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Study on Fusion Algorithm of Multi-source Image Based on Sensor and Computer Image Processing Technology

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Abstract: Multi-source image fusion as a research area with image as its object in multi-source information fusion, is a combination of sensor, computer image processing, artificial intelligence and other disciplines. This article mainly focused on work summary and new ideas based on multi-resolution decomposition and fusion method. Using variational partial differential equation for the fusion exploration based on feature level fusion study of regional and multi-resolution decomposition. Discussed how to realize the objective evaluation of image fusion performance and the specific application of multiple source image feature level fusion in road target recognition. *Copyright © 2013 IFSA.*

Keywords: Sensor technology, Computer image technology, Multiple image fusion.

1. Introduction

With the development of image sensor technology, more and more sensors are used in various fields. The increase of number of sensors leads to rapid increase in the amount of data received and presents diversity. Traditional information processing methods cannot satisfy the new requirements. Therefore, multi-source information fusion technology emerges at the right moment in this context. Multi-source information fusion refers to carry on a comprehensive processing with multi level s, multi-aspects and multilayers of the multi-source information from multiple sensors, so as to obtain more abundant, accurate and reliable useful information [1]. Its main idea is through the adoption of a certain algorithm, to fuse two or more source images with complementary or redundant features into a new image. Make the image after fusion maximize the use of complementary information, reduce redundancy, to gain higher clarity and understandability.

Multi-source image fusion refers to the comprehensive processing of information in multiple carriers in order to achieve a certain purpose. The scope of multi-source image fusion is very extensive. It can be concluded as a multi-source image fusion process. The general conclusion is obtained after the integration and abstraction of several special cases. Therefore, there exists essential contact between inductive reasoning and information fusion. And inductive reasoning is the source of all the science and technology. In recent years, multi-source image fusion has received great attention in many fields and multi-source image fusion technology developed rapidly.

2. Multiple Image Fusion Technology

Currently, the imaging sensor mainly consists of infrared imaging, radar imaging and optical imaging. Infrared imaging has the characteristics of penetrating smoke, work double tides, etc, therefore, it is particularly valued at close range imaging tracking system. Active radar imaging sensor has the ability to work with all-weather, but due to its complex structure and large equipment, its application in many occasions is limited. And radar images are easily influenced by the ground clutter [2]. Visible light CCD imaging system is of small size and simple structure and with high resolution, strong anti-jamming capability, but is more easily affected by weather conditions.

In contrast, multi-source image fusion integrated sensor, computer image processing, signal processing, and artificial intelligence and other disciplines. Its main idea is through the adoption of a certain algorithm, to fuse two or more source images with complementary or redundant features into a new image. Make the image after fusion maximize the use of complementary information, reduce redundancy, to gain higher clarity and understandability. And provide more effective information for further image processing such as image segmentation, object detection and recognition, battle damage assessment and understanding [3]. Fig. 1 is redundant and complementary information between source images. Multi-source image fusion is not a simple superposition, it produces a new image which contains more value information. Image fusion can not only fuse images of the same kind of sensors, but also can fuse images of different types of sensors. But sensor of the same type is with the same physical significance and the images are with the same properties. Images from different types of sensors have greater complementarity, So the meaning of the fusion of heterogeneous images is more apparent.

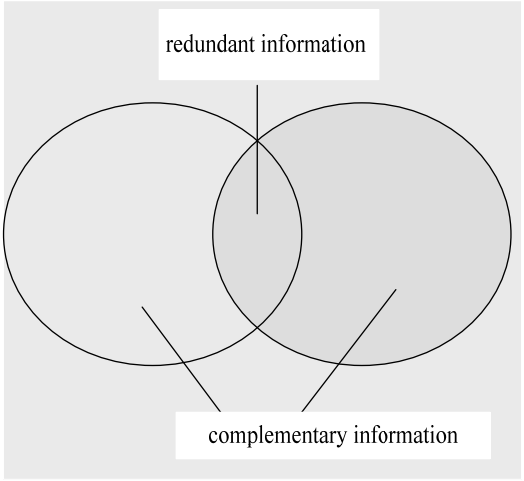


Fig. 1. Diagram of redundancy and complementary information between source images.

Multi-source image fusion can improve the performance of the sensor system from the following aspects:

1) Extend system coverage. Measured object or environmental information can be obtained more accurately. And information received has higher accuracy and reliability.
2) By complementation between each sensor, independent characteristic information is obtained which is beyond the ability of single sensor.
3) According to the prior knowledge of the system, by fusion processing, classification, identification and decision-making can be accomplished.
4) Improve the system reliability. Because the data are from multiple (kind of) sensors, when one or more sensors fail or make mistakes, system continues to work.

Multi-source image fusion as a specific research area of multi-source information fusion, while having the characteristics of information fusion, it also exerts stricter requirements on preprocessing such as the image registration. Image fusion algorithm makes the fusion image contain the important information in its original image. Image fusion algorithm should not introduce any misleading for human visual perception or error message of image processing [4].

3. Basic Principle, System Structure and Algorithm of Multi-Source Image Fusion

3.1. Basic Principle and System Structure of Multi-source Image Fusion

Image fusion is an emerging technology with the integration of sensor, signal processing, image processing and artificial intelligence. General processing flow of multi-source image fusion is: Image preprocessing, image registration, image fusion, feature extraction and recognition and decision making. Based on the stage of fusion in the processing flow and abstraction degree of the information, multi-source image fusion is generally divided into three levels: Pixel level fusion, feature level fusion and decision level fusion [5]. The frame structure of decision level fusion is shown in Fig. 2.

3.2. Classification of the Algorithm

The algorithm of multi-source image fusion at pixel level can be divided into six types: linear weighted fusion, false color image fusion, image fusion based on the modulation, statistics-based image fusion, neural network-based image fusion and image fusion based on multi-resolution decomposition.

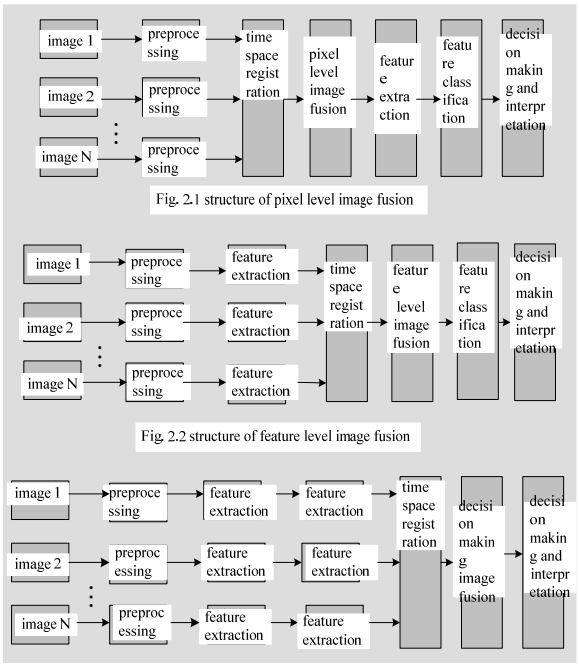


Fig. 2. Frame structure of decision level fusion.

4. Multi-source Image Fusion Based on Multi-resolution Decomposition

4.1. Orthogonal Wavelet Transform

Digital signal in space can be projected onto each subspace. In many cases, it is much easier to analyze signal projection in each subspace than to analyze the original signal. Signal multi-resolution analysis reflected in frequency space is shown in Fig. 3.

