WEIGHTED LEAST SQUARES PAN-SHARPENING OF VERY HIGH RESOLUTION MULTISPECTRAL IMAGES

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1. ABSTRACT

Pan-sharpened Multispectral (MS) image is a fusion product in which the MS bands are sharpened via the higher-resolution panchromatic (PAN) image. In fact, the latter is acquired with the maximum resolution allowed by the imaging sensor, as well as by the datalink throughput, while the former are acquired with coarser resolutions, typically, two or four times lower, because of SNR constraints and transmission bottleneck. The goal of Pan-sharpening is to make the fused bands the most similar to what the narrow-band MS sensor would image if it had the same resolution as the broad-band one (PAN).

We have recently proposed a pan-sharpening algorithm for very-high resolution multispectral (MS) images [1], which is optimal in the minimum mean squared error sense and computationally practical, even when local optimization is performed. This solution adopts a linear injection model in which an optimal detail image extracted from the panchromatic band is calculated for each MS band of size $N_R \times N_c$ by evaluating a band-dependent generalized intensity from the $N$ multispectral bands, for more details see [1].

The injection model written in compact form by representing images columnwise lexicographically ordered, is the following:

$$\hat{B}_l = \tilde{B}_l + H \gamma_l \quad l = 1, 2, \ldots N$$

where $\hat{B}_l$ is the $l$-th fused band, $\tilde{B}_l$ is the $l$-th MS band up-sampled to the pan resolution, $H = [\tilde{B}_1, \tilde{B}_2, \ldots, \tilde{B}_N, P]$ is the observation matrix of the linear model, having $R \times N_c \times N_c$ rows and $(N + 1)$ columns, $P$ is the panchromatic image with resolution $R$ times higher than the MS image, and the $N$ vectors $\gamma_l = [\gamma_{l,1}, \gamma_{l,2}, \ldots, \gamma_{l,N+1}]^T$, $l = 1, 2, \ldots, N$, completely define the set of the $N \times (N + 1)$ model parameters [1].

Those parameters are jointly optimally estimated, in the MMSE sense, by applying the following Minimum Variance Unbiased (MVU) estimator [2] on MS and PAN data at a spatial resolution reduced by $R$:

$$\gamma_l = (H_d^T H_d)^{-1} H_d^T (\hat{B}_l - \tilde{B}_l^\mu) \quad l = 1, 2, \ldots N$$

where the subscript $d$ indicates that data is first considered at the MS spatial resolution and then upsamples to the resolution of the panchromatic band.

This method, which is in the framework of the ARSIS Concept [3], and can be also formalized as a Least Square (LS) problem, has been demonstrated to outperform the best state-of-the-art pan-sharpening algorithms both on true and simulated data, and in particular on the specific dataset which was proposed as a benchmark test set for the 2006 IEEE Data Fusion Contest [1, 4].

In this paper, we propose to incorporate additional information into the fusion process in order to improve the parameter estimation phase in (2) and consequently the performances of the fusion algorithm.

First, the original MS/PAN dataset is classified into $L$ classes. The supervised classification map has been demonstrated to be very accurate when an SVM classifier is adopted [5]. Then, for each class $k$, the classification map is used to define a diagonal weighting matrix $W^{(k)}$ of size $(N_R \times N_c) \times (N_R \times N_c)$ having 1’s at the positions corresponding to the image pixels belonging to class $k$. The estimate $\gamma_l$ in (2) becomes $\gamma_l^{(k)}$ in the following new formulation which formally corresponds to the solution of a weighted least squares (WLS) problem:
\[ \gamma_l^{(k)} = \left( H_d^T W^{(k)} H_d \right)^{-1} H_d^T W^{(k)} \left( \tilde{B}_l - \tilde{B}_l^{(p)} \right) \quad l = 1, 2, \ldots N, \quad k = 1, 2, \ldots L. \] (3)

The fusion process of the new WLS algorithm assumes the following form

\[ \tilde{B}_l = \tilde{B}_l + H \gamma_l^{(k)} \quad l = 1, 2, \ldots N \quad k = 1, 2, \ldots L \] (4)

for a pixel belonging to class \( k \).

Preliminary results obtained on true IKONOS and QuickBird data confirm the validity of the proposed method in terms of objective and visual comparisons with the fusion results obtained by advanced methods, based on multiresolution analysis [6, 7], or based on component substitution [8]. The fusion result may be used for improved display or feature extraction purposes.

2. REFERENCES


