Applied Geography 37 (2013) 63–87

Contents lists available at SciVerse ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Evaluation of pansharpening algorithms in support of earth observation based rapid-mapping workflows

Chandi Witharana [a,*], Daniel L. Civco [b], Thomas H. Meyer [b]

[a] Center for Integrative Geosciences, University of Connecticut, Storrs, CT 06269-4087, USA
[b] Department of Natural Resources and the Environment, University of Connecticut, Storrs, CT 06269-4087, USA

Keywords:
Image fusion
Humanitarian information
Fusion evaluation
Crisis management

ABSTRACT

In order to satisfy the humanitarian information demand in ongoing- and post-crisis situations, earth observation (EO) data must be streamed through time-critical workflows. Data fusion serves as an integral segment of EO-based rapid-mapping workflows. Fused images form the basis for manual, semi-, and fully-automated classification steps in the information retrieval chain. Many fusion algorithms have been developed and tested for different remote sensing applications, however, the efficacy of data fusion is weakly assessed in the context of rapid-mapping workflows. In this research, we investigated how different fusion algorithms perform when applied to very high spatial resolution (VHSR) satellite images that encompass ongoing- and post-crises scenes. The evaluation entailed twelve fusion algorithms: Brovey transform, color normalization spectral sharpening (CN) algorithm, Ehlers fusion algorithm, Gram-Schmidt fusion algorithm, high-pass filter (HPF) fusion algorithm, local mean matching algorithm, local mean variance matching (LMVM) algorithm, modified intensity-hue-saturation (HIS) fusion algorithm, principal component analysis (PCA) fusion algorithm, subtractive resolution merge (SRM) fusion algorithm, the University of New Brunswick (UNB) fusion algorithm, and the wavelet-PCA fusion algorithm. These algorithms were applied to GeoEye-1 satellite images taken over three geographical settings representing natural and anthropogenic crises that occurred recently: earthquake-damaged sites in Haiti, flood-impacted sites in Pakistan, and armed-conflicted areas and internally displaced persons (IDP) camps in Sri Lanka. Fused images were assessed for spectral and spatial fidelity using a variety of quantitative quality indicators and visual inspection methods. Spectral quality metrics include correlation coefficient, root-mean-square-error (RMSE), relative difference to mean, relative difference to standard deviation, spectral discrepancy, deviation index, peak-signal-to-noise ratio index, entropy, mean structural similarity index, spectral angle mapper, and relative dimensionless global error in synthesis. The spatial integrity of fused images was assessed using Canny edge correspondence, high-pass correlation coefficient, and RMSE of Sobel-filtered edge images. Under each metric, fusion algorithms were ranked and best competitors were identified. Ehlers, WV, and HPF had the best scores for the majority of spectral quality indices. UNB and Gram-Schmidt algorithms had the best scores for spatial metrics. HPF emerged as the overall best performing fusion algorithm.

Introduction

Humanitarian crisis management is a time-critical process. Effective crisis management relies on rapid and rigorous production and dissemination of pre-, ongoing- and post-crisis information (Witharana & Civco, 2012). Remote sensing is an indispensable tool in crisis management (Cheema, 2007; Kaya, Musaogglu, & Ersoy, 2011). Earth observation (EO) data exhibit the highest demand in the response phase of the crisis management cycle (Dell' Acqua & Polli, 2011; Joyce, Wright, Samonsov, & Ambrosia, 2009). From a humanitarian perspective, the most critical parameter to be mapped and monitored is the number of people affected by a crisis (Lang, Tiede, Holbling, Fureder, & Zeil, 2010). On-demand census on affected population is of high value for coordinating and implementing relief operations. Time-series imagery acquired during and post-crisis can assist humanitarian relief agencies to implement high priority tasks such as, monitoring civilian movements, locating transitional shelter sites (TSS) and determining dwelling counts (e.g., internally displaced persons (IDP) and refugee camps),

* Corresponding author. Tel.: +1 860 486 1876; fax: +1 860 486 1383.
E-mail address: chandi.witharana@uconn.edu (C. Witharana).

0143-6228/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apgeog.2012.10.008

and rapidly quantifying the extent and severity of damage to buildings and infrastructure.

Owing to the frequent occurrence and adverse impacts of natural and man-made disasters, several global initiatives have been formulated to strengthen crisis support services. The International Charter Program, a globally functioning mechanism initiated in 1999, coordinates the tasking of multiple satellites and archiving systems in a very short time to respond natural and man-made disasters (Kim, Holt, & Madden, 2011; Voigt et al., 2007). The program has been activated in major crisis situation providing timely EO data to key stakeholders involved in the crisis management cycle. The European Earth monitoring programme – Global Monitoring for Environment and Security (GMES) is another global initiative led by the European Union (EU), which provides earth observation services for various policy-related issues including emergency management (Lang et al., 2010).

Despite EO data and global EO-data dissemination initiatives, in humanitarian emergencies the timeliness of data provision and the short time window available for dispatching value-added information pose major challenges to the mapping community. Unlike other remote sensing application domains, such as land use/cover mapping, environmental monitoring, and natural resource management, in crisis scenarios, EO data need to be streamed through time-critical workflows for delivering reliable and effective information (Tiede et al., 2011). Thus, there is always a compromise among response time, analysis depth, and thematic accuracy (Voigt et al., 2011). Typically, in the context of an EO-based rapid-mapping workflow, the pre-preprocessing step serves as an integral segment that stands in between data acquisition and analysis steps. In this respect, the role of data fusion cannot be overlooked since it serves as a cohesive component and routine procedure in rapid information production. However, there is an emerging concept of challenging the necessity of data fusion in the geographic object-based analysis (GEOBIA, also called OBIA) framework. For example, Tiede et al. (2011) attempted to bypass major preprocessing steps including data fusion and developed a methodology for automated extraction of damage information from very high spatial resolution (VHSR) satellite image data.