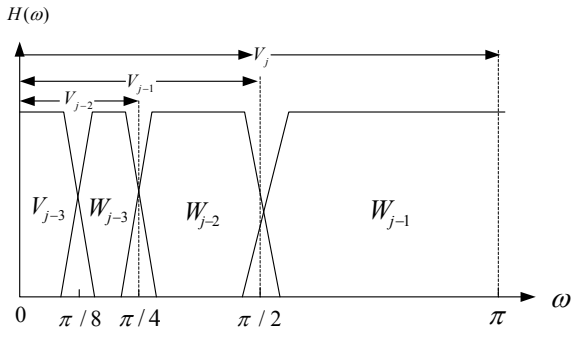


Fig. 3 Multi-resolution frequency separation characteristics.

Use a high-pass filter g and a low-pass filter h to decompose the original signal into two sub-bands. Then for the low frequency sub-band, use low-pass filter and high-pass filter recursively to make further decomposition [6]. Using a series of the FIR filter bank to realize the above multi-resolution decomposition, as shown in Fig. 4.

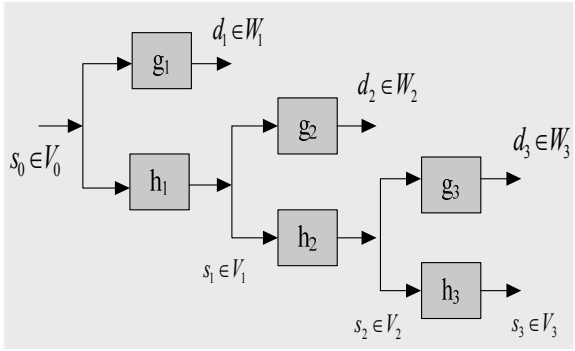


Fig. 4. Parse tree of filter bank for multi-resolution analysis.

If $\psi(t) \in L^2(R)$ meets the "permissible" condition: $C_\psi = \int_{-\infty}^{+\infty} \frac{|\hat{\psi}(\omega)|^2}{|\omega|} < \infty$, then $\psi(t)$ is called a basic wavelet.

For a basic wavelet $\psi(t)$, square integrable space function $f(t) = L^2(R)$, its wavelet transform definition is:

$$W_{\psi,f}(a,b) = |a|^{-1/2} \int_{-\infty}^{+\infty} f(t) \cdot \overline{\psi(\frac{t-b}{a})} dt, (a,b \in R, a \neq 0) \quad (1)$$

Of which, a>0 is the scale factor, b reflects the displacement, its value can be positive or negative, t is the continuous variable.

Therefore, it is known as the continuous wavelet transform.

Discrete wavelet $\psi_{j,k}(t)$ is:

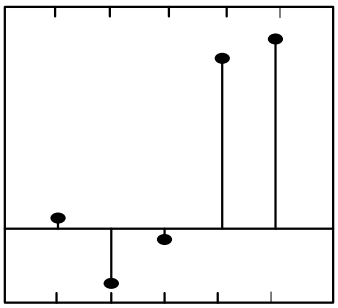
$$\psi_{j,k}(t) = a_0^{-j/2} \psi(a_0^{-j} t - k b_0), j \in Z, k \in Z \quad (2)$$

In the family of orthogonal wavelets structured by Daubechies, the decomposition and reconstruction filter group is shown in Fig. 5.

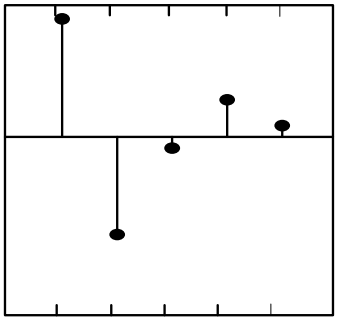
4.2. Fast Wavelet Transform-Mallat Algorithm

Mallat based on multi-resolution analysis, puts forward the famous fast wavelet transform algorithm-mallat algorithm. By the preceding multi-resolution analysis, expanded form of random signal *f*(*t*) in space is:

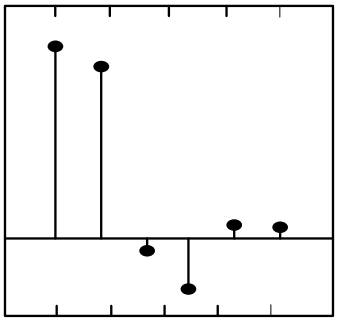
$$f(t) = \sum_k c_{j+1,k} 2^{(j+1)/2} \varphi(2^{(j+1)} t - k) \quad (3)$$



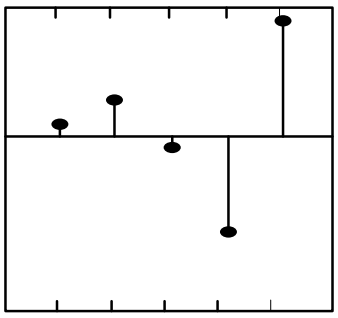
(a) low pass decomposition filter



(b) High pass decomposition filter



(c) Low pass reconstruction filter



(d) High pass reconstruction filter

Fig. 5. Wavelet decomposition filter group.

Make a decomposition of $f(t) = V_{j+1}$, projection to V_j, W_j respectively. Then:

$$f(t)=\sum_k c_{j,k}2^{j/2}\varphi(2^j t-k)+\sum_k d_{j,k}2^{j/2}\psi(2^j t-k) \quad (4)$$

Of which, $c_{j,k}$ is scale factor, discrete approximation of f(t) on space V_j. $d_{j,k}$ is a wavelet coefficient, discrete value of f(t) on space W_j i.e., the wavelet transform $W_{\psi,f}(j,k)$ we require.

$$\begin{cases} c_{j,k} \le f(t), \varphi_{j,k}(t) \ge \int_{-\infty}^{+\infty} f(t)2^{j/2}\overline{\varphi(2^j t-k)}dt \\ d_{j,k} \le f(t), \psi_{j,k}(t) \ge \int_{-\infty}^{+\infty} f(t)2^{j/2}\overline{\varphi(2^j t-k)}dt \end{cases} \quad (5)$$

Restructuring algorithm is:

$$c_{j+1,l}=\sum_l \bar{h}(n\text{-}2l)c_{j,l}+\sum_l \bar{g}(n-2l)d_{j,l} \quad (6)$$

Fig. 6 is Mallat pyramidal decomposition and reconstruction algorithm based on DB4 wavelet. The source signal is leleccum signal in Matlab.

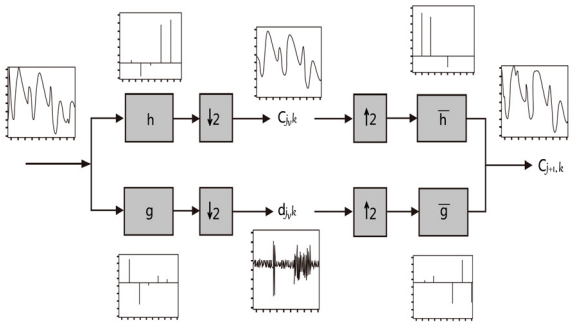


Fig. 6. Mallat decomposition and reconstruction structure chart.

4.3. Multi-Spectral Image Fusion Enhancement Based on Biorthogonal Multiwavelet

Multiwavelet theory is the development of the unit-wavelet theory. Structurally, Multiwavelet is with greater degrees of freedom, and can meet the requirements of orthogonality and symmetry simultaneously. If an orthogonal basis is replaced by two biorthogonal base, the biorthogonal multiwavelet is obtained. Two biorthogonal base are made up of two mutual dual scaling functions. One for the decomposition, and the other for reconstruction. For each scale function $\varphi(t)$ and the corresponding wavelet function $\psi(t)$, still meet double dimension equations as follows:

$$\begin{aligned} \varphi(t) &= \sum_{k=0}^{m\text{-}1} C_k \varphi(2t\text{-}k) \\ \psi(t) &= \sum_{k=0}^{m\text{-}1} D_k \psi(2t\text{-}k) \end{aligned}, \quad (7)$$

Biorthogonal multiwavelet is structured on the basis of ordinary GHM orthogonal multiwavelet, as shown in Fig. 7.

