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Research on Methods of Infrared and Color Image Fusion Based on Wavelet Transform

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Abstract: There is significant difference in the imaging features of infrared image and color image, but their fusion images also have very good complementary information. In this paper, based on the characteristics of infrared image and color image, first of all, wavelet transform is applied to the luminance component of the infrared image and color image. In multi resolution the relevant regional variance is regarded as the activity measure, relevant regional variance ratio as the matching measure, and the fusion image is enhanced in the process of integration, thus getting the fused images by final synthesis module and multi-resolution inverse transform. The experimental results show that the fusion image obtained by the method proposed in this paper is better than the other methods in keeping the useful information of the original infrared image and the color information of the original color image. In addition, the fusion image has stronger adaptability and better visual effect. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Infrared image, Color image, Image fusion, Wavelet transform.

1. Introduction

Image fusion [1] is a technology by which the images on the same scene deriving from different sensors are processed by image fusion algorithm, extracting useful information to the maximum, weeding out the useless information and finally integrating into a high quality image in order to enhance the spatial and spectral resolution of the original image, facilitating subsequent image processing and recognition.

According to different classification of image fusion, image fusion algorithms can be divided into the pixel level, feature level and decision level. Commonly used image fusion rules are pixel weighting method, regional energy method, contrast method, etc. Multiple sensor fusion, multi-resolution fusion and multiple focus fusion are hot spots of image fusion at present. From the point of the characteristics of HVS and observation, in the process of the gray level image fusion, a multi-resolution structure is often adopted for the image fusion at pixel level. The commonly used multi-resolution image fusion methods of decomposition and reconstruction can be divided into two main categories: the pyramid and decomposition and reconstruction based on Wavelet Transform. Wavelet Transform in recent years has developed thoroughly and rapidly. Multi-resolution analysis based on wavelet transform has more and more applications in the field of image fusion.

This paper studies the infrared and color image fusion based on wavelet transform, using the image multi-resolution structure derived from wavelet transform. The fused color images not only contain the useful information of the infrared images which is imperceptible in visible light image, but make full use of the color information in the optical image, so that the fusion image possesses the characteristic of natural color in visible light image, conforms to the human eye perception and enhances the discernibility degree of fused images.

Subsequent chapters are arranged as following: principles of the wavelet multi-resolution image fusion and methods of infrared and color image fusion will be first introduced in this paper, followed by Piella [11] image fusion framework, the results and analysis of fusion simulation, and finally references.

2. Principles of the Wavelet Multi-resolution Image Fusion

The image fusion based on Wavelet Transform is most widely discussed in academia. Image fusion method based on wavelet analysis [2, 3] mainly applies multi-scale decomposition of wavelet transform, first to the wavelet decomposition of multi original images, and then to corresponding fusion processing of the wavelet coefficients attached to the different decomposed sub bands. Finally the corresponding fusion image process is obtained by wavelet inverse transform. In the case of two image fusion, an image fusion process based on wavelet analysis is as follows:

1) Two-dimensional wavelet decomposition of the two registered original images at certain levels.

2) Fusion of high frequency and low frequency components on each layer after the wavelet decomposition according to certain rules

3) Getting the final fusion image through the corresponding wavelet inverse transform

The algorithm flow chart is shown in Fig. 1.

3. Image Fusion Methods of the Infrared and Color Image

Infrared and color image fusion [4] can be divided into color image fusion and gray level image fusion according to the color of the output.

Commonly used infrared and color image fusion methods [5, 6] are: color transformation in some brightness – color [7, 8], such as HSV transform. YC_bC_r transform separates the color component of visible light image, and then builds color information of the final color fusion image directly with these color components.

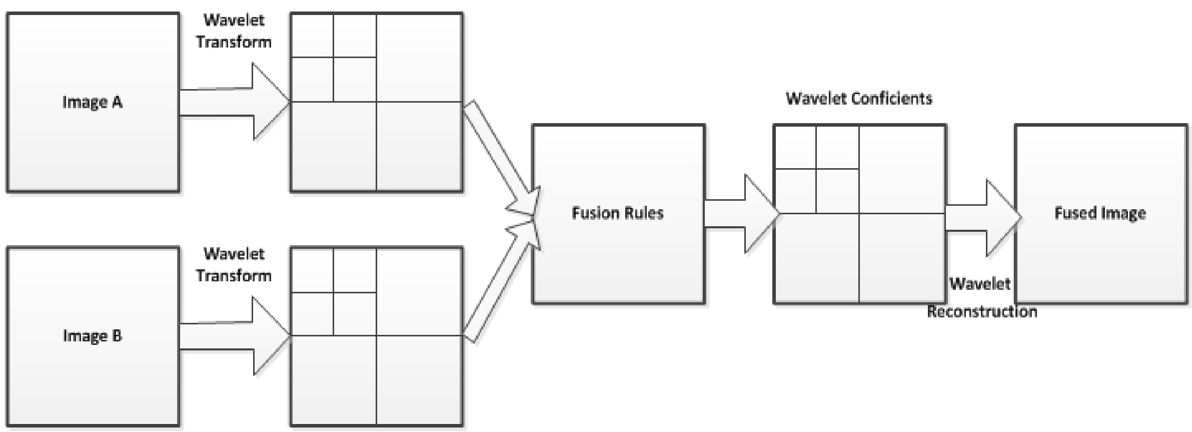


Fig. 1. Flow Chart of image fusion based on wavelet analysis.

This method makes full use of the color in the visible light image information, thus getting more natural color fusion images and conforming to the human eye observation. However, if there is not enough color information in the visible-light images taken, such as visible-light images taken on the nights with inadequate illumination, the final fusion image looks like a gray image. To a certain extent, infrared and color image can draw lessons from remote sensing image fusion methods, such as HIS fusion method and PCA fusion method [9]. HIS fusion method is adopted in this paper, first of all to convert color images to HIS space, and then to fuse the transformed intensity component I and the infrared image, followed by HIS inverse transform for RGB color images.

A common HIS transform [10] formula is shown in formula (1)-(6):

$$\begin{bmatrix} I \\ V1 \\ V2 \end{bmatrix} = \begin{bmatrix} 1/3 & 1/3 & 1/3 \\ -1/\sqrt{6} & -1/\sqrt{6} & 2/\sqrt{6} \\ 1/\sqrt{6} & -1/\sqrt{6} & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}, \quad (1)$$

$$H = \tan^{-1}(V2/V1), \quad (2)$$

$$S = \sqrt{V1^2 + V2^2}, \quad (3)$$

The corresponding HIS inverse transform is as follows:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{6} & 3/\sqrt{6} \\ 1 & -1/\sqrt{6} & -3/\sqrt{6} \\ 1 & 2/\sqrt{6} & 0 \end{bmatrix} \begin{bmatrix} I \\ V1 \\ V2 \end{bmatrix}, \quad (4)$$

$$V1 = S * \cos(H), \quad (5)$$

$$V2 = S * \sin(H), \quad (6)$$

where I is the luminance component, H is the chrominance component, S is the saturation component, $V1$ and $V2$ are the intermediate variables required for transform from RGB to HIS, containing the image color information.

4. Piella Image Fusion Framework

In this paper, infrared and color image fusion is conducted in Piella image fusion framework [11, 12]. Take the fusion of image A and B as an example. Piella image fusion framework is shown in Fig. 2, with y_A and y_B being multi-resolution coefficients respectively of input for fusion of original image. The core module processed in the whole system can be divided into three parts: matching measure, decision module and synthesis module. Matching measure m_{AB} is used to measure the degree of matching or similarity among multi-resolution decomposition coefficients of the original image. Information of similarity matching measures is applied to decision module, and the corresponding decision factor d is derived. Then the multi-resolution analysis coefficient y_F of the fused image is derived from synthesis module, followed by multi-resolution inverse transform for the fusion image.

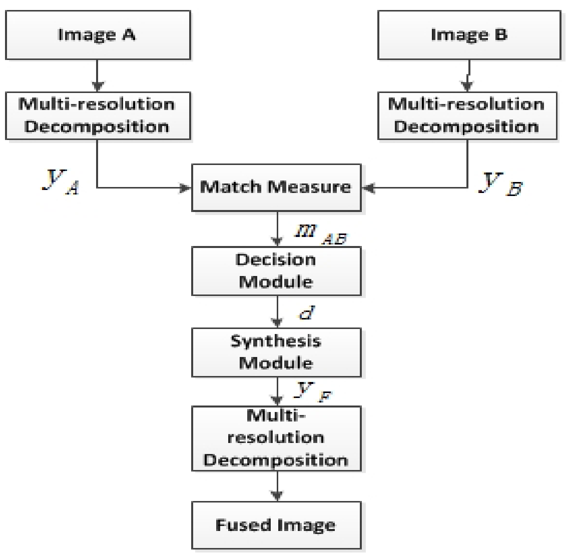


Fig. 2. Piella image fusion framework.

4.1. Matching Measure

By analysis and calculation of the matching measure m_{AB}, the difference in the multi-resolution decomposition coefficients of the original image can be learned. The information can be used to determine the appropriate rules for corresponding fusion processing of original image decomposition coefficient. There is usually a very big difference when determining the source image at some point according to the matching measure, so the original image decomposition coefficient of high active measure is selected in the fusion image. On the other hand, if the original image decomposition coefficients are similar at that point, then a weighted average of the original image is usually used as the decomposition coefficient of the final fusion image.

Low frequency component, horizontal high frequency, vertical high frequency, high frequency diagonal component are derived from two-dimensional wavelet decomposition of image. Low frequency component represents the information of image outline and the high frequency component stands for the details of the image.

In traditional image fusion rules, the weighted average method is often used in the processing of low frequency component, which is simple, easy to implement and can effectively restrain the noise of the image, but does not contain the information of the image edge characteristics.

The regional standard variance, to a certain extent, can reflect gray-level intensity change of the images in the area, which in part reflects the difference of the images in the area. Therefore, this paper uses standard variance in relevant signal area as matching measure of low frequency component [13], whose definition formula is shown in formula (7)

$$I_{i,AB}^{x}(m,n) = \sum_{m' \in L, n' \in M} M(m',n') \left| p_{i,AB}^{x}(m+m', n+n') \right|, \quad (7)$$

Relevant regional variance ratio will be regarded as the matching measure of high frequency component, whose definition is shown in the following formula:

$$R_{i,AB}^{x} = \frac{I_{i,A}^{x}}{I_{i,A}^{x}}, \quad (8)$$

The $I_{i,A}^{x}$ and $I_{i,B}^{x}$ respectively represent signal variance of original images A and B in the X direction at the i-layer window area. Thereby the relevant signal variance ratio is that of $p_{i,A}^{x}$ and $p_{i,B}^{x}$ in the window area. (m,n) is the pixel coordinates for the image, M for mask window area, used for linear filtering to the window area, L and M for the area of the window, for change in range L, K.

4.2. Decision Module

Decision module is the core of the image fusion algorithm, whose decision factor of output value d decides the values of multi-resolution coefficient of the final synthesis module in the fusion image.

Usually the selection of decision factor d should also follow the following principles:

1) When the match measure values between the two images are the same or similar, part of detail components should be chosen respectively from the two images as those of the fused image.

2) When there is a relatively big difference in the match measure values between the two images, all or as many image detail components as possible with bigger matching measure values should be chosen as the detail components of the fused image.

4.2.1. Low Frequency Component of the Decision Factors

$$d_{i,\ L}^{x}(m,n)=\frac{i_{i,A}^{x}}{i_{i,A}^{x}+i_{i,B}^{x}}, \tag{9}$$

4.2.2. The Decision Factors of High Frequency Component

This paper selects the Butterworth high-pass filter [14] function as the decision factor. The transfer function of Butterworth high-pass filter with n order cut-off frequency of 1 is shown in formula (10):

$$d_{i,\ H}^{x}(m,n)=\frac{1}{1+(1/R_{i,AB}^{x}(m,n))^{2n}}, \tag{10}$$

where n is for Butterworth high-pass filter order, control the growth rate of the curve. $R_{i,AB}^{x}(m,n)$ is for the variance ratio in the related signal region. $d_{i,\ H}^{x}(m,n)$ is for the decision factors we need.

Butterworth high pass filter function diagram is shown in Fig. 3.

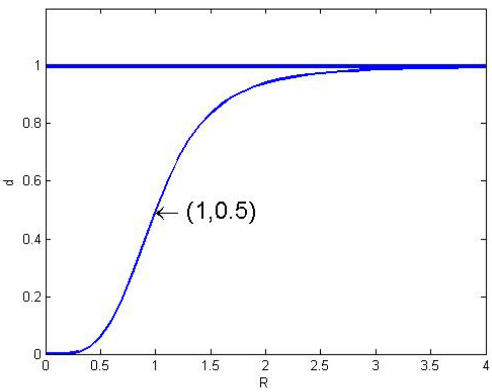


Fig. 3. The Butterworth filter function.

By analysis of Fig. 3, when the relevant regional variance ratio R is 1, decision factor d is valued at 0.5, when R value changes from 0, the d value will slowly change from 0 to 1, corresponding with the principle that should be followed when selecting decision factors.

4.3. Synthesis Module

Synthesis module is used to merge the multi-resolution decomposition coefficient of source image, thus producing y_F, the multi-resolution decomposition coefficient of the final fusion image.

$$y_{i,F}^{x}(m,n)=d_{i,A}^{x}y_{i,A}^{x}(m,n)+d_{i,B}^{x}(m,n)y_{i,B}^{x}(m,n), \tag{11}$$

In it,

$$d_{i,B}^{x}(m,n)y_{i,B}^{x}(m,n)=1\text{-}\ d_{i,A}^{x}(m,n), \tag{12}$$

where $y_{i,F}^{x}(m,n)$ is the detail component of fusion image F at pixel (m,n), $y_{i,A}^{x}(m,n)$ and $y_{i,B}^{x}(m,n)$ are the detail components of each original image respectively.

4.4. The Overall Process of the Algorithm

1) Read in infrared image A and color RGB image B. Transform color RGB image into HIS space by formula (1-3). And transform four-layer two-dimensional wavelet decomposition of infrared image A and the I component of color RGB image converted through HIS space.

2) Extract the low frequency coefficient of wavelet decomposition on each layer and high frequency coefficients of horizontal, vertical and diagonal direction.

3) Use formula (9) and (10) respectively to calculate the original image matching measures of low frequency and high frequency components.

4) Use formula (11) to calculate the decision factors of the low frequency and high frequency components.

5) Make wavelet inverse transformation and image enhancement of low frequency and high frequency components in each layer and obtain the final fusion image by HIS inverse transformation.

5. The Results and Analysis of the Simulation

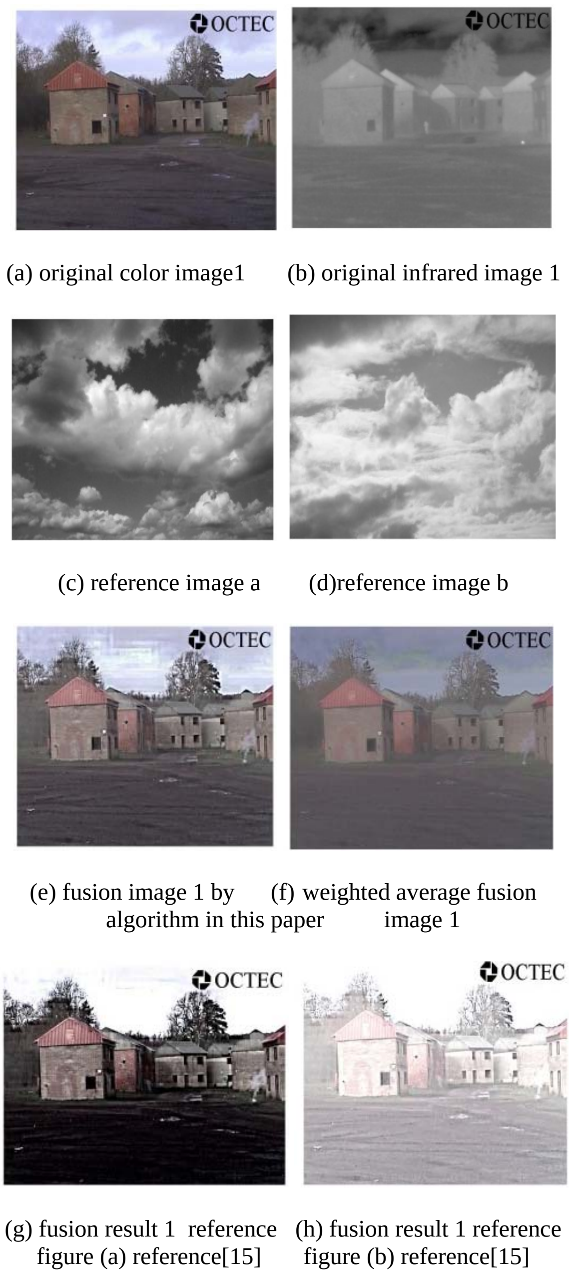
In order to verify the effectiveness of the algorithm, this paper respectively fuses two groups of original infrared image, adopting the weighted average method, the brightness and contrast transfer method (two reference images) and the fusion method in this paper, as shown in Fig. 4 and Fig. 5.

Two groups of registered infrared image and color visible image provided by British Octec Company are regarded as experiment source images. The groups of images are taken with the barrier of smog, including people, houses and trees in the scene.

It is proposed in this paper the weighted multi-resolution image fusion algorithm based on the related signal region variance ratio is adopted for the fusion of infrared image and color visible light image. Related signal region variance ratio is used as fusion rules to better preserve the details on the edge of the image, effectively retaining the characteristics of infrared image and color image and detail information, and getting better fusion effect close to human visual characteristics. Haar wavelet is used in both the paper and reference [15] as a multi-resolution analysis tool, with four decomposition layers. In reference [15], the threshold value is 0.6, mask is [1/16, 1/8, 1/16, 1/8, 1/4, 1/16, 1/16, 1/8, 1/16).

Simulation processing is done in the environment of Matlab experiment. Processed by two proposed algorithm in this paper, the weighted average fusion algorithm and algorithm in reference [15], fusion images are respectively shown in Fig. 4 and Fig. 5.

After analysis of the fused images, the source image is visible, but the invisible man and the mist emitted from a point in color images can have good showing in the fusion image by such a combination of algorithms as this.



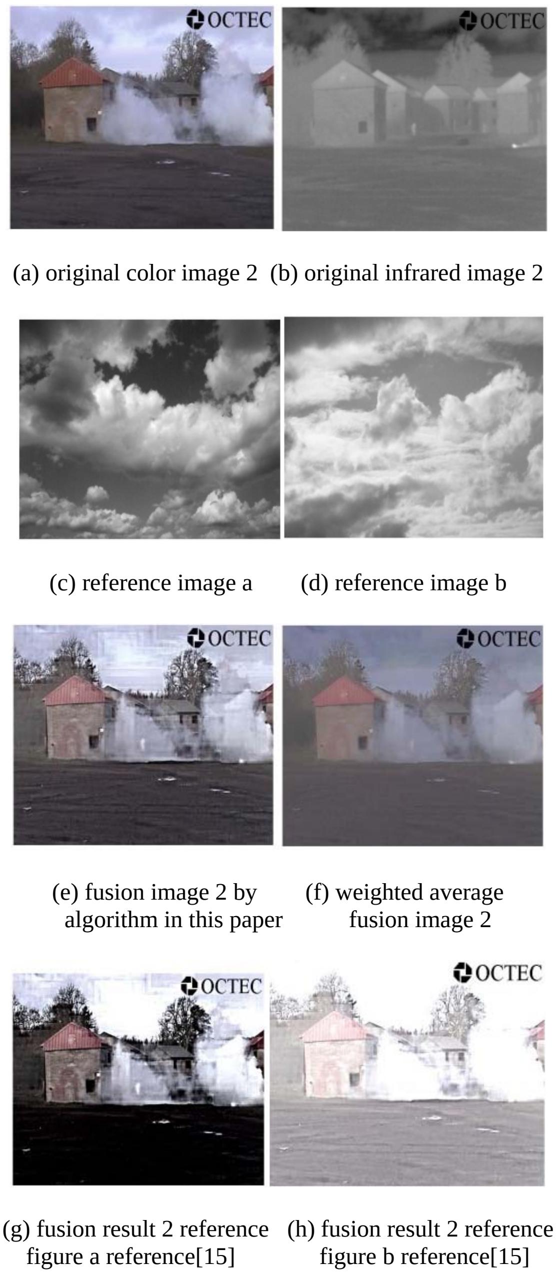
(a) original color image1 (b) original infrared image 1

(c) reference image a (d)reference image b

(e) fusion image 1 by algorithm in this paper (f) weighted average fusion image 1

(g) fusion result 1 reference figure (a) reference[15] (h) fusion result 1 reference figure (b) reference[15]

Fig. 4. Image 1 fusion experiment.



(a) original color image 2 (b) original infrared image 2

(c) reference image a (d) reference image b

(e) fusion image 2 by algorithm in this paper (f) weighted average fusion image 2

(g) fusion result 2 reference figure a reference[15] (h) fusion result 2 reference figure b reference[15]

Fig. 5. Image 2 fusion experiment.

A reference image needs to be provided when using reference [15] algorithm, which is strongly dependent on the reference image. The different selection of images has a great effect on the result of fusion. Compared with the original color image, the fused image in reference [15] has relatively large color distortion. Reference [15] algorithm, i^{th} poor adaptability, needs to be provided with a reference image and artificial input of threshold and mask.

The proposed algorithm in this paper, with a better adaptability, does not need artificial input of any parameter. The fusion image not only presents the useful information of the source infrared image, but well preserves the color information in the source color image. Compared with other algorithms, the fused image, with little color distortion, has a good visual presentation in terms of subjective evaluation.

6. Conclusion

According to the characteristics of infrared image and color image, a method of area standard deviation based on correlation signal is proposed in this paper to make image fusion, and image fusion and image enhancement are combined in the process of fusion. Experimental results show that compared with the brightness and contrast of transmission fusion algorithm based on wavelet transform, the method proposed in the paper, with a strong adaptive ability, does not need reference images and any human-input parameter. The fused image derived fully saves the color information compared to source color while at the same time keeping the useful information of the source infrared image, which conforms to the visual requirements more and shows a good potential of popularization.

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