Fusion evaluation is a well-addressed research problem. There is a plethora of literature on fusion-quality assessments addressing general context (Ehlers, Klonus, Johan, Strand, & Rosso, 2010; Karathanassi, Kolokousis, & Ioannidou, 2007; Ling, Ehlers, Usery, & Madden, 2007, 2008; Nikolakopoulos, 2008; Vijayaraj, Nicolas, & Charles, 2006) and focusing on specific application domains (Ashraf, Brabyn, & Hicks, 2012; Yang, Kim, & Madden, 2012). Despite data fusion being linked to routine rapid-mapping workflows, we have a little knowledge on the effectiveness of data fusion algorithms when applied to crisis image scenes. The choice of fusion algorithm depends on the application domain because the reflectance varies with different environmental features. Different fusion algorithms introduce spectral and spatial distortions to the resultant data depending on the scene content; therefore a careful selection of the fusion method is required. An image scene of an intact city-block exhibits different spectral and spatial properties when compared to another image scene acquired over the same area after a major disaster, due, perhaps, to flood waters surrounding the buildings or to post-earthquake partially-collapsed buildings. Thus, a fusion algorithm that is designed to address high-frequency edge information of urban landscapes might not produce satisfactory results when the same area is underwater. In case of IDP camps and transitional shelters (TS) sites, even human interpreters face major challenges when extracting individual shelters because these structures are very small (compared to regular man-made dwellings), randomly oriented (e.g., TS shelters), highly crowded, and typically disturbed by existing land cover types (e.g., tree canopies). In this respect, it is challenging to transfer the knowledge on the performances of fusion algorithms that have been tested for a different application domain (e.g., freshwater habitat mapping) to another application domain. Our contention is that fusion algorithms are scene-dependent and they should be tested with respect to the application domain in focus. Thus, the central objective of this research is to investigate how well different fusion algorithms perform when applied to VHSR images of ongoing- and post-crisis scenes with different scene contents.

Modern satellite sensor technology provides space-borne imagery whose spatial resolution rivals aerial images (Blaschke, 2010; Dey, Zhang, & Zhong, 2010). Satellite sensors like IKONOS, QuickBird, GeoEye-1, and WorldView-2 provide very high spatial resolution (VHSR) multispectral imagery (at sub-meter level) that can capture the fine details needed for crisis information, e.g., city-block to individual house or an IDP camp to an individual shelter (Lang et al., 2010; Li, Xu, & Guo, 2010; Vu, Yamazaki, & Matsuoka, 2009). Due to shorter revisit times of these sensors, it is also possible to acquire near real-time imagery over impacted areas (Kim et al., 2011).

VHSR satellite sensors typically record image data in a low resolution multispectral (MS) mode and high resolution panchromatic (PAN) mode. The high spatial resolution is needed to accurately describe the shapes of features and structures, and the high spectral resolution is needed to classify complex land-use and land-cover types (Ehlers et al., 2010; Myint et al., 2011; Rachin et al., 2003; Wald, 2000). Humanitarian crisis management remote sensing applications require high spatial and spectral resolution images. Fusing PAN and MS images with complementary characteristics can provide a better visualization of the observed area (Ranchin, Aiazzi, Alparone, Baronti, & Wald, 2003; Wald, 2000). Pohl and Van Genderen (1998) defined image fusion as a tool to combine multisource imagery using advanced image processing techniques that can be performed at three different processing levels (pixel, feature, and decision) depending on the stage at which the fusion takes place. Image fusion can occur in different ways such as inter-sensor, intra-sensor, singled-date, and multi-date. Pansharpening, also called resolution merge (Gangkofner, Pradhan, & Holcomb, 2008) is a pixel-level fusion technique used to increase the spatial resolution of the multispectral image while preserving the spectral information (Vijayaraj et al., 2006). The perfect pansharpening result would be the MS image that would have observed if the multispectral sensor had the spatial resolution of the panchromatic sensor (Vrabel, 1996; Wald & Ranchin, 1997; Nikolakopoulos, 2008). Many image-fusion algorithms were developed for combining complimentary characteristics of PAN and MS images to produce an enhanced multispectral image of high spatial resolution. Several classifications for grouping fusion algorithms have been proposed. Pohl and Van Genderen (1998) grouped fusion algorithms into color-related methods and statistical/numerical methods. Ehlers et al. (2010) treated the latter as two separate classes (statistical and numerical) and discussed different fusion techniques under three groups. Ranchin and Wald (2000) and Wald (2002) proposed grouping by (1) the projection and substitution methods, (2) the relative spectral contribution, and (3) the method relevant to the ARSIS (a French acronym: *Amélioration de la Résolution Spatiale par Injection de Structures*, which means spatial improvement by injection structures) concept. Based on the information used in a pansharpening procedure, Gangkofner et al. (2008) grouped fusion techniques as spectral substitution methods, arithmetic merging, and spatial-domain methods. Yakhdani and Azizi (2010) further developed the classification of Pohl and Van Genderen (1998) and noted four fusion algorithms groupings: 1) color-related techniques, 2) statistical/numerical methods, 3) Pyramid-based methods, and 4) hybrid methods.