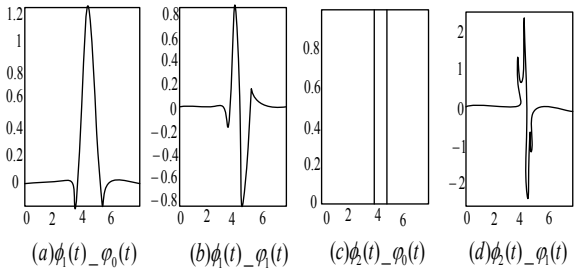


Fig. 7. Biorthogonal multiwavelet (GHW base) scale function.

Good characteristics of multi-resolution analysis in signal analysis wins widespread attention in the field of image fusion. At present, most of the fusion algorithm unfolds under the framework of multi-resolution analysis. Image fusion method based on multi-resolution analysis is the mainstream research direction in the field of image fusion [7]. In this chapter we put forward the use of the properties of the biorthogonal multiwavelet transform, combining with the fusion strategy of selection of low frequency coefficients, realize multi-spectral image fusion enhancement. It is a try to realize image fusion by multi-resolution analysis. On the other hand, for the researchers in the field of image fusion, it is a foundation for further research on fusion field to have in-depth knowledge of the framework of realizing image fusion based on multiresolution analysis.

5. Image Fusion Based on Variational Partial Differential Equation

5.1. Variational Method and Euler-Lagrange Equation

Functional extremum is as follows:

$$J[y(x)]=\int_{x_0}^{x_1} F(x,y,y')dy \tag{8}$$

Of which, $F\in C^2, y(x)\in C^2[x_0,x_1]$ and satisfy the boundary condition:

$$y(x_0)=y_0, y(x_1)=y_1 \tag{9}$$

Assume $y(x)$, and J arrives its extreme value, consider a series of curves with α as its parameter: $y=y(x)+\alpha\delta y$. δy is a variation of $y(x)$. When $\alpha=0$, y=y(x) is the curve which arrives functional extremum. Apply y into the equation and the following can be obtained:

$$\varphi(\alpha)=J[y+\alpha\delta y]=\int_{x_0}^{x_1} F(x,y+\alpha\delta y,y'+\alpha\delta y')dx \tag{10}$$

When $\alpha=0$, $\varphi(\alpha)$ arrives the extreme value. By necessary conditions of extreme value, it can be obtained that:

$$\varphi(0)=\frac{\partial}{\partial\alpha}J[y+\alpha\delta y]\Big|_{\alpha=0}=\int_{x_0}^{x_1}(F_y\delta y+F_{y'}\delta y)dx=0 \tag{11}$$

Note by integration by parts, $\delta y\big|_{x=x_0}=\delta y\big|_{x=x_1}=0$, and:

$$\int_{x_0}^{x_1}F_y\delta y'dx=F_{y'}\delta y\Big|_{x_0}^{x_1}-\int_{x_0}^{x_1}\delta y\frac{d}{dx}F_{y'}dx=-\int_{x_0}^{x_1}\delta y\frac{d}{dx}F_{y'}dx \tag{12}$$

$$\varphi(0)=\delta J=\int_{x_0}^{x_1}(F_y-\frac{d}{dx}F_{y'})\delta y dx=0 \tag{13}$$

Function y(x) which makes $J[y]$ arrives extreme value should meet the equation:

$$F_y-\frac{d}{dx}F_{y'}=0 \tag{14}$$

This equation is called Euler-Lagrange eqution of functional $J[y]$.

5.2. Optical System Imaging Features

Band width of the system function corresponding to blurred image is narrower than that of sharply focused image. Fig. 8 illustrates the general characteristics of the optical imaging system.

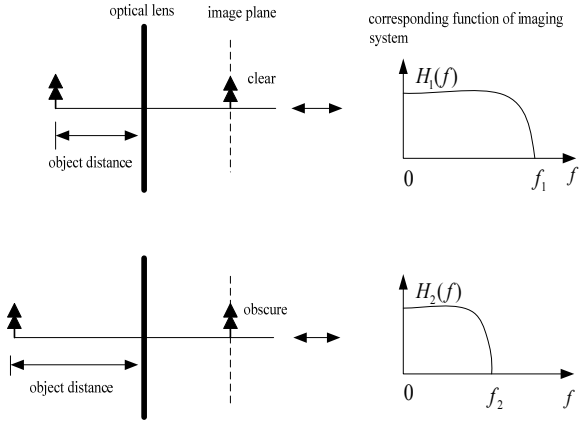


Fig. 8. Optical system imaging features.

5.3. Color Fusion Model

The color fusion model based on HSV color space is shown in Fig. 9. HSV color space can be described

as a cone. It consists of three components which are respectively V(Value), S(Saturation) and H(Hue). They are independent of each other. H represents the angle formed by rotation around the center axis in the cone with range of (0, 360), with order of red, yellow, green, blue and then back to red again. Saturation S depends on the proportion of with-color composition and decolorization composition (gray) with a range of (0, 1). The bigger the color composition, the greater the degree of saturation. The bigger the decolorization composition, the smaller the degree of saturation. V can be regarded as a characterization of color image on the gray level domain, which contains the main space details of color image.

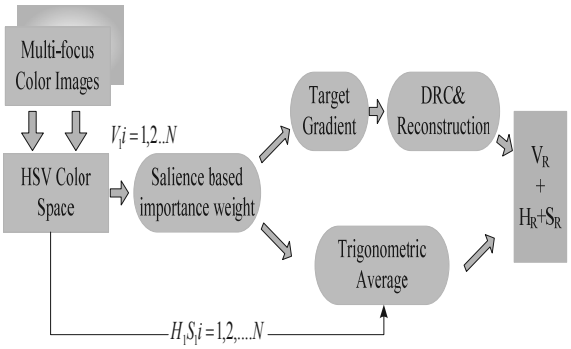


Fig. 9. Fusion model of color multi-focused image.

To solve the problem of color distortion, We put forward triangle average algorithm based on significant weighted. Tonal component of k band source image is denoted by H_k, and Synthesis of tonal component H_R, then:

$$H_R = Arg(\sum_{k=1}^{N} w_k^2 \sin H_i, \sum_{k=1}^{N} w_k^2 \cos H_i) \quad (15)$$

$$S_R = \sum_{k=1}^{N} w_k^2 S_k \quad (16)$$

Color component processing by this method can effectively avoid the color distortion. It can be applied to any number of color source image fusion.

Considering from the perspective of spatial domain, visual information obtained by the image observer is realized through the change of the image contrast, that is, the edge or gradient of the image. So we according to the importance of different features reflected by source image, design different weights based on the characteristic diagram strength. Then according to the corresponding weighting of contrast information of the source image, calculate the principal component as target gradient field of the fusion. So as to realize the image fusion of characteristic keeping. That is to design a special contrast in advance as the target of the fusion, variational problem is then used to calculate the fusion results close to the target.

6. Region-Based Multi-Source Image Fusion

6.1. Image Segmentation Based on Graph Theory

Define a metric area R_1 and R_2, with a boundary predicate:

$$D(R_1, R_2) = \begin{cases} tureifRD(R_1, R_2) > MID(R_1, R_2) \\ falseotherwise \end{cases} \quad (1)$$

Of which, $RD(R_1, R_2)$ represents the difference between R_1 and R_2, denoted by:

$$MID(R_1, R_2) = \min(ID(R_1) + k/|R_1|, ID(R_2) + k/|R_2|) \quad (18)$$

Internal differences of R is denoted by ID(R), Greatest weight edge e of minimum spanning tree in R is:

