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A PARALLEL FUSION ALGORITHM OF MULTI-SPECTRAL IMAGE AND PANCHROMATIC IMAGE BASED ON WAVELET TRANSFORM

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АЛГОРИТМ ПАРАЛЕЛЬНОГО ЗЛИТТЯ МУЛЬТИСПЕКТРАЛЬНОГО ТА ПАНХРОМАТИЧНОГО ЗОБРАЖЕНЬ НА ОСНОВІ ВЕЙВЛЕТ-ПЕРЕТВОРЕННЯ

Purpose. To take the advantages of a variety of remote sensing data, the application of remote sensing image fusion is a very important choice. Remote sensing image fusion is large in computing capacity and time-consuming, and with the development of modern remote sensing technology, the amount of various remote sensing data obtained is getting larger and larger, the issue of how to fuse remote sensing image quickly and accurately and of getting useful information is becoming more and more urgent especially in some remote sensing applications such as disaster monitoring, prevention and relief , etc. In this paper, in order to fuse remote sensing image quickly and accurately, a parallel fusion algorithm of multi-spectral image and panchromatic image based on wavelet transform is proposed.

Methodology. In the method, based on parallel computing, the low-frequency components of wavelet decomposition are fused with the fusion rule based on the feature matching, and the high-frequency components of wavelet decomposition are fused with the fusion rule based on the sub-region variance. Then the low-frequency components and the high-frequency components after fusion are processed with the inverse wavelet transform, and the fused image is obtained.

Findings. The experiment results show that the proposed method can get better fusion results and faster computing speed for multi-spectral image and panchromatic image.

Originality. In the proposed fusion algorithm of multi-spectral image and panchromatic image, wavelet transform and different proper fusion rules for low-frequency components and high-frequency components of wavelet decomposition are used. To get a high speed, parallel computing is also taken in some complex parts of the proposed fusion algorithm. Thus, better fusion results and faster computing speed are obtained.

Practical value. The experiments have proved that the proposed algorithm can quickly get good fusion results for remote sensing images, and it is useful in remote sensing applications in some aspects such as disaster monitoring, prevention and relief, etc.

Keywords: *remote sensing, image fusion, panchromatic image, multi-spectral image, wavelet transform, parallel computing*

Introduction. With the development of modern remote sensing technology, a variety of earth observation satellites could continue to tremendously provide remote sensing image data of different spatial resolution, time resolution, spectral resolution, and the remote sensing data obtained is increasing with great capacity, which forms a multi-source image pyramid in the same area. In such cases, while describing the same object with multiple-source remote sensing information, considering how to conduct effective data processing along with overcoming the contradiction that it is not possible to obtain vast remote sensing image information of different kinds for shortage of funds, many researchers in the world proposed fusion theory of multi-source remote sensing image based on theories of information integration and data fusion. Multi-source remote sensing image fusion is an important option in the image processing. The application of remote sensing image fusion is a very important choice for taking the advantages of a variety of remote sensing data [1, 2].

Multi-sensor image fusion belongs to the scope of multi-sensor information fusion, which refers to that according to a certain algorithm, the images of the same scene obtained from different sensors, or the images of the same scene obtained from the same sensor at different times are synthesized into one image which can meet certain requirement. It is very difficult to obtain high spectral, spatial and time resolution simultaneously by a single sensor due to three constraints which include the resolution limit determined by the energy and diffraction of light, imaging system modulation transfer function, and signal to noise ratio (SNR). The multi-sensor image fusion technology can effectively use complementary information and redundant information provided by multiple images, so the description of the scene through the image after fusion is more comprehensive and accurate than any single source image. In general, the multi-sensor information fusion technology has the following advantages: 1 – it can improve system reliability and robustness; 2 – it can extend the observation range of space and time; 3 – it can improve the accuracy and credibility of information; 4 – it can improve performance of target monitoring and identification; 5 – it can reduce the redundancy investment of the system [3–5].

Remote sensing image data fusion is divided into three levels: pixel fusion, feature fusion, and decision fusion. The pixel fusion is a kind of low level integration, which is data layer integration of the raw data collected directly, and it is often used in multi-source image compounding, image analysis and interpretation, etc. The process of feature level fusion is as follows: the first step is feature extraction of the original remote sensing image information, and then comprehensive analysis and processing of the features are conducted so that the fusion result can give the maximum feature information required for decision making. The decision level fusion is a high level of integration, which is the image information identification, classification or target detection on the basis of information provided by the pixel-level and feature-level fusion, and after obtaining information of regional decision-making, the topic image fusion is done, the integration results obtained can directly provide the basis for the command, control and decision-making system.

The multi-source remote sensing data fusion has a very important practical significance. On the one hand, the information that multi-source remote sensing images provide possesses redundancy, complementarity and cooperativeness. The multi-source remote sensing image data fusion does not only expand the scope of application of all the data, but also improves the accuracy of analysis, application effect, and practical value. On the other hand, various remote sensing information that various earth observation satellites provide in the process of the modern remote sensing technology, is growing with great capacity. With the emergence of more and more remote sensing image data, people face more difficulties and challenges in data processing and analysis. Remote sensing image data processing is far behind the remote sensing image data acquisition. To meet people's urgent need for high-quality images and intelligent processing of observation data of terrain, to achieve real-time processing of massive data and take full advantage of the remote sensing image data, it is the urgent requirement for the use of remote sensing data so that information extraction and analysis of multi-source remote sensing image is done by comprehensive application of multi-source remote sensing image fusion. Effective remote sensing image data fusion algorithms are all complex. To play the full role of the various kinds of earth observation satellites, combining with the advantage of remote sensing image fusion technology, research on the effective and quick fusion methods of remote sensing image becomes increasingly urgent. According to the remote sensing image fusion methods, which have appeared, and our actual research in remote sensing image fusion, it is known that the remote sensing image fusion is relatively complex, the amount of calculation is large, and the corresponding cost time is also longer, which puts forward very high requirements for the computer speed and memory resources. Although computer technology develops very quickly, the expansion of computer speed and memory is limited, and the improvement of the performance of the computer takes large cost; thus, it is significant for the application of a variety of earth observation satellites to use other ways to study rapid integration of remote sensing image.

In the high performance computing, parallel cluster computing system has higher cost performance and good scalability, can satisfy the different sizes of large computational problems, so it is paid more and more attention. In this paper, based on the advantages of the parallel computing in high performance computing, and the advantages of wavelet transform in the information processing, a parallel fusion method of multispectral image and panchromatic image based on wavelet transform is studied and proposed. The experimental results show that the proposed fusion method can achieve better fusion effect of remote sensing image, and faster computing speed [6].

Wavelet transform. Wavelet transform is a new analysis method of transformation; it has inherited and developed localization idea of the short-time Fourier transform, also overcome shortcoming that the window size does not change with the frequency as well as other shortcomings. It can provide time and frequency window that changes with frequency, and be the ideal tool for time-frequency analysis and processing of a signal.

Supposing $y = x + z$, its Fourier transform is $\widehat{\psi}(w)$, when $\widehat{\psi}(w)$ satisfies the formula

$$C_\psi = \int_R \frac{\left|\widehat{\psi}(w)\right|}{|w|} dw < \infty, \quad (1)$$

where $\psi(x)$ is called a basic wavelet. Let it flex and move flatly, then we get

$$\psi_{a,b}(x) = \frac{1}{\sqrt{|a|}} \psi\left(\frac{x-b}{a}\right); \quad a, b \in R; \quad a \neq 0 \quad (2)$$

it is called wavelet sequence, in it, the parameter a is the flexing gene, b is the gene of moving flatly.

To any function $f(x) \in L^2(R)$, its continuous wavelet transform is

$$W_f(a,b) = \left\langle f, \psi_{a,b} \right\rangle = |a|^{-\frac{1}{2}} \int_R f(x) \overline{\psi\left(\frac{x-b}{a}\right)} dx. \quad (3)$$

Its reverse transform is

$$f(x)=\frac{1}{C_{\psi}}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{1}{a^{2}}W_{f}(a,b)\psi\left(\frac{x-b}{a}\right)dadb. \quad (4)$$

In practice, especially in the realization on a computer, the continuous wavelet must be discrete, the discreteness must aim at continuous parameter a and b, not x. In equation (4), $\psi_{j,k}(x)=2^{j/2}\psi(2^{j}x-k)$ is just the discrete binary wavelet which is in the most common use.

Image fusion algorithm based on wavelet transform. The pixel-level image fusion method is the most widely used, the main methods include the weighted average method, the logical filtering method, the statistical optimization method, the wavelet transform method, the neural network fusion method, etc. Among them, the pixel-level image fusion method based on wavelet transform is currently one of the most widely used methods [7–9].

The traditional image fusion based on wavelet transform. The images to be fused are processed with two-dimensional wavelet decomposition, low frequency components, high frequency components in horizontal direction, high frequency components in vertical direction, the diagonal high frequency components, are obtained respectively. Fig. 1 is the schematic diagram of two-dimensional wavelet decomposition for two layers, the low frequency component of the image, LLi (i = 1, 2) is the approximate image of the original image, which contains the information of the most energy of the image, however the high frequency components, LHi, HLi, HHi (i = 1, 2), are detail expression of the original image, including image texture, edge, etc.

According to the principle of the wavelet transform fusion algorithm, selection of a fusion rule is of great concern for quality of the fusion image, and it is a key step in the algorithm. The fusion methods which are commonly used include the weighted average method, method of taking large magnitude, etc. In the method of taking large magnitude, for every two corresponding image pixels in the 2 images to be fused, the bigger pixel value is directly selected as the gray value of the pixel of the fusion image. In the weighted average method, for every two corresponding image pixels in the 2 images to be fused, their weighted sum is selected as the gray value of the pixel of the fusion image. Let $IAw(x, y)$ and $IBw(x, y)$ be wavelet components after wavelet decomposition for the original image A and B, $IFw(x, y)$ is the fusion of the component, then

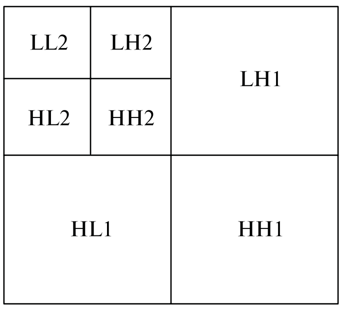


Fig. 1. The schematic diagram of two-dimensional wavelet decomposition for two layers

$$IFw(x, y) = W_1 \times IAw(x, y) + W_2 \times IBw(x, y). \quad (5)$$

Where, $W_1 + W_2 = 1$, W_1 and W_2 are the weighting factors. When $W_1 = 0.5$, $W_2 = 0.5$, it is called the average method.

The fusion algorithm of panchromatic and multi-spectral remote sensing images based on wavelet transform in this paper. The fusion strategy of the traditional wavelet algorithm usually adopts the simple weighted average. The advantage of this algorithm is simple, easy to realize, suitable for real-time processing and it can achieve a certain effect when the gray level difference is not large; however, when the gray difference image fusion is very large, there will be obvious mosaic trace, and the contrast of the fusion image will decline.

In this paper, a parallel fusion algorithm of remote sensing images based on wavelet transform is proposed. In the method, the low-frequency components of wavelet decomposition are fused according to the fusion rule based on the feature matching, and the high-frequency components of wavelet decomposition are fused according to the fusion rule based on the sub-region variance. With the fusion rules, better fusion effect than that with the traditional fusion method can be obtained.

