Improving spatial and spectral resolution of satellite images

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Abstract

In this paper we present a new approach of image fusion to different spatial and spectral resolutions. Our approach uses the supervised trainning to find the appropriate space representation. The aim is to generalize the different nonlinear color space transformations. Thus, this allows to generalize perceptual methods.

To compare our approach with existing methods we have used the assessment techniques of the image fusion quality. A generic protocol that treats the consistency and synthesis property has been retained. This requires the application of the extrapolation hypothesis and the global quality index.

The different methods have been tested on extracts acquired by the IKONOS and the QuickBird satellites. The result show a slight improvement of perceptual methods in comparison with others. Also, we have compared the HSV transformation with our approach. It emerges of this study that the result obtained by our approach are slightly better.

1 Introduction

Nowadays, the demand for very high spatial and spectral resolution in color images is increasing. The images acquired by satellites don't meet these requirements,therefore techniques of images fusion has emerged [1, 2, 3, 4, 5]. They allow to merge multispectral images with low spatial resolution (noted MS_b) and a monospectral (panchromatique) images with high spatial resolution (noted PAN_h) in order to obtain an multispectral images with high spatial resolution (noted $MS_h^\star$).

From the inventory of the different image fusion methods, we distinguish four main categories [6] : projection-substitution, relative spectral contribution, the ARSIS concept and hybrid methods. In this last category, we refer to the methods which have not been classified by [6] and/or methods which have been developed after this proposition of classification (year 2000) and which don't belong to any of these three categories.

After analysis of the advantages and inconveniences of these categories, here we are interested in the projection-substitution category. This category is generally divided in two classes :

– The methods based on one the transformations belonging to nonlinear color spaces, named perceptual systems. These methods will be designated by *perceptual methods* (PM),

– The methods based on different statistical tools provide the less correlated components. We designate by *independent axes methods* (IAM).

Either on be the chosen class, one of the components of these methods must be capable to reduce the redundancy of information contained in MS_b image. The figure 1 shows the general algorithm of the methods of this category.

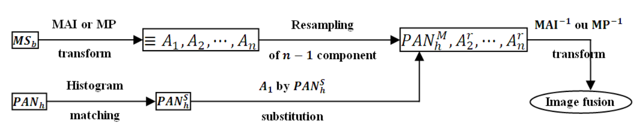

Figure 1: Images fusion algorithm for methods of projection-substitution category.

The first step consists to project the MS_b image into another representation spaces (ex. HSV for the PM). Then, the bearer component of the spatial information (ex. intensity (V)) is substituted by PAN_h^S image after having applied the histogram matching procedure [7]. The other components are resampled up to the resolution of PAN_h image (ex. H and S). Finally, the inverse transform is applied to obtain the $MS_h^\star$ fused image in RGB color space.

Our contribution in image fusion domain is introduced below (section 2). Firstly, we are interested in perceptual concept based image fusion techniques. To bring some improvements and to generalize the different methods used, we suggest using a transformation which combines all nonlinear color components. The aim is to find the appropriate components. The major advantage of this technique is the dependence between data processing and component choice. The evaluation of this approach and its comparison with other methods are shown in the results section (section 4).

2 Image fusion approch

Since the introduction of perceptual methods, several studies have beencarried out [8, 9, 3]. One of the difficulties of these methods is to find three color components (Intensity I, Hue H, Saturation S) that allow to isolate the spectral contents of the spatial contents in the MS_b image.

To address this problem, our approach uses a training sequence of MS_b image in order to find an optimal three-dimensional hybrid color space. This allows to consider the specificities and the particularities of the satellite images, to generalize the existing methods and to improve the $MS_h^\star$ (fusion product).

By the introduction of this approach we limit the radiometric distortion phenomenon, we maintain and we improve the quality measures. This approach has been applied on the image representation of Guadeloupe island. A visual and digital comparison between our approach and the classic approaches (independent axes methods (IAM) and the perceptual methods (PM) based on HSV transformation (matlab)) is presented in the section 4.

2.1 Algorithm

In the different improvements found in the literature concerning the PM image fusion methods, we notice that the major difference comes from the expressions used to determine the I, S and H components. At least, there exist 6 expressions of I, 7 of S and 6 of H [7]. Several color spaces use these components (HSV, HSL, IHS, etc.). They are expressed from different expressions. Each combination of these expressions gives a new color space. We propose to choose an appropriate expression of I, S and H for each image.

Indeed, we used the hybrid color space construction method (figure 2) (for details see [7]). After application of this method, we obtained the appropriate $I^\star S^\star H^\star$ color spaces with $I^\star$ component containing the most spatial information and thus the closest to the PAN_h image. This allows to verify the identification constraint between the high and the low frequencies. Also, to conserve the color information, the search of good hue and saturation expressions is necessary. The figure 2 illustrates the main steps allowing the image projection on the hybrid color space ($I^\star S^\star H^\star$). It shows a phase of color components selection (training stage) is added as compared to classic approaches (PM).

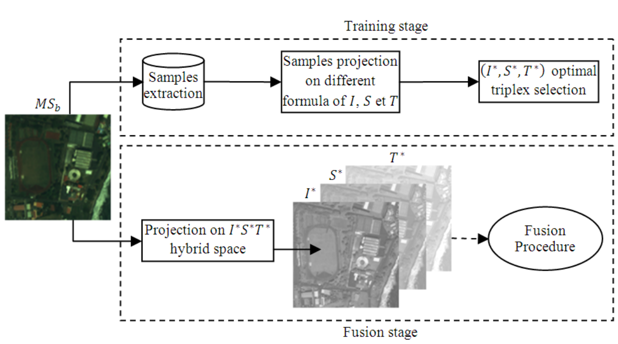

FIGURE 2: Hybrid color spaces selection for images fusion.

The rest of the fusion procedure does not differ much to the classic procedure. The advantage of this added step is to extract from MS_b image, the best color space. Thus we have a total dependence between the color space and the processed image. We indicate that in certain cases the computed $I^\star S^\star T^\star$ hybrid color space can be equivalent to one of the existing standard color spaces.

2.2 Remarks

- we indicate that the supervised training phase used here to find appropriate hybrid color space is same as [7].
- the application of classic approaches (PM) requires the use of a reversal color space. It allow to find the fused product. In our approach, we considered this particularity,
- we remind that the adapted hybrid color space is three-dimensional and (I, S and H) components are separately analyzed. Once the adapted components selected, the reversal components are then determined and are fused product is calculated (figure 2).

3 Quality measures of images

In this work, we are interested in consistency and synthesis properties [6, 5] to decide the quality of fused product of a monomodal (component by component) and multimodal (all components) case. For this we used the hypothesis of extrapolation and some quality measures allowing to have a global idea on the fusion product and to judge its quality.

3.1 Extrapolation hypothesis

The main difficulty in the assessment of the quality of the fusion product is the absence of reference images. To solve this problem, extrapolation hypothesis suggests that reference images (noted MS_h^{ref}) could be multispectral images with low spatial resolution ($MS_h^{ref} \equiv MS_b$). In this case multispectral and panchromatique images respectively MS_b and PAN_h (at low and at high spatial resolution) are degraded by a factor r. Thus, we obtain $MS_{b'}$ and $PAN_{h'}$ images where $b' = \frac{b}{r}$ and $h' = \frac{h}{r}$. In these conditions, quality measures can be computed and a comparison between reference images and fused images ($MS_{h'=b}^{ref} \equiv MS_{h'=b}^\star$) is now possible (figure 3).

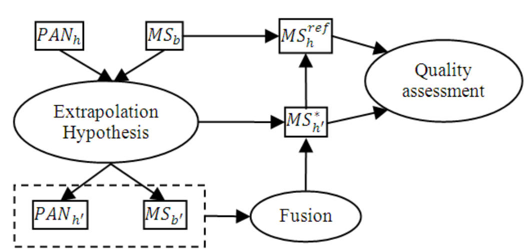

Figure 3: Extrapolation process.

Extrapolation hypothesis as it is defined, requires to resampling MS_b and PAN_h images. The generic term of resample consists in modifying the number of pixels of an image (i.e. the size of the image). There are two types of resampling:

- under sampling: to decrease the number of pixels, the application removes some information.

- over sampling: to increase the number of pixels, the application creates supplementary pixels from the values of image intensity.

In the two cases, the application uses an interpolation method to determine the way in which pixels are added or removed. Several methods are introduced. In our case we have tested three of these methods (nearest neighbor method, bilinear method and bicubic method).

3.2 Quality measures

In this paper, fusion product quality is evaluated visually and numerically. Criteria are used to verify the following properties:

- consistency: degraded fusion product must be egual to original product ($MS_b^{deg} \equiv MS_{b'}$),

- synthesis: fusion product must resemble to reference product, if it exists ($MS^*_{h'=b} \equiv MS^{ref}_{h'=b}$).

They can be calculated in following ways:

- monomodal: separate comparison of each component,

- multimodale: simultaneous comparison of all components.

After our bibliographical study, we noticed that criteria used, in monomodal case, to compare image fusion are based on the calculation of an informative distance of the global quality for example the RMSE (Root Mean Square Erreur) [4] and/or correlation coefficient. In multimodal case, other criteria have been introduced. As example ERGAS (l'Erreur Relative Globale Adimensionnelle de Synthèse) [10] whose threshold must be less than 3 to judge fusion product quality [4]. These criteria allow to quantify the geometric and radiometric image quality.

Visual assessment

A visual evaluation of the fusion product is almost essential inspite of the differences which can appear between two judgments because the opinions differ according to the needs, the objectives and the knowledge. In this work we have recourse, repeatedly, to the opinions of our experts [11, 12] in order to have a visual evaluation. In [13] the author has given an idea to generalize his assessment, by proposing to classify fused images according to the level of information contents. This idea is made available to users and is called MIIRE (Multispectral Imagery interpretability Rating Scale).

Quantitative assessment

Many authors recommend to take precautions at the time of visual assessment and insist on the utility to add quantitative analysis. The aim is to obtain a reliable objective judgment. In [5], the author discussed of the existence of thirty nine different distances and classifies them in seven categories for the monomodal and multimodal tests.

In this study, we have restricted ourselves to use global quality index (GQ) (see formula 1). This allows to combine the coherence and synthesis properties in monomodal and multimodal cases.

4 Results

The figure 4 presents the tested satellite images. These images offer a good landscape variability and a good spatial and spectral content (forest, agricultural parcels, houses, pavements, etc.). Fusion methods are tested on these images where the resolution factor is $r = 4$. The size of these images are respectivly 256×256 for PAN_h images (on the right) and 64×64 for MS_b images (on the left). Here, we wanted to put the small, objects for example planes and markings to soil, in order to evaluate and to study the behavior of image fusion techniques with respect to image details (figure 4(a)). In the figure 4(b), our goal is to study the behavior of image fusion algorithms with respect to the color distribution on the house roofs and their behaviour in the presence of the tree shadous.

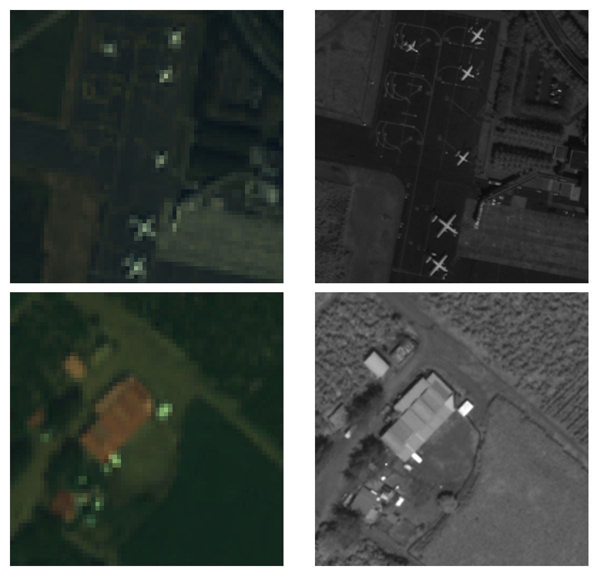

Figure 4: MS_b and PAN_h used images. They acquired by IKONOS and QuickBird satellite.

The IKONOS satellite allows the acquisition of a PAN_h (resp. MS_b) mono component (resp. multi component) image with spatial resolution equal $h = 1$ (resp. $b = 4$) meters/pixel. However, the QuickBird satellite images have better spatial resolution. This resolution is $h = 0.7$ (resp. $b = 2.8$) metres/pixel for PAN_h (resp. MS_b). In two cases the relationship of resolution is $r = 4$.

4.1 Visual presentation

The figure 5 represents the fusion products computed by our approach, the PM method based on HSV transformation (MATLAB source) and the IAM method (using the PCA method) respectively.

Obtained fusion products have the advantage to respect the geometric property of the original image (figure 4) which induce a good visual quality. However, one of the most significant defects is translated by the non radiometric property disrespect. Spectral signature of $MS_h^\star$ fusion images is far being MS_b low resolution multispectrale images. Thus we observe a color distortion in fusion products (figure 5). This distortion is less flagrant for MP methods by applying our approach or using the HSV color space than that of IAM methods based on PCA.

For IAM algorithms (here PCA), we see the presence of a stronger spatial information. The main reason is the first component is most representative in variance terms. In general, this componnet is replaced by PAN_h images.

These results show the PM techniques (our approach and HSV) provide same fusion product with a slightly better visibility which our approach. On the other hand, color distortion problem is slightly less important as compared to IAM techniques. They preserve same advantages i.e. the respect of geometric property and offer a high-quality visual preview towards MS_b images. The major inconvenience is that one can not apply these techniques if the number of components is superior to three (contrary case a compromise must be) contrary to IAM techniques.

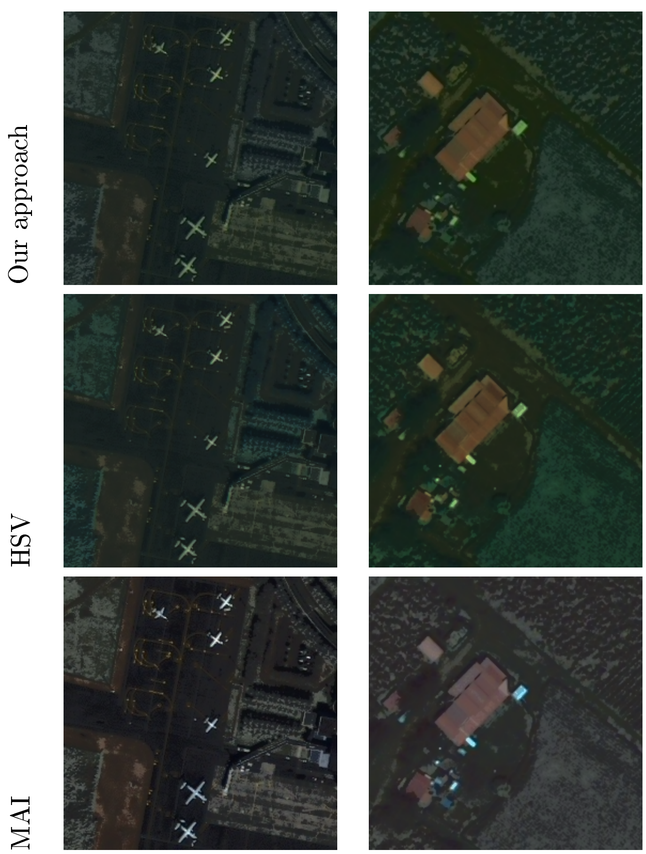

Figure 5: Fusion product obtain used different fusion method based bicubic operator.

4.2 Numerical analysis

For the numerical evaluation, we choose to use bigger MS_b and PAN_h images in order to apply extrapolation hypothesis is a better way. The chosen extracts contain MS_b and PAN_h with size respectively 512×512 and 2048×2048 with factor, $r = 4$. The interpretations and the conclusion of this study have been based on about thirty satellite images. We kept bilinear technical interpolation knowledge the difference between it and the nearest neighbor or bicubic method on distance measures is really very light.

In results presentation, we have evaluated consistency property. For this, the $MS_h^\star$ fusion image is degraded at spatial resolution of MS_b original image. This step is noted $Test1$ [10]. Then, we have verified synthesis property. We have applied the extrapolation hypothesis and quality measures between $MS_{h'}^\star$ synthesis image and $MS_{h'}^{ref} \equiv MS_b$ reference image. This step is noted $Test2$ [10]. Finally, to combine these properties, we estimated the Global Quality index [10] on fusion product expressed as a function of the $Test1$ and $Test2$ results. The expression is given by the following equation:

$$GQ = 1 - \frac{\sqrt{\sum_{k=1}^{K} \left(RMSE_k^{Test1}\right)^2 + \sum_{k=1}^{K} \left(RMSE_k^{Test2}\right)^2}}{255} \quad (1)$$

Where K is the number of component of multispectral images.

Here we used $RMSE$ distance to determine GQ, it is possible to replace this distance by others distance metrics. Furthermore, it is important to indicate that a best fusion product must have a $GQ \simeq 1$ (table 1).

	Image fusion methods						optimal value
	IKONOS images			QuickBird images			
	Our approach	HSV	MAI	Our approach	HSV	MAI	
GQ	0.93	0.92	0.85	0.92	0.92	0.87	1
GQ (R)	0.93	0.94	0.81	0.92	0.93	0.84	1
GQ (V)	0.93	0.91	0.87	0.92	0.89	0.91	1
GQ (B)	0.93	0.92	0.87	0.92	0.93	0.87	1

Table 1: Global Quality index for different image fusion methods.

In general, these results show that quality of the fusion product is same for the IKONOS and QuickBird satellite images. We note that it is difficult to choose a fusion method over an other. The obtained results show a contradiction and a complementarity at the same time. In the context of this study, we can conclude that our approach and the technique based on the HSV color space produce the best numeric results. In the same way, we notice a stability of GQ values of our approach as compared to other methods (table 1).

5 Conclusion

Different image fusion methods have been identified. We have tried to describe some of them so that we can introduce our approach. Our approach is based on a supervised training applied to MS_b images. It allows to take into account the particularities of each image and to increase the identification part of the spectral information in relationship to the frequency information. In the same way, this approach permitted to generalize the method while using nonlinear color spaces. Thus, we classify it in the projection-substitution category, specifically among the perceptual methods.

In order to compare our approach to other fusion methods, we used the Global Quality index GQ based on $RMSE$ distance. It showed as light advantage of our approach. While taking into consideration this advantage, we achieved good results by generalizing different space representations.

Image fusion of a different spatial and spectral resolution is a very recent domain where image acquisition technologies one rapidly growing. Therefore, we think that a consequent development must be made in order to improve the expressions that quantify and evaluate the quality of radiometric and geometric properties contribution.

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