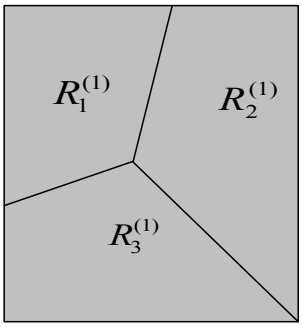
$$ID(R) = \max_{e \in MST(R,E)} w(e) \quad (19)$$

Regional image obtained by the source image segmentation generates a joint area image as follows:

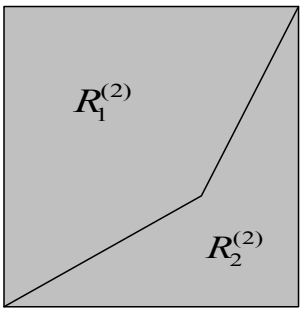
6.2. Fusion Strategy Based on Regional Characteristics and Multi-Scale Decomposition

Multi-scale decomposition is simulation of the human eye perception process in computer vision research. Multi-scale decomposition decompose image from bottom to top. Each layer of image is formed through a template filtering of the former layer of image. And multi-scale decomposition can effectively perform many basic image arithmetic, produce a set of low pass or band pass images. Through the interconnection between the layers, provides the connection between the local and global processing. So combination of multi-scale decomposition and regional characteristics of fusion strategy will obtain better fusion effect.

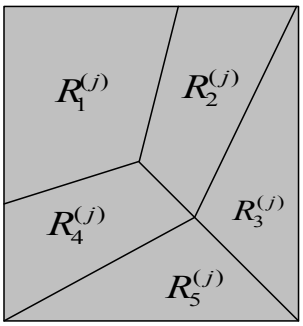
Wavelet analysis is a good method of multi-scale decomposition. Usually discrete wavelet is adopted in the fusion to make multi-scale decomposition. Considering the multiwavelet has better signal processing features, such as short support set, orthogonality, symmetry and vanishing moment, therefore, biorthogonal multiwavelet is selected to make multiscale decomposition. Based on the biorthogonal multiwavelet, We put forward fusion algorithm with a combination of regional characteristics and multi-scale decomposition, as shown in Fig. 11.



(a) regional segmentation image of source image1.



(b) regional segmentation image of source image2.



(c) Synthetic regional figure.

Fig. 10. Generating sample of synthetic regional figure.

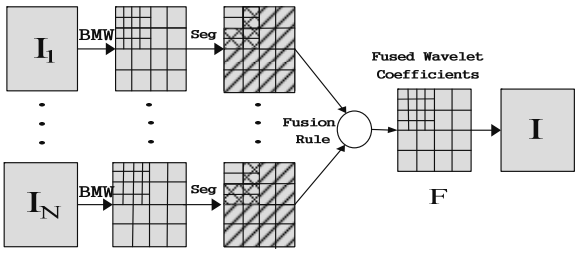


Fig. 11. Fusion algorithm flow with a combination of regional characteristics and biorthogonal wavelet decomposition.

Because of the differences between scale coefficient and wavelet coefficient in the physical sense, different fusion rules are needed in the fusion process. The point with larger absolute value in the wavelet coefficient corresponds to the dramatic gray level change. Which are the edge, linear features and regional boundaries in the image. Scale factor is a rough representation of the source image. It may inherits some texture and gray level characteristics of the source image. So in many of the fusion method, scale coefficient of the composite image usually is the weighted average of the scale coefficient of the source image. Wavelet coefficients are selectively merged.

