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An object-level strategy for pan-sharpening quality assessment of high-resolution satellite imagery

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Abstract

Current satellite imaging systems offer a trade-off between high spatial and high spectral resolution providing panchromatic images at a higher spatial resolution and multispectral images at a lower spatial resolution but rich in spectral information while a wide range of applications need the highest level of this information, simultaneously. Image fusion techniques as means of enhancing the information content of initial panchromatic and multispectral images produce new images, titled pan-sharpened, which inherent the advantages of the initial images. Considering the impact of fusion accuracy on the quality of corresponding applications, it is necessary to evaluate the quality of these processed images. During the last decade, a lot of quality evaluation metrics have been proposed which are mostly inspired by traditional image quality metrics. These methods are mostly based on applying quality metrics at the pixel level and evaluating final quality value based on averaging of obtained metric values through the whole image. However, obtained results clearly show that the behaviour of image fusion quality is inconsistent amongst different image objects. In this article, by applying image fusion quality metrics (IFQMs) to image objects, an object-level strategy for quality assessment of the image fusion process is proposed. The proposed strategy is applied to different satellite imagery covering residential and agricultural areas. Experimental results show higher capabilities of object-level quality assessment strategy in the quality assessment of the fusion process. Evaluating fusion quality at the object level provides the potential of fusion quality assessment for each individual image object in compliance with different parameters such as the type of objects and the effective size of objects in data set.

Keywords: Pan-sharpening; Quality evaluation; Object-level strategy; QuickBird satellite imagery

1. Introduction

Topographic earth observation satellites, such as *IKONOS*, *QuickBird* and *GeoEye*, provide both panchromatic images at a higher spatial resolution and multispectral (MS) images at a lower spatial resolution but rich spectral information (Thomas and Wald, 2004; Choi et al., 2014). Due to several technological limitations, it is impossible to have a single sensor with both high spatial and spectral resolution (Thomas and Wald, 2004; Yuhendra et al. 2012). To overcome such a problem, image fusion as a means of enhancing the information content of initial images to produce new images rich in information content is found interesting in recent years (Asha and Philip, 2012; Thomas and Wald, 2004; Choi et al., 2005; Ranchin and Wald, 2000; Wald et al., 1997; Alparone et al., 2007; Wang et al., 2004).

Since then, a wide range of pan-sharpening methods have been developed to produce MS images having the highest spatial resolution available (Choi et al., 2005; Ranchin and Wald, 2000; Zheng et al., 2010). Although these generated images provide both high spectral and

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spatial information content, they do not exactly match with hypothetically acquirable satellite imagery. Therefore, quality assessment of these data is crucial before considering them in the framework of any further application such as image classification, recognition and change detection.

Pan-sharpened images are widely used in applications nowadays not only for classical applications such as image classification but also for large-scale map generation and three dimensional (3D) city modelling (Alkan and Marangoz, 2009; Vincent and Gosselin, 2012). The widespread use of pan-sharpened images and the need for robust quality assessment of these data has led to a rising demand of presenting methods for evaluating the quality of these images (Wald, 2000; Piella and Heijmans, 2003; Zhang, 2008). Basically, image quality assessment methods could be divided into two classes: Human-initiated subjective assessments and objective assessments by algorithms designed to mimic human interpretation (Shi et al., 2005). A subjective analysis involves visual comparison of colors between the original MS and fused images, and the spatial detail between original panchromatic and fused images (Zhang, 2008). This method merely depends on the observers' experiences or bias, and therefore certain ambiguities may arise (Zhang, 2008). Furthermore, these techniques are mainly visual, expensive and time-consuming procedures (Wald, 2000). Considering limitations of the subjective quality assessment, efforts have been made to develop objective image fusion quality assessment methods (Alparone et al., 2007; Zhang, 2008; Shi et al., 2005). These kinds of methods involve a set of predefined quality indicators for measuring the spectral and spatial similarities between the fused image and the original MS and/or panchromatic images (Zhang, 2008). The initial concept of some objective fusion assessment techniques is usually based on traditional image quality metrics, such as universal quality index (UQI) and entropy.

Most of objective fusion quality assessment techniques consider a single value to represent fusion quality of the whole image. However, as the whole image data set does not response uniformly to the fusion process, assigning a single value to the whole image area could not efficiently define a comprehensive index for quality of image fusion. In this case, the effect of each type of image object is not considered in the assessment process to overcome the limitations of the traditional strategies for evaluation of fusion quality, this paper presents an object-level strategy. Evaluating fusion quality at the object level provides the capability of fusion quality assessment for each individual image object.

2. Image fusion quality metrics

Image quality metrics are classified based on the level of spectral information, considered in the quality assessment process (Alparone et al., 2007; Thomas and Wald, 2006). Traditionally, these metrics are classified as mono-modal and multimodal techniques (Xydeas and Petrovic, 2000). A mono-modal metric considers a single image layer while a multimodal metric considers several image canals.

Thomas and Wald (2006) applied difference in variance (DIV), standard deviation (SD) and correlation coefficient (CC) as mono-modal metrics. These metrics were used for quality evaluation to the well-known images of the mandrill and Lenna as well as satellite data from SPOT-2 and SPOT-5. Similarly, Riyahi et al. (2009) made use of DIV and CC as quality metrics to evaluate fusion performance of *QuickBird* satellite imagery. Chen and Blum (2005) performed some experimental tests to evaluate quality of image fusion for a night vision imaging system. They used SD, signal-to-noise ratio (SNR) and entropy indices as standard quality metrics to extract features of quality from fused image itself. They also used cross-entropy-based and information-based measures to compare features present in both the fused and the source image. Shi et al. (2005) applied a variety of objective quality metrics, such as correlation, mean value and standard variation, to evaluate wavelet-based image fusion of a panchromatic image of Spot and a MS image of *Landsat* TM satellite imagery.

Entropy, CC and mean square error are some of mono-modal metrics, used by Vijayaraj et al. (2004) for quantitative analysis of pan-sharpened images. Wang et al. (2004) introduced the main idea of structural similarity metric (SSIM) as a mono-modal metric. A simplified version of the metric, entitled as UQI was introduced by Wang and Bovik for quality evaluation of *IKONOS*-fused images by Zhang (Zhang, 2008; Wang and Bovik, 2002). Piella and Heijmans (2003) added weighted averaging to UQI to measure the performance of image fusion. This new metric was entitled a saliency factor and was adopted by Hossny et al. (2007) for image fusion quality assessment.

On the other hand, Wald introduced global error in synthesis (ERGAS) as a multimodal index to characterize the quality of fusion performance, and to present the normalized average error for all bands of the generated image (Wald, 2000). Alparone et al. (2007) used ERGAS and spectral angle mapper (SAM) for image fusion assessment of IKONOS satellite imagery. In this study, amongst all the mentioned image fusion quality metrics (IFMQs), UQI has been chosen for quality assessment as it has been more frequently used in previous studies and brought up to be more efficient, reliable and robust (Alparone et al., 2007; Piella and Heijmans, 2003; Chen and Blum, 2005; Wang and Bovik, 2002; Samadzadegan and DadrasJavan, 2011). Moreover, it was a locally applicable patch-wise quality metric and tried to partially consider spatial behaviour of images.

SSIM, a common mono-modal metric, was introduced by Wang and Bovik (2002) and more formally discussed in Wang et al. (2004). Simply explaining, suppose x and y are local image patches taken from the same location of two images that are being compared. The local SSIM index measures the similarities of three elements of the image patches: the similarity $l(x,y)$ of the local patch luminance (brightness values), the similarity $c(x,y)$ of the