), and optimised high pass filter addition (OHPFA). A QuickBird image representing a lacustrine habitat is used for this comparison.

Ideally, data fusion techniques add the spatial and spectral contents of both the HRPI and LRMI respectively to produce an enhanced HRMI; however, these techniques often focus on either one of these qualities and offer only one result (Chen, Deng, Li, Li, & Shi, 2006). Different applications may require different balances between spectral characteristic preservation and high spatial detail retention. For classification purposes it is important to preserve the spectral information whereas other applications (e.g., feature extraction and cartography) may only require a sharp and detailed display of the scene (Cetin & Musaoglu, 2009; Chen et al., 2006). SRM offers the user the control to adjust spectral and spatial retention to suit the purpose of the data fusion.

This paper reviews different data fusion techniques available, including a description of the SRM algorithm, which uses a technique to produce a synthetic panchromatic image from the LRMI. The different data fusion techniques are applied to a QuickBird image and the results are then downgraded to the original resolution and compared with the original LRMI using Pearson's correlation coefficient and Root Mean Squared Error (RMSE). A Sobel filter based RMSE is also used to compare the magnitudes of edges between the HRPI and the HRMI.

Overview of data fusion techniques

A comprehensive review of early data fusion methods can be found in (Pohl & Van Genderen, 1998; Yang, Zhang, Li, Sun, & Pu, 2010). These methods can be divided into spatially-centric and spectrally-centric techniques. The spatially-centric techniques have more focus on the retention of the spatial content of an HRPI. Spectrally-centric techniques provide better spectral details for when distinction between classes is required.

Spatially-centric techniques use two different approaches: a simple intensity modulation (Liu, 2000; Schowengerdt, 1980) or a complex wavelet transformation based on multi-resolution decomposition (Garguet-Duport, Girel, Chassery, & Pautou, 1996; Ranchin & Wald, 2000; Teggi, Cecchi, & Serafini, 2003; Yocky, 1996). An intensity modulation uses high-pass or low-pass kernels applied to the HRPI that help detect edge features. Common techniques within this category include the High Pass Filter Addition (HPFA) (Gangkofner, Pradhan, & Holcomb, 2008), Smoothing Filter-based Intensity Modulation (SFIM) (Liu, 2000), and Local Mean and Variance Matching (LMVM) (de Béthune, Binard et al., 1998; de Béthune, Donnay et al., 1998).

Spectrally-centric techniques can be divided into three groups: (i) Projection and substitution models, (ii) Arithmetic models, and (iii) Synthetic variable ratio based models.

Projection and substitution models use statistical techniques and a range of transformations such as Intensity, Hue, Saturation (IHS) (Gillespie, Kahle, & Walker, 1986), Principal Component (PC) (Chavez Jr., Sides, & Anderson, 1991), and Gram-Schmidt (GS) (Laben & Brower, 2000).

Arithmetic models operate at the individual pixel level to proportion spectral information to the resulting HRMI so that the bands can be assigned spectral brightness near to the HRPI. Such models include the Brovey Transformation (BT), Multiplicative Model, and Pixel Block Intensity Modulation (PBIM) (Cliche, Bonn, & Teillet, 1985; Crippen, 1989; Gillespie, Kahle, & Walker, 1987; Liu & Moore, 1998).

Synthetic variable ratio (SVR) based procedures produce low resolution synthetic panchromatic images ($LRPI_{SYN}$) from LRMI by assigning different weights to the bands (Rahman & Csaplovics, 2007). A common practice for deriving such weights is through multivariate regression analysis as initially proposed by Munechika et al. (1993) and later modified by Zhang (1999). An HRMI is then produced from the $LRPI_{SYN}$ using arithmetic models.

There is now a new class of data fusion techniques that use a mix of both spatial and spectral centric approaches. These techniques include SRM (ERDAS, 2009), and fast Fourier transformation (FFT)-enhanced Intensity Hue Saturation method (Ling, Ehlers, Usery, & Madden, 2007). SRM is described in detail in a later section.

As this paper compares SRM with Brovey transformation (BT), principal component substitution (PCS), optimised high pass filter addition (OHPFA), and local mean and variance matching (LMVM), each of these techniques are summarised below.

Brovey transformation (BT)

BT, as popularised by R. L. Brovey, is one of the most widely used methods and is relatively simple and efficient (W. Li, Zhang, & Zhang, 2007). It has limitations because it uses only three bands, and also results in colour distortion (Dong, Zhuang, Huang, & Fu, 2009). The BT was developed to visually increase contrast in the low and high ends of the image histogram and for producing visually appealing images (ERDAS, 2009). The formula for the BT is:

$$HRMI_n = (LRMI_n \times HRPI)/LRPI \quad (1)$$

where: HRMI is a high resolution multispectral image – subscript n represents one of the three bands, LRMI is a low-resolution multispectral image, HRPI is a high resolution panchromatic image, LRPI is a low resolution panchromatic image derived from the sum of any three LRMI bands.

Principal component substitution (PCS)

With principal component substitution (PCS), the LRMIs are transformed to the principal component (PC) images according to the eigenvectors of their corresponding covariance matrices. The first PC (PC1) image is replaced by the HRPI. Prior to its replacement, the HRPI is statistically adjusted to match with the PC1 through two commonly used methods – the min-max stretch method, and the mean and variance stretch method. The fused images are obtained by applying an inverse transformation on the