5.3. Compatibility Test

Similarity of area R_l of source image A and B is denoted by $M(R_1)$, then:

$$M(R_1) = \frac{2\sum_{x,y\in R_l}[C_A^l(x,y)\bullet C_B^l(x,y)]}{S(A,R_l)+S(B,R_l)} \tag{20}$$

$$S(I,R_1) = \sum_{x,y\in R_l}[C_I^l(x,y)]^2,\ I = A,B \tag{21}$$

In the case of low similarity, points with larger coefficient values in the source image should be converted into the composite image. When similarity is high, make average of the coefficient value of the source image. Similarity threshold is denoted by T. When $T > M(R_l)$,

$$C_F^l(R_l) = \begin{cases} C_A^l(R_l), if S(A,R_l) \geq S(B,R_l) \\ C_B^l(R_l), otherwise \end{cases} \tag{22}$$

When $T < M(R_l)$,

$$C_F^l(R_l) = \begin{cases} w_{\max}(R_l)\bullet C_A^l(R_l)+w_{\min}(R_l)\bullet C_B^l(R_l), if S(A,R_l) \geq S(B,R_l) \\ w_{\min}(R_l)\bullet C_A^l(R_l)+w_{\max}(R_l)\bullet C_B^l(R_l), otherwise \end{cases} \tag{23}$$

Of which, $w_{\max}(R_l)$ *and* $w_{\min}(R_l)$ are respectively the maximum and minimum coefficient weight, defined by:

$$w_{\min}(R_l) = \frac{1}{2} - \frac{1}{2}\left(\frac{1-M(R_l)}{1-T}\right), w_{\max}(R_l) = 1 - w_{\min}(R_l) \tag{24}$$

Overall, the threshold value is small. Because when the similarity of source image is small, small threshold is more accord with human visual system.

In image fusion, people tend to focus on the image of the actual target or area, rather than a single pixel. Moreover, Pixel-based fusion is greatly affected by source image noise and source image registration precision. However, region-based feature level fusion method is not sensitive to these influences, and more flexible fusion strategy can be put forward according to the target or regional characteristics and effectively retain significant information of source image.

6. Conclusion

The rapid development of computer science and microelectronics technology makes more and more sensors applied to various fields. And because of the increase of quantity of sensors, the amount of data recived has increased dramatically and presents diversity. The traditional information processing method already can not satisfy the new requirements. So the multi-source image fusion technology is proposed.

Multi-source image fusion technology has been widely regarded as a very valuable processing method in the image application field. With the increase of multi-source image fusion demand, a main method of image fusion quality evaluation is subjective assessment, i.e, the visual evaluation method.

The realization of multi-source image fusion roughly includes three layers which are pixel level, feature level and decision level. Among which the pixel level fusion research is the most widely and deeply. There are mainly six implementation method which are linear weighted fusion, false color image fusion, modulation-based fusion, statistical-based fusion, neural network-based fusion, and fusion based on multi-resolution decomposition. This paper makes simple analysis for some fusion ways. The study has shown that the current existent fusion method can effectively solve many problems encountered in image fusion and some practical systems have been successfully developed.

References

[1]. A. A. Goshtasby, Image Fusion: Advances in the state of the art, *Information Fusion*, Vol. 8, Issue 2, 2007, pp. 114-118.

[2]. G. Simone, A. Farina, F. C. Morabito, et al., Image fusion techniques for remote sensing applications, *Information Fusion*, No. 3, 2002, pp. 3-15.

[3]. Liu Gang, Multi-sensor image fusion research based on the multiresolution, *Jiao Tong University*, Shanghai, 2005.

[4]. Liu Yanyan, Research on key technologies in multi-sensor data fusion, *China Science and Technology University*, 2006.

[5]. Ni Guoqiang, Research and new development of multi-band image fusion algorithm, *Optoelectronic Technology & Information*, Vol. 14, Issue 5, 2001, pp. 11-17.

[6]. Liu Gang, Jin Zhongliang, Sun Shaoyuan, Image fusion based on the expectation maximum algorithm, *Laser & Infrared*, Vol. 35, Issue 2, 2005, pp. 130-133.

[7]. Wang Haihui, Peng Jiaxiong, Image fusion based on multiwavelet transform, *Journal of Image and Graphics*, Vol. 9, Issue 8, 2004, pp. 1002-1007.

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