Expanded Q4 Quality Assessment for Pan-Sharpened MultiSpectral Image

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ABSTRACT

In this paper, we took into account both the spectral information and the spatial information and estimated how well the needed information contained within the multispectral (MS) and panchromatic (PAN) images was represented by the pan-sharpened image. Based on that, we proposed a new quality index which could be seen as an expanded index of the global quality measurement Q4. In our method, we first measured the spectral information preserving quality between the MS image and the fusion result. Then, we constructed a virtual spatial detail image considering the spatial resolution ratio between the source MS image and the PAN image, and also extracted the detail image contained in the merged image using the same technology, followed by a spatial information preserving quality index calculated from these two detail images. At last, we integrated the two indices by means of weighted addition determined by fusion model. To illustrate the superiority of this new index, we took experiments on two pairs of ZY-2 PAN and ASTER MS (1 2 3 bands) remote sensing imageries, and adopted the tradeoff FIHS fusion method in which the tradeoff parameter was set to different values standing for different fusion models. After using the proposed index to assess the quality of fusion, we think that the new index is compliant with subjective evaluations and could therefore be used to compare different image fusion or to find the best parameters for a given fusion model. Finally, we gave an experiential weight parameter of the quality index while assessing the tradeoff FIHS fusion with images from these two sensors by the author's experiments.

Keywords: pan-sharpen, non-reference quality assessment, fusion model, quaternion algebra, weight parameter

1. INTRODUCTION

Quality assessment of the pan-sharpened MS images is an uneasy task [1]. There are basically two classes of quality assessment approaches: measurement methods considering human visual system (HVS) characteristics and mathematically defined measures. Compared with the former, the latter is more attractive because it is easy to calculate and independent of viewing conditions and individual observers [2]. But for the latter, it usually faces several problems: Firstly, fusion quality is dependent on the fusion model decided by the applications of the pan-sharpened MS images, since there are generally three kinds of fusion model which are the spectral information preserving model mostly for digital classification purposes、the spatial information preserving model mainly for visual interpretation, image mapping and photogrammetric purposes 、the color enhancing model for visualization and GIS integration purposes [3]; Secondly, image quality is often space variant, although in practice it is usually desired to evaluate an entire image using a single overall quality value [2]. Thirdly, a reference image can not be acquired in most applications and the reference image is dependent on the specific applications where the merged image is used, so a practical measurement may belong to the kind of non-reference quality index [4].

As the non-reference fusion quality indexes were concerned, there was a restricted number of objective fusion performance measures proposed in the last few decades. Among them, mutual information (MI) was employed for evaluating fusion performance [5]; C. Xydeas and V. Petrovic [6] proposed a metric which evaluated the relative amount of edge information that was transferred from the input images to the composite image; G. Piella proposed a so-called edge-dependent fusion quality index using 'edge images' for multi-focus fused image based on Wang - Bovik universal image quality index (UIQI) [4], which is also the basement of our quality measures.

In this paper, we mainly work on the quality assessment of the spatial information preserving model and the spectral information preserving model.

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2. UIQI AND ITS EXPANDED INDEX

2.1 The UIQI of Wang

We start our research base on the UIQI of Wang. Given two images x and y of size M*N, Wang [4] defined UIQI (also with a well-known name Q) as Eq. (1):

$$Q(x,y) = \frac{\sigma_{xy}}{\sigma_x \sigma_y} \cdot \frac{2\overline{xy}}{\overline{x}^2 + \overline{y}^2} \cdot \frac{2\sigma_x \sigma_y}{\sigma_x^2 + \sigma_y^2} = \frac{4\sigma_{xy}\overline{xy}}{(\overline{x}^2 + \overline{y}^2)(\sigma_x^2 + \sigma_y^2)} \tag{1}$$

Where:

$$\overline{x} = \frac{1}{MN-1}\sum_{m=1}^{M}\sum_{n=1}^{N} x(m,n) \qquad \overline{y} = \frac{1}{MN-1}\sum_{m=1}^{M}\sum_{n=1}^{N} y(m,n)$$

$$\sigma_x^2 = \frac{1}{MN-1}\sum_{m=1}^{M}\sum_{n=1}^{N} (x(m,n)-\overline{x})^2 \qquad \sigma_y^2 = \frac{1}{MN-1}\sum_{m=1}^{M}\sum_{n=1}^{N} (y(m,n)-\overline{y})^2$$

$$\sigma_{xy} = \frac{1}{MN-1}\sum_{m=1}^{M}\sum_{n=1}^{N} (x(m,n)-\overline{x})(y(m,n)-\overline{y})$$

Q has three components: the first component is the correlation coefficient between x and y; the second component measure how close the mean luminance is between x and y; the third component measures how similar the contrasts of the images are. The best value 1 is achieved if and only if $x = y$, and the lowest value is -1.

Since image quality is often space variant, it is appropriate to measure the index Q over local regions and then combine the different results into a single measure. Wang proposed to use a slide window approach: a window of a given size slides pixel by pixel over the two images from top-left corner to bottom-right corner. In each sliding window w, a local quality index $Q(x,y\,|\,w)$ is computed, followed by an overall image quality index calculated by averaging all local quality indices.

$$Q(x,y) = \frac{1}{|W|}\sum_{w \in W} Q(x,y\,|\,w) \tag{2}$$

where $|W|$ is the total of sliding step.

2.2 Expanded indices based on UIQI

Wang Zhou expanded Q to the structural similarity (SSIM) index by multiplying the three components' power values [7]. L. Alparone expanded Q using quaternion algebra in order to assess the global quality measurement of pan-sharpened MS imagery with the widely used name $Q4$ in which an N*N size window was used to evaluate the local qualities ($Q4_N$) which were then integrated to evaluate an entire image. Although SSIM and $Q4$ had been used as a common quality index [8, 9, 10], it is still a reference index, that is to say, it is useless without reference. G. Piella introduced it into the measurement of multi-focus image fusion with a popular name Q_E, which gave an indication of how much of the salient information contained in each input multi-focus images had been transferred into the composite image. He first got a weighted fusion quality measure $Q_W(a,b,f)$ by adding the weighted Qs between each input image and the merged image, and then got another index $Q_W(a',b',f')$ between the edge images extracted from each input image and the merged image with the same technique; finally he multiplied these two indices with his own method. It was noticeable that Q_E belonged to the kind of non-reference quality index for measuring multi-focus image fusion quality and not suitable for pan-sharpened MS images, since the source input images of pan-sharpened MS images have different properties to be integrated into the fusion result.

2.3 The Global quality measurement $Q4$

L. Alparone defined a global quality measurement based on quaternion algebra. Let

$$\mathbf{Z}_1 = \mathbf{a}_1 + i\mathbf{b}_1 + j\mathbf{c}_1 + k\mathbf{d}_1, \ \ \mathbf{Z}_2 = \mathbf{a}_2 + i\mathbf{b}_2 + j\mathbf{c}_2 + k\mathbf{d}_2 \tag{3}$$

Denote the four-band $\mathbf{Z}_1$ and $\mathbf{Z}_2$ image respectively, both expressed as quaternion. If there are only three bands to be measured, we usually set $\mathbf{a}_i$ to be a zero vector. The $Q4$ is defined as

$$Q4(\mathbf{z}_1, \mathbf{z}_2) == \frac{4\left|\sigma_{\mathbf{z}_1\mathbf{z}_2}\right| . \left|\overline{\mathbf{z}}_1\right| . \left|\overline{\mathbf{z}}_2\right|}{({\sigma_{\mathbf{z}_1}}^2 + {\sigma_{\mathbf{z}_1}}^2)(\left|\overline{\mathbf{z}}_1\right|^2 + \left|\overline{\mathbf{z}}_2\right|^2)} \tag{4}$$

He also uses the local quality index to form the global index, with the same technique with Q. The physical meanings of variables are almost the same as Q, while the only difference is calculating $Q4$ in the hyper complex space. The highest value of Q4 is 1; the lowest value is zero.

3. THE EXPANDED $Q4$ QUALITY INDEX

Considering the drawback of $Q4$ and Q_E, we propose a new quality index which can be seen as an expanded index of $Q4$. As is known to all, the aim of fusion is to get a high-resolution MS image. The difference between the spatial information preserving model and the spectral information preserving model is how much the spatial and the spectral information contained in the merged image, which is a big tradeoff problem fusion algorithms should deal with. So, the quality assessment of fusion results must take into account both the spectral information and the spatial information preserving quality.

Before giving our method, we define several variables: H is the source input PAN image; M is the resample MS image with the same size as H; F is the pan-sharpened MS image. We use the $Q4$ index in Eq. (4) to define $Q4_{MS}(M,F)$, which measures the spectral information preserving quality between M and F.

$$Q4_{MS}(M,F) = \frac{1}{|W|}\sum_{w \in W} Q4(M,F \mid w) \tag{5}$$

Then, in order to assess the spatial information preserving quality, we had better extract the spatial information from H and F. The most common used method is high-pass filter (HPF). LIU. H.G. used a method based on low-pass filter (LPF) to propose the famous smoothing filter-based intensity modulation (SFIM) fusion algorithm, in which he suggested the smoothing filter kernel size was one step larger then the resolution ratio [11]. In ERDAS IMAGINE V9.1, an advance HPF resolution merge tool was introduced which adopted HPF with special detail information extraction strategy to yields results comparable to redundant wavelets [12].

Here, we construct a virtual ideal detail image considering the spatial resolution ratio between MS and PAN image based on the method of HPF resolution merge in ERDAS IMAGINE V9.0. If the resolution ratio is r, we use a HPF template of a (2r+1)*(2r+1) kernel size window, in which the center value is (2r+1)*(2r+1)-1 and others are -1. By doing this, we extract the details of every direction from H and F, and we can see that this strategy also contains the influence of resolution ratio. Of course, to avoid the influence of the unequal intensities in detail images, we adjust one detail image by a coefficient calculating from these exact images. Let H' be the spatial information image of H, F' be the spatial information image of F. We define $Q4_{PAN}(H',F')$ to measure the spatial information preserving quality between H and F.

$$Q4_{PAN}(H',F') = \frac{1}{|W|}\sum_{w\in W} Q4(\frac{Std(F')}{Std(H')}H',F'|w) \tag{6}$$

Where $Std(*)$ is the standard deviation of image *.

At last, we integrated $Q4_{MS}(M,F)$ and $Q4_{PAN}(H',F')$ by means of weighted addition.

$$Q4_{expand} = tQ4_{MS}(M,F) + (1-t)Q4_{PAN}(H',F') \quad 0 \le t \le 1 \tag{7}$$

Where t is a weight parameter, it can be adjusted according to the fusion model. If the fusion is the spatial information preserving model, higher t is selected, compared with lower t for the spectral information preserving model.

4. ERPERIMENTS AND RESULT

To illustrate the superiority of this new index, we use two pairs of real remote sensing imageries, while PAN images are acquired by ZY-2 with 3 meter spatial resolution and MS images are acquired by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) GREEN(1 band) / RED(2 band) / NIR(3 band) with 15 meter spatial resolution. These images are widely used in the field of nation resources survey、 environment monitoring、 protection etc. Individually, the two pairs of images cover some areas of Henan (HN) province and Heilongjiang (HLJ) province in china. We select a subset from each image due to the large calculation mount in $Q4_{expand}$. The size of HN subset is 460*330 pixels; the size of HLJ subset is 517*361 pixels. In HN subset, ground objects are greenland、alleys and small buildings. In HLJ subset, ground objects are different kinds of farmland.

As the fusion model is concerned, we adopt the tradeoff FIHS fusion method proposed by Myungjin Choi [9], and the tradeoff parameter is set to two corresponding to the spectral information preserving model and five standing for the spatial information preserving model.

For the window size of HPF, we choose 11*11 pixels size since the spatial resolution ratio of MS and PAN is five. For $Q4_{MS}(M,F|w)$ and $Q4_{PAN}(H',F'|w)$ values, we use a local window size of 16, which has the same trend as $N > 16$ [1].

Fig. 1 shows the source MS images and PAN images of the two subsets、 fusion results of different fusion models. For simplicity's sake, we donate HN-2 to the fused images by tradeoff FIHS with tradeoff parameter two of HN subset, HN-5 to the fused images by tradeoff FIHS with tradeoff parameter five of HN subset, HLJ-2 to the fused images by tradeoff FIHS with tradeoff parameter two of HLJ subset , HLJ-5 to the fused images by tradeoff FIHS with tradeoff parameter five of HLJ subset.

According to visual analysis, for the spectral information, it seems that all fusion results have a good spectral preserving quality, so we need quantitative index to decide which one does the best for each subset; For the spatial information, we focus on linear features, e.g. the alleys in HN subset and the boundary between different kinds of farmland in HLJ subset. Based on that, approximately, we could come to the conclusion that (*-2) has higher spectral information preserving quality and lower spatial information preserving quality than (*-5).

We use the proposed $Q4_{expand}$ for quantitative evaluation. Table 1 shows $Q4_{MS}(M,F)$ and $Q4_{PAN}(H',F')$ values of fused images. These values indicate the same phenomenon as the conclusion of visual analysis, while $Q4_{MS}$ of HN-2 is a litter higher than that of HN-5, $Q4_{MS}$ of HLJ-2 is much higher than that of HLJ-5; $Q4_{PAN}$ of HN-2 is much lower than that of HN-5, $Q4_{PAN}$ of HLJ-2 is a litter lower than that of HLJ-5.