The fusion strategy for low frequency component of wavelet transform of images. Low-frequency components of wavelet transform is fused according to the fusion strategy based on the feature matching rule. For the computing of the wavelet energy feature ($E(x, y, k)$, the mathematical formula is the following

$$E(x,y,k)=\frac{1}{M*N}\sum_{x,y=0}^{M*N-1}\left|c(x,y,k)\right|^{2}, \quad (6)$$

where $c(x, y, k)$ expresses wavelet coefficient at position (i, j) in layer k, (m, n) defines the size of matching windows (3×3 or 5×5 normally taken), in the neighbourhood, the sum of the wavelet coefficient square is the local energy at point (x, y, k).

The matching degree measures the matching degree of feature information at the corresponding position of 2 images A and B, which is used in defining the feature information ratio between different original images in the fusion scheme. The calculation formula of the feature matching degree at position (x, y, k) is as follows

$$F_{PM}(x,y,k)= =\frac{2\sum_{M}\sum_{N}C_{P}(x+M,y+N,k)C_{M}(x+M,y+N,k)}{E_{P}(x,y,k)E_{M}(x,y,k)}, \quad (7)$$

where $F_{PM}(x, y, k)$ is the matching degree at position (x, y) in layer k, it measures the matching degree of feature information at the corresponding position of 2 images, *IP* and *IM*. C_P, C_M respectively express the wavelet coefficients at the location (x, y) on k decomposition level of *IP*, *IM*. E_P, E_M respectively express the local energy in the field with (x, y) as the center on k decomposition level of *IP*, *IM*.

The corresponding wavelet coefficients by doing wavelet transform for the component *IM* and the panchromatic image PImage are fused based on the fusion rules of feature matching, the calculation process is as follows,

$$C_F(x,y,k) = W_P C_P(x,y,k) + W_M C_M(x,y,k), \quad (8)$$

where $C_F(x, y, k)$ is the fusion coefficient at point (i,j) of K decomposition level, *WP*, *WM* is calculated as follows.

If $F_{PM} \le T$, then $W_{\min} = 0$, $W_{\max} = 1$, usually $0.5 < T < 1$.

If $E_P > E_M$, $WP = W_{\max}$, $W_M = W_{\min}$, or else $W_M = W_{\max}$, $W_P = W_{\min}$.

If $FPM > T$, then $W_{\min} = 1/2 - (1 - F_{PM})/2(1 - T)$, $W_{\max} = 1 - W_{\min}$.

If $E_P > E_M$, $WP = W_{\max}$, $W_M = W_{\min}$, or else $W_M = W_{\max}$, $W_P = W_{\min}$.

Among them, $T \in (0, 1)$ represents the matching threshold. Obviously, the calculation process of feature matching rule has good locality, the wavelet coefficients at (i, j, k) of the fusion result are only defined by value of coefficients of the $m * n$ neighbourhood including points (i, j, k) .

The fusion strategy for high-frequency component of wavelet transform of images. Because the high frequency component contains the detail information such as the edge of an image, and change more intensely, a fusion strategy based on variance is used. *IA* and *IB* are the high frequency component which are extracted by wavelet transform of 2 images, *IF* is the high frequency component after fusion, the specific steps of the method is as the following

In $IA(x, y, k)$ and $IB(x, y, k)$ on the level of K decomposition, let us calculate regional variance of the neighborhood (usually 3 * 3 or 5 * 5 or 7 * 7) with $IA(x, y, k)$ as the centers, which are denoted as var1 and var2, Fusion weighting coefficient can be calculated according to the following parameter, which can be calculated with the following formula

$$T\,\mathrm{var} = \frac{2 \times \mathrm{var}_1 \times \mathrm{var}_2}{\mathrm{var}_1^2 + \mathrm{var}_2^2}. \quad (9)$$

If $T\,\mathrm{var} \ge T$, usually $0.5 < T < 1$, then

$$IF(x,y) = W_1 \times IA(x,y) + W_2 \times IB(x,y);$$

$$W1 = \frac{\sigma_{IA}}{\sigma_{IA} + \sigma_{IB}}. \quad (10)$$

In the formula, $W_1 + W_2 = 1$, σ_{IA} and σ_{IB} are respectively standard deviations within the field of *IA*, *IB*.

If $T\,\mathrm{var} < T$, then

$$IF(x,y) = \begin{cases} IA(x,y), \mathrm{var}_1 \ge \mathrm{var}_2 \\ IB(x,y), \mathrm{var}_1 < \mathrm{var}_2 \end{cases}. \quad (11)$$

The detailed steps of the parallel fusion algorithm of multi-spectral image and panchromatic image based on wavelet transform proposed in the paper. This integration is mainly about parallel wavelet fusion for multi-spectral remote sensing image and panchromatic remote sensing image. For the high frequency coefficients and low frequency coefficients by wavelet decomposition, different fusion strategies are used. The main steps of the fusion algorithm are the following:

1. Parallel *IHS* transform is done for the multi-spectral images after registration, MImage, the components *IM*, *HM*, *SM* are obtained, the components *IM* and the panchromatic image are decomposed with the two tower wavelet transform.

2. Parallel computing of N wavelet transform is done for the *IM* component and panchromatic remote sensing image *IP* (panchromatic image). With parallel computing, the corresponding low frequency wavelet coefficients are fused based on the fusion rule of feature matching, the coefficients are fused with the fusion rule based on the sub-region variance.

3. With parallel computing, the wavelet coefficients after the fusion are done with inverse wavelet transform, the fusion component, *IF*, is obtained.

4. With parallel computing, the components, *IF*, *HM*, *SM*, are done with inverse *IHS* transform, and the fused image is obtained.

Experiment and result analysis. The experimental data is Multi-spectral Image and Panchromatic Image of Beijing-1 Micro-satellite Image [10]. The images obtained from image data distribution department are their two level products, which are the standard image data through the system radiometric calibration, system geometric correction. After format conversion, the Geo Tiff data is transformed into IMG format, the reference data with the ratio, one to ten

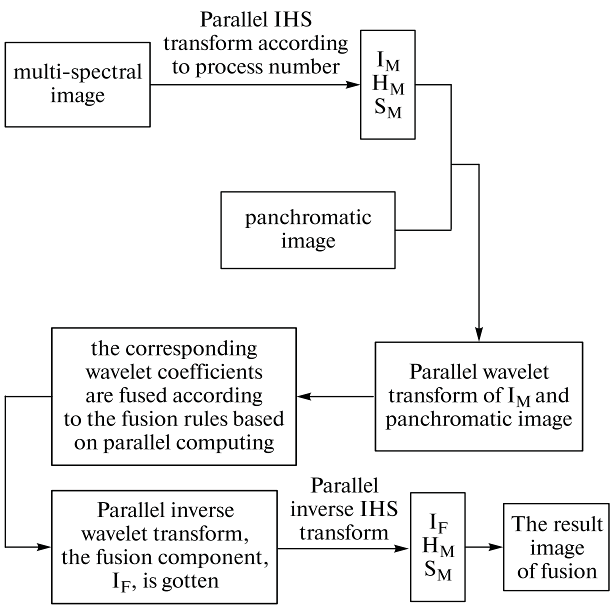
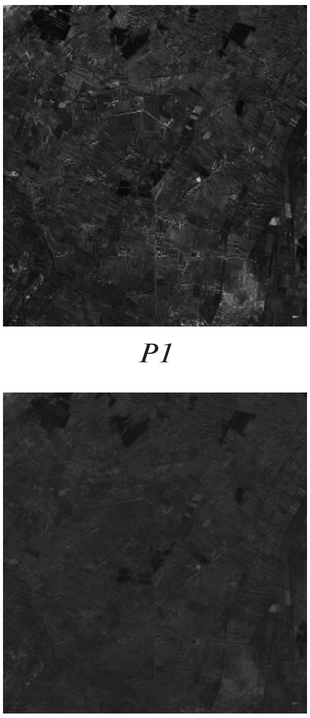


Fig. 2. The flow chart of the parallel fusion algorithm of multi-spectral image and panchromatic image based on wavelet transform

thousands is used to do geometric correction for the images of the area to be studied. After the process, the three-band multi-spectral image and panchromatic image obtained in the same area are used as the basis data for image fusion.

We achieve the parallel algorithm in the parallel cluster system. Since the size of the image affects the parallel performance of the algorithm, in the experiments we use different sizes of the Beijing-1 Micro-satellite images and conduct the experiment with different number of processes. We also do analysis and comparison of the results. The test platform is configured as the following, 8 computers constitute a cluster architecture (one as the management node (it also does computing), 7 computing nodes), each node is configured in the following way: its CPU is Intel™ Core™2 Duo CPU, memory is 2G; the 8 computers are interconnected through the 100Mbps Fast Ethernet switch, and the software environment is made up of the Windows XP operating system, NT-MPICH message passing parallel libraries, etc. Fig. 3, Fig. 5 and Fig. 6 are the thumbnails for the two groups of original panchromatic image and multi-spectral image of Beijing-1 Micro-satellite. Fig. 4 and Fig. 7 are the thumbnails for the corresponding fusion results.

To test the algorithm's parallel performance, some images of Beijing-1 Micro-satellite with different sizes are used to test on different number of computers. Table 1 gives the cost time and parallel efficiency of fusion for images of Beijing-1 Micro-satellite with different sizes on 1, 2, 4 and 8 computers respectively. The experiment results show that good result of fusion



P1

M1

Fig. 3. P1 — The panchromatic image of Beijing-1 small satellite, M1 — the multispectral image of Beijing-1 small satellite

Fig. 4. The fusion result image of Beijing-1 small satellite with the method of image fusion proposed in the paper (F1)

Fig. 5. The panchromatic image of Beijing-1 small satellite (P2)

Fig. 6. The multispectral image of Beijing-1 small satellite (M2)

Fig. 7. The fusion result image of Beijing-1 small satellite with the method of image fusion proposed in the paper (F2)

Table

The parallel efficiency (Efficiency = running time on *n* computers/running time on one computer)

N		1	2	4	8
Fusion one	Time cost (ms)	21351	10 868	6704	4249
	Efficiency		0.509	0.314	0.199
Fusion two	Time cost (ms)	323 262	162 278	99 565	61 743
	Efficiency		0.502	0.308	0.191

N is the umber of computers.

can be obtained quickly with the new method. On the other hand, the algorithm's parallel performance is affected by the time of data transfer; the time can be reduced by improving the network bandwidth. By the analysis of the relation between the efficiency of the new method and network bandwidth, it has been discovered that the network bandwidth influences the efficiency, the wider the network bandwidth is, the higher the efficiency is, and the better the extensible function is.

Conclusions. Image fusion algorithm has been one of the research hotspots in recent years, to play a better role of remote sensing, a parallel fusion algorithm of multi-spectral image and panchromatic image based on wavelet transform are studied and realized in the environment of distributed memory. In the paper, the algorithm is discussed, and it is achieved in a cluster system. The parallel fusion method is tested with different sizes of multi-spectral and panchromatic images of Beijing-1 Micro-satellite. The results show that the new algorithm has better convergence results and good parallel performance; moreover, the wider the network bandwidth is, the higher the efficiency is, and the better the extensible function is.

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Мета. Для використання переваг різноманітних даних дистанційного зондування Землі (ДЗЗ), важливим вибором є застосування злиття зображень ДЗЗ. Злиття зображень ДЗЗ вимагає великої потужності комп'ютерів і значних витрат часу. З розвитком сучасних технологій ДЗЗ об'єм зібраних даних ДЗЗ стає все більше, тому зростає необхідність здійснювати злиття зображень ДЗЗ швидко й точно та отримувати корисну інформацію, особливо в таких додатках ДЗЗ, як моніторинг лих, їх запобігання, рятувальні операції і тому подібне. У цій роботі для швидкого й точного синтезування зображень пропонується паралельний алгоритм злиття мультиспектральних і панхроматичних зображень на основі вейвлет-перетворення.

Методика. У методі, на основі паралельних обчислень, низькочастотні компоненты вейвлет-розкладання об'єднуються за правилом злиття на основі зіставлення ознак, а високочастотні компоненти вейвлет-розкладання об'єднуються на основі субрегіональної дисперсії. Після злиття низькочастотні й високочастотні компоненти піддаються зворотному вейвлет-перетворенню, тим самим отримуємо зображення, що синтезується.

Результати. Експериментальні результати показують, що запропонований метод дозволяє покращити результати та збільшити швидкість обчислень при злитті мультиспектрального й панхроматичного зображень.

Наукова новизна. У запропонованому алгоритмі злиття мультиспектрального й панхроматичного зображень використані вейвлет-перетворення та різні відповідні правила злиття для низькочастотних і високочастотних компонент вейвлет-розкладання. Для отримання високої швидкості обробки в деяких частинах запропонованого алгоритму використовуються паралельні обчислення. Для таких отримані кращі результати злиття та вища швидкість обробки.

Практична значимість. Експерименти довели, що запропонований алгоритм дозволяє швидко отримати гарні результати злиття зображень ДЗЗ і є корисним у деяких аспектах ДЗЗ, таких як моніторинг і запобігання стихійним лихам, рятувальні операції.

Ключові слова: *дистанційне зондування, злиття зображень, панхроматичне зображення, мультиспектральное зображення, вейвлет-преретворення, паралельні обчислення*

Цель. Для использования преимуществ разнообразных данных дистанционного зондирования Земли (ДЗЗ), важным выбором является применение слияния изображений ДЗЗ. Слияние изображений ДЗЗ требует большой мощности компьютеров и значительных затрат времени. С развитием современных технологий ДЗЗ, объем собранных данных ДЗЗ становится всё больше, поэтому растёт необходимость производить слияние изображений ДЗЗ быстро и точно и получать полезную информацию, особенно в таких приложениях ДЗЗ, как мониторинг бедствий, их предотвращение, спасательные операции и т.п. В этой работе для быстрого и точного синтезирования изображений предлагается параллельный алгоритм слияния мультиспектральных и панхроматических изображений на основе вейвлет-преобразования.

Методика. В методе, на основе параллельных вычислений, низкочастотные компоненты вейвлет-разложения объединяются по правилу слияния на основе сопоставления признаков, а высокочастотные компоненты вейвлет-разложения объединяются на основе субрегиональной дисперсии. После слияния низкочастотные и высокочастотные компоненты подвергаются обратному вейвлет-преобразованию, тем самым получаем синтезируемое изображение.

Результаты. Экспериментальные результаты показывают, что предложенный метод позволяет улучшить результаты и повысить скорость вычислений при слиянии мультиспектрального и панхроматического изображений.

Научная новизна. В предложенном алгоритме слияния мультиспектрального и панхроматического изображений использованы вейвлет-преобразование и различные соответствующие правила слияния для низкочастотных и высокочастотных компонент вейвлет-разложения. Для получения высокой скорости обработки в некоторых частях предложенного алгоритма используются параллельные вычисления. Для таковых получены лучшие результаты слияния и более высокая скорость обработки.

Практическая значимость. Эксперименты доказали, что предложенный алгоритм позволяет быстро получить хорошие результаты слияния изображений ДЗЗ и является полезным в некоторых аспектах ДЗЗ, таких как мониторинг и предотвращение стихийных бедствий, спасательные операции.

Ключевые слова: *дистанционное зондирование, слияние изображений, панхроматическое изображение, мультиспектральное изображение, вейвлет-преобразование, параллельные вычисления*

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