SIMULATION OF PAN-SHARPENING USING HYPERSONTRAL DATA TO EVALUATE THE METHOD AND BAND COMBINATIONS

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ABSTRACT: This study proposes a framework for simulating pan-sharpening using hyperspectral data in order to evaluate pan-sharpening methods and band combinations of panchromatic and multispectral data. This framework was applied to two pan-sharpening methods (block-SVR, Gram-Schmidt spectral sharpening) to characterize the spectral and spatial qualities of pan-sharpened images. Panchromatic images were generated from Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) hyperspectral data by changing the position and width of the spectral waveband, and these were subjected to pan-sharpening with multispectral bands, also generated from hyperspectral data. In this study the multispectral bands had fixed spectral positions and bandwidths for simplicity. The pan-sharpened multispectral data were evaluated from the viewpoints of both spectral and spatial qualities using three indices: ERGAS, $Q^p_{AB}$, and QILV.

1. INTRODUCTION

Pan-sharpening is an image-fusion technique used to combine low-spatial-resolution multispectral (MS) data and high-resolution panchromatic (PAN) images to generate high-resolution multispectral data. Pan-sharpening alters the spectral characteristics of MS data; consequently, many pan-sharpening methods have been developed in attempts to retain the original spectral responses of the MS data. Since the quality of pan-sharpened data is affected not only by the pan-sharpening method, but also the spectral properties, such as band position and bandwidth, the evaluation of pan-sharpening methods with various spectral combinations of PAN and MS is effective (Matsuoka et al., 2012). A hyperspectral (HS) sensor can observe a smooth spectral curve of the target making it convenient for simulating multispectral data using the weighted average of the bands. This study presents a scheme for evaluating pan-sharpening methods by changing the spectral combination of PAN and MS, which were simulated from HS data. This study focused on the spectral properties of PAN, i.e., the qualities of pan-sharpened images were assessed according to the changing band position and bandwidth of PAN.

2. MATERIALS AND METHODS

2.1 Hyperspectral Data

This study used Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data, using “Lunar Lake” (f090819t01p00r06) and “Low Altitude” (f960705t01p02r02) data from the AVIRIS website (NASA/JPL, 2011). Data in 16 bits were converted to 8 bits, and two areas were clipped from each scene with the pixel size of 512 × 512. This study used the data for 94 bands from the visible to near-infrared wave-regions, from band 5 (404.6 nm) to band 100 (1283.3 nm), excluding bands 31 or 32. The spectral bandwidth of each band was approximately 10 nm. Figure 1 shows the two areas of data in false color.

2.2 Methods

The evaluation scheme consisted of four steps; MS generation, PAN generation, pan-sharpening, and quality evaluation.

MS Generation: Four MS bands were generated by spectral averaging of HS. The spectral band positions corresponded to those of the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) (EORC/JAXA, 2015). AVIRIS band 7 to 14, 17 to 25, 27 to 36, and 44 to 57 were averaged to produce AVNIR-2 band 1 (420-500 nm), 2 (520-600), 3 (610-690), and 4 (760-890), respectively. The spectral responses of the AVNIR-2 bands were not considered in the averaging. Subsequently, spatially degraded low-resolution data were generated by averaging 4 × 4 pixels of the original MS. The image size was 128 × 128. These degraded MS were used for pan-sharpening to generate an image with the same size as the original.
PAN Generation: Many PAN were generated by spectral averaging of HS. From the viewpoint of bandwidth, the narrowest bandwidth was the original HS band (approximately 10 nm). For second narrowest band, a PAN image was generated by averaging two adjacent bands (20 nm bandwidth). The widest bandwidth was generated by averaging all 94 bands. Consequently, 94 levels of bandwidth were generated. From the viewpoint of band position, the central wave position was dependent on the band sets. Figure 2 shows a conceptual diagram of the PAN generation; we refer the triangle as the PAN pyramid.

Figure 1. False-color images of the study areas. Figure 2. Scheme used for PAN generation

Pan-sharpening: Two methods were performed using degraded MS and each PAN image. The first was the block-based synthetic variable ratio (BlkSVR) (Zhang et al., 2010). The processing steps of this method are as follows:
1. The low-resolution MS is expanded to the same size as the PAN by nearest-neighbor resampling.
2. N × N blocks (a square region of pixels) are fetched from the MS and from expanded PAN.
3. Multiple linear parameters are calculated through multiple linear regression of the PAN and MS using the pixels in the blocks.
4. The pixels in the central block are pan-sharpened by multiplying the MS band by the ratio of the original and synthesized PAN, which is derived by multiple regression.
5. Steps (2) to (4) are repeated for all blocks in sequence.
In this study, one block was composed of 16 × 16 pixels, and 3 × 3 blocks were used in the regression.

The second method was Gram-Schmidt spectral sharpening (GST) (Laben et al. 2000, Aiazzi et al., 2007). This method uses Gram-Schmidt orthogonalization. The steps are as follows:
1. A degraded PAN is derived by spatial averaging of 4 × 4 pixels.
2. The modified Gram-Schmidt transformation is performed on the degraded PAN with the MS; here, PAN is used as the first band in the GS transformation.
3. The statistics of the original PAN are adjusted to those of first transform band of the GS transformation.
4. The adjusted PAN is substituted for the first transformation band to produce a new set of bands.
5. The inverse GS transformation is performed on the new set of bands to produce the pan-sharpened MS image.

Image Quality Evaluation: We used three statistical indices to evaluate the quality of pan-sharpened images: ERGAS, Qf_AB, and QILV (Li et al., 2010). ERGAS (‘erreur relative globale adimensionnelle de synthèse’ or relative dimensionless global error in synthesis) is a difference-based measure, calculated with equation (1).

\[
ERGAS = 100 \frac{h}{l} \sqrt{\frac{1}{B} \sum_{b=1}^{B} \left( \frac{RMSE_{b}}{\mu_{b}} \right)^{2}},
\]

where \(h/l\) is the ratio between the pixel sizes of PAN and MS (0.25 in this study), \(\mu_{b}\) and \(RMSE_{b}\) are the average and root mean square error in \(b^{th}\) band of the pan-sharpened image, respectively, and \(B\) is the number of spectral bands. The evaluation was carried out on a single-band basis; so, \(B = 1\) in this study.

The second index, objective image fusion performance measure \(Q_{f, AB}^{f}\), is an overall-based measure, and is computed with equation (2). Please refer to Xydeas et al. (2000) for details. We used MATLAB code downloaded from
\[ Q_{AB}^f = \frac{\sum_{n=1}^{N} \sum_{m=1}^{M} (Q_{AF}(n, m) \cdot w_A(n, m) + Q_{BF}(n, m) \cdot w_B(n, m))}{\sum_{n=1}^{N} \sum_{m=1}^{M} (w_A(n, m) + w_B(n, m))}, \]  

(2)

The last index, the universal image quality index or quality index based on local variance (QILV), is an information- and clarity-based measure, and is computed using equation (3).

\[ QILV = \frac{2\mu_f \mu_r}{\mu_f^2 + \mu_r^2} \cdot \frac{2\sigma_f \sigma_r}{\sigma_f^2 + \sigma_r^2} \cdot \frac{2\sigma_{fr}}{\sigma_f \sigma_r}, \]  

(3)

where \( \mu_f \) and \( \sigma_f \) are the average and standard deviation, respectively, of the fused image \( f \) and the reference image \( r \), and \( \sigma_{fr} \) is covariance of the fused and reference images. We used MATLAB code downloaded from http://www.mathworks.com/matlabcentral/fileexchange/36950-quality-index-based-on-local-variance--qilv-.

3. RESULTS AND DISCUSSION

Figure 3 shows pan-sharpened images generated using various combinations of band position and bandwidth, together with the reference (original) and degraded MS images. The positions of PAN images in the PAN pyramid are shown in Figure 4.

Most of the images were successfully sharpened in area 1; the results were similar with the reference in both color and texture. In area 2, however, the appearance differed with the method and spectral properties of the PAN. BlkSVR resulted in excess enhancement, especially in the band combinations 005-005, 053-053, 100-100, and 054-100. GST generated better quality images in 005-005, 005-053, and 005-100, but showed remarkable blurring in other cases. Main reason for the difference between areas was local variability of the land surface: area 2 has greater complexity. The effects of both pan-sharpening methods and the spectral properties of PAN will be much clearer with complex land cover.

Figure 5 shows the quality indices of pan-sharpened images according to the PAN pyramid. The colors in the pyramid indicate the score of the

Figure 3. Pan-sharpened images using different PAN, with reference and degraded images. XXX-YYY means that PAN was produced using HS bands XXX to YYY; the number within a circle is the position in the PAN pyramid shown in Figure 4.

Figure 4. Position of PAN in the pyramid for the image in Figure 3.
index derived using PAN at the position. At lower level of averaging, higher scores resulted for the cases in which the band positions of PAN and MS were similar: e.g., a high score in near infrared band (band 4) was resulted if PAN was generated from near-infrared bands of HS. The reason is simply because the lower- and higher-resolution images were similar. However, the scores vary with the indices and methods. BlkSVR had larger variations in ERGAS than GST; this means that spectral differences of the original and pan-sharpened MS were larger in the bands that had different spectral sensitivity with PAN, because ERGAS is a difference-based measure. By contrast, GST showed large variation in $Q'_{AB}$, an overall-based measure; this might have been due to the blurring. QILV in area 2 showed a different trends according to the method. BlkSVR could retain the local variance if PAN had a wide spectral range (i.e., at higher level of averaging), but GST lost the variance in the same simulation.

![Figure 5. Quality indices of pan-sharpened images using different combination of band position and bandwidth of PAN. Red indicates better quality, and purple is worse. The four triangles correspond band 1 to 4 of MS, respectively; band 2 and 4 are flipped vertically.](image)

4. CONCLUSIONS

The selection and development of better pan-sharpening method are important for better understanding of targets. This paper proposed a simulation scheme for evaluating the quality of pan-sharpened image using hyperspectral data. We applied this scheme to two pan-sharpening methods using different panchromatic images that were simulated from hyperspectral data. Each method showed its own response to the spectral properties of the panchromatic image and to the land cover. This investigation can assist in the selection of a pan-sharpening method and band selection of remote sensors.

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REFERENCES


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