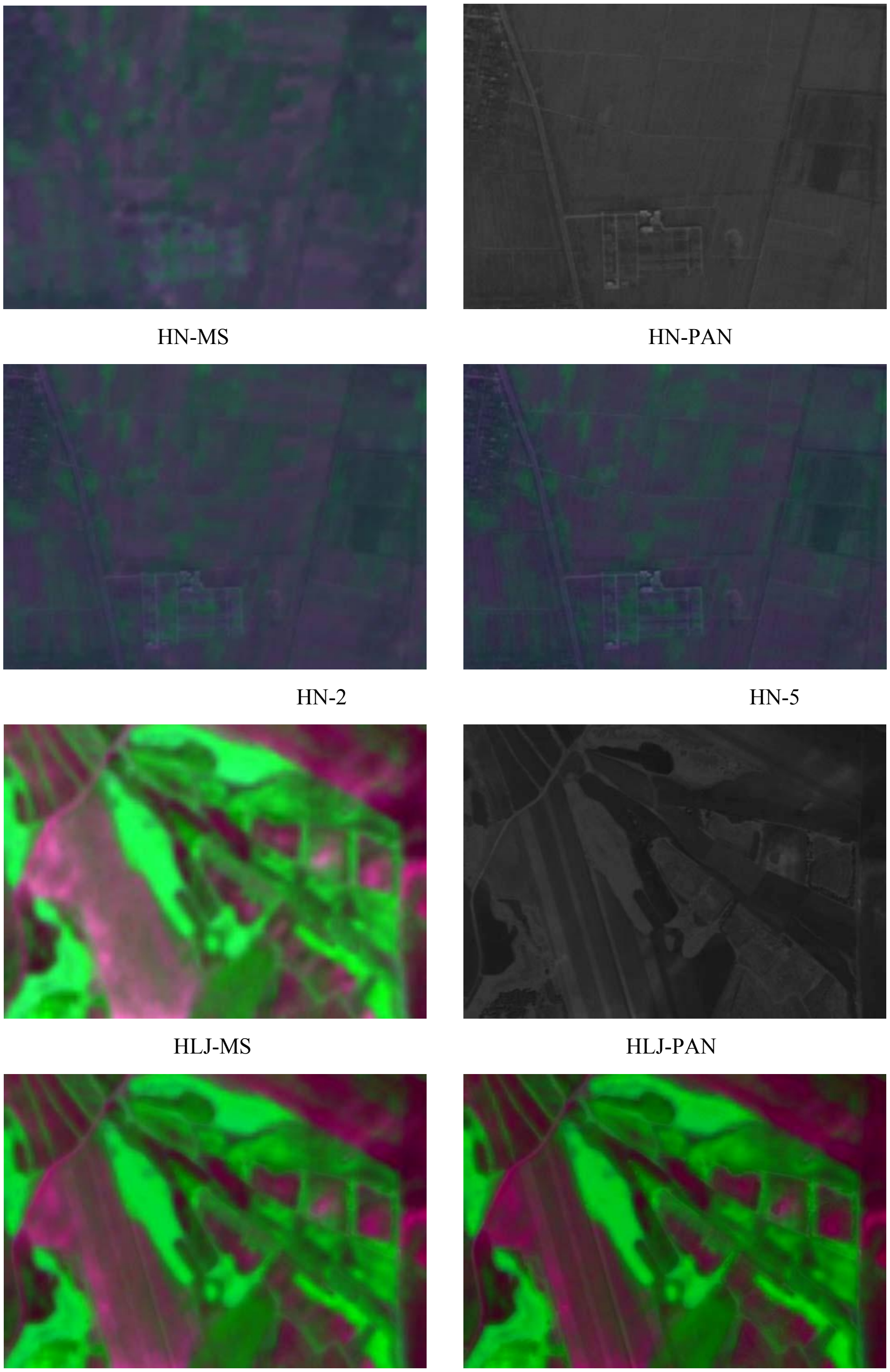


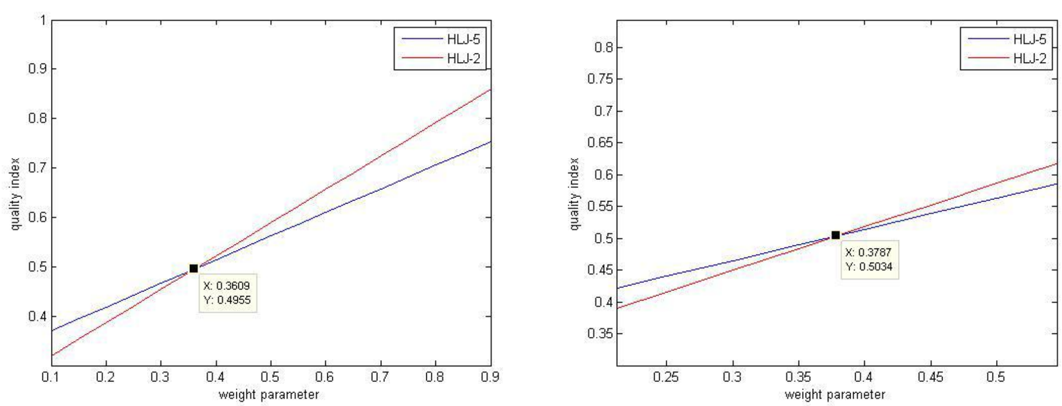
Figure 1: the experiment subsets and fusion results of different fusion models. (*-MS) are the source MS images of * subset; (*-2) are the source PAN images of * subset; (*-3) are the fusion results of spectral information preserving fusion model; (*-5) are the fusion results of spatial information preserving fusion model;

Table 1: quantitative evaluation of different fusion models using the expanded Q4

Subset	Fusion Model	$Q4_{MS}(M,F)$	$Q4_{PAN}(H',F')$	$Q4_{expand}$		
				t = 1	t = 5	t = 9
HN	HN-2	0.9939	0.4541	0.5081	0.7240	0.9399
	HN-5	0.9823	0.6293	0.6646	0.8058	0.9470
HLJ	HLJ-2	0.9263	0.2522	0.3196	0.5893	0.8589
	HLJ-5	0.8012	0.3228	0.3706	0.5620	0.7534

From the integrated value $Q4_{expand}$, we could find that:

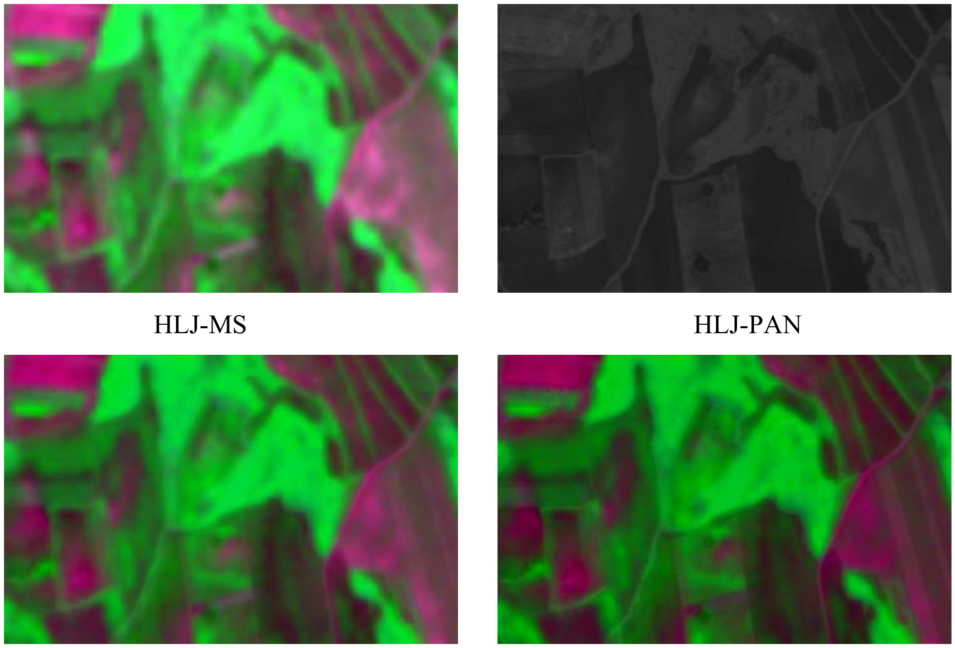
1. For HN subset, $Q4_{expand}(\mathrm{HN-2}) < Q4_{expand}(\mathrm{HN-5})$, $1 \le \mathrm{t} \le 1$, which means that the quality of HN-5 is better than that of HN-2 whatever the weight parameter of $Q4_{expand}$ is;
2. For HLJ subset, while $t=1$ or $t=5$, $Q4_{expand}(\mathrm{HLJ-2}) < Q4_{expand}(\mathrm{HLJ-5})$. But while $t=9$, $Q4_{expand}(\mathrm{HLJ-2}) > Q4_{expand}(\mathrm{HLJ-5})$. So the quality of HLJ-2 and HLJ-5 is dependent on the weight parameter of $Q4_{expand}$, determined by the fusion model. Fig. 2 (a) shows the relation between the quality and the weight parameter in the HLJ subset, with a balance while $t = 0.3609$;
3. To testify the weight parameter, we use another subset (Fig. 3) in original HLJ PAN and MS image. Fig. 2 (b) shows the relation between the quality index and the weight parameter, with a balance while $t = 0.3787$.



(a) (b)

Figure 2: the relation between the quality and the weight parameter of the HLJ subsets

With these experiments, we think that the new index $Q4_{expand}$ quality index is much more suitable for the assessment of pan-sharpened MS images, specially for those achieved by the spatial information preserving model and the spectral information preserving model, and that our measure is compliant with subjective evaluations.



HLJ-2 HLJ-5

Figure 3: the experiment images and fusion results of another HLJ subset

5. CONCLUSION

In this paper we have proposed a new objective quality measure for pan-sharpened MS images which do not require a reference image and are compliant well with subjective criteria. The new quality index takes the spatial and spectral information into account, thus more suitable for the assessment of pan-sharpened MS images resulted by either the spatial information preserving model or the spectral information preserving model.

According to our experiment, it seems that a weight parameter of approximately 0.36-0.38 suitable for our situation. But we could not carry more experiments since we have not got enough images in hand. Further research is necessary to study the influence of different fusion algorithms、input images from other sensors etc. There are several areas our quality measure can be expanded. We can adjust the edge image H' much closer to F' in Eq. (4) by multiplying another factor and also can redefine the weighted strategy between $Q4_{MS}(M,F)$ and $Q4_{PAN}(H',F')$. Those will be our next research plans.

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