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FUSION OF REMOTELY SENSED IMAGES USING WAVELET TRANSFORMS AND DECORRELATED MULTISPECTRAL CHANNELS

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Abstract**—***The article is devoted to the development of mathematical models based on combining images obtained by remote sensing means with different spatial and radiometric resolutions. An analysis of modern means of remote sensing, which form images that are fixed under the same positional conditions of projection, in different spectral ranges of radiation, was carried out. Images formed in a wide spectral range and have a higher linear resolution than images formed in narrower ranges, but the latter contain spectral information. An applied model of combining images captured in different spectral ranges using the pyramidal wavelet transform has been developed. The optimal model of decorrelation of spectral channels of multispectral images based on signal entropy was determined.*

Index Terms—Remote sensing; multispectral image; panchromatic image; fusion image; wavelet-decomposition; wavelet-synthesis; decorrelation; signal entropy.

I. INTRODUCTION

Modern remote sensing system in the visible and infrared electromagnetic spectrum provides photogrammetric images, which are mathematically created with use central projection. The acquisition of remote sensing data in these spectral ranges is based on the detection of radiation reflected from Earth's surface objects, from natural (e.g., the Sun) and artificial (e.g., active radar) sources of radiation. The significant advantage of this type of data is that it is captured under the same positional conditions for different spectral ranges. However, the spatial brightness distributions significantly differ due to the various reflective characteristics of sensing objects in different spectral ranges. Wide spectral range data (panchromatic images, PI), have a considerably higher linear resolution than images got in narrow spectral intervals that form multispectral images (MSI). On the other hand, MSI contain spectral information absent in panchromatic images. A characteristic feature of modern remote sensing images is that their brightness distributions are discretized at the moment of capture, meaning that the brightness of each pixel is measured with a certain level of precision and recorded as a digital value that can be processed by a computer.

II. PROBLEM STATEMENT

The current level of requirements for the accuracy of interpreting images get by remote sensing techniques necessitates the use of methods to enhance their informativeness, in particular by combining high spatial and spectral resolution in a one image, which corresponds to the concept of "Data Fusion" [1]. The main condition that such methods must meet is to ensure a linear representation of the brightness distributions of the primary images in a set of processed spectral data.

III. RELATED WORKS

In studies devoted to the processing of MSI, the main attention has been given to improving their visual quality without considering the physical mechanisms of fixation of species-specific information, in particular inter-channel correlation, which makes it impossible to determine the informativeness of images from the perspective of their analysis and interpretation [2] – [5]. Some studies are based on the transition to color-difference metrics, in which the decorrelation of primary spectral data is implemented, but these methods only take into account the contribution of spectral information contained in primary MSI [6], [7] – [9].

The works of Daubechies I., Chui C., Strang G., Mallat S., Coifman R., Meyer Y., Wickerhauser M., Antonini M., Villasenor J., Vetterli M. formed the basis of a number of applied methods for implementing the concept of Data Fusion based on the principles of pyramid decomposition of primary data, dedicated to pyramid decomposition [10], defined as wavelet analysis [11] – [16]. The group of methods built on the use of such mathematical method is devoid of most of the mentioned drawbacks [17] – [22], but they also do not take into account the nature of species-specific data formation and are not sufficiently developed.

IV. PROBLEM SOLUTION

A. The proposed fusion model

For the effective fusion of images with high spatial and spectral resolution, a method with pre-transformation is proposed. Method is based on the processing of one of the most informative channels formed by decorrelating the MIS spectral channels, followed by its pyramidal decomposition using wavelet bases. This pre-transformation can be by analogy with the principal component analysis method or the method based on the convert to other color metrics [23], [24]. The proposed fusion method can be presented by the following mathematical model:

1) Geometric and radiometric correction of MSI and PI.

2) Contrast and contour correction of MSI and PI.

3) Resampling the MIS to match the spatial resolution of the panchromatic image.

$$f_{\mathrm{RGB}}(\mathrm{r}) \to f_{XYZ}(\mathrm{r}).$$

4) Decorrelating the original multispectral image represented in the RGB metric to the virtual *XYZ* metric.

5) Pyramidal decomposition using a specified wavelet basis up to a given decomposition level (L) for the corresponding brightness channel (*X*):

$$f_X(\mathrm{r}) = c_X^L(\mathrm{r}) + \sum_{l=1}^{L}\left[d_X^{l,1}(\mathrm{r}),\ d_X^{l,2}(\mathrm{r}),\ d_X^{l,3}(\mathrm{r})\right].$$

6) Pyramidal decomposition using a specified wav6elet basis up to a given decomposition level (*L*) for the PI:

$$f_P(\mathrm{r}) = c_P^L(\mathrm{r}) + \sum_{l=1}^{L}\left[d_P^{l,1}(\mathrm{r}),\ d_P^{l,2}(\mathrm{r}),\ d_P^{l,3}(\mathrm{r})\right].$$

7) Forming new components of the decomposition according to the chosen rule for combining coefficients:

$$\mathrm{App}_{\bar{X}}(\mathrm{r}) = c_X^L(\mathrm{r}),$$

$$\mathrm{Det}_{\bar{X}}(\mathrm{r}) = \sum_{l=1}^{L}\left[d_P^{l,1}(\mathrm{r}),\ d_P^{l,2}(\mathrm{r}),\ d_P^{l,3}(\mathrm{r})\right].$$

8) Wavelet synthesis and transform to the RGB color metric:

$$f_{\bar{X}YZ}(r) = \mathrm{App}_{\bar{X}}(r) + \mathrm{Det}_{\bar{X}}(r),$$

$$f_{\bar{X}YZ}(\mathrm{r}) \to f_{\overline{\mathrm{RGB}}}(\mathrm{r}).$$

The level of wavelet decomposition can be determined experimentally or computed by solving an optimization problem based on a selected quality criterion for the fused image. The maximum level of decomposition is determined to the next expression:

$$n = \left]\log_2\left(\frac{L_S}{L_W - 1}\right)\right[,$$

where L_S is the signal length, L_W is the maximal length of wavelet filter.

B. The choice of informativeness criterion for the fused image

The traditional integral characteristic (IC) of the informativeness of signals of any physical nature is entropy, the definition of which was given in classical works by C. Shannon regarding quantized and discretized one-dimensional signals in the context of the general theory of information [25]:

$$E = -\lambda \sum_i p_i \log p_i,$$

where λ is an arbitrary constant, p_i is the frequency of the *i*th quantized signal level. Entropy as a measure of informativeness should satisfy the axioms of Hinchin [26].

But Shannon's entropy does not correspond to the generally accepted interpretation of images as carriers of information about material objects, according to which an image is more informative the greater the range of brightness levels it contains. On the other hand, the brightness of each point of a projection image is proportional to the radiation energy that reaches it from the corresponding point of the object. Taking this into account, we introduce the generalized concept of entropy as a measure of informativeness for MSI (hereinafter referred to as "signal entropy") [27], [28]:

$$E = -\sum_{n=0}^{255} p_n \log_2 p_n,$$

where $p_n = nN_n / \sum_{m=0}^{255} mN_m$ and N_n is the number of pixels with brightness level n (n = 0, ..., 255). This criterion was used to assess the quality of fused images as an IC.

C. The choice of decorrelation method

A comparative analysis of wavelet fusion methods with pre-transformation based on color metrics HSV and YIQ to the wavelet fusion method without pre-transformation depending on the level of decomposition has been done. The signal entropy criterion was used as the effectiveness IC. The creation of new wavelet decomposition components was realized using the rule of replacing detail wavelet decomposition components of MSI with the corresponding detail wavelet components obtained from the wavelet decomposition of PI. The wavelet decomposition was done for four filters represented by two groups – orthogonal (db4, db6) and biorthogonal (bior 3.3, bior 4.4). Three sets (Fig. 1) were corresponding to three fusion methods.

The results indicate that the most effective method by signal entropy is the fusion method with pre-transformation based on the YIQ color metric, which allows achieving MSI spectral.

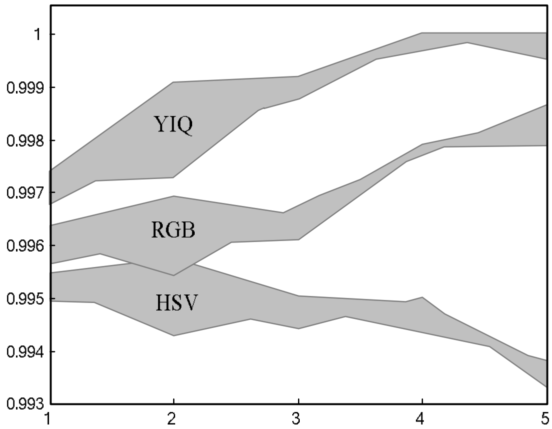

Fig. 1. The effect of using merging methods with a transition to decorrelated metric, on the example of representatives of orthogonal and biorthogonal wavelet bases: Daubechies 4 and 6 order, Villasenor 8/4 and 9/7 (Vertically – normalized value of signal entropy, horizontally – decomposition level)

D. Experimental results

The proposed image fusion model was tested on images obtained from the IKONOS satellite (panchromatic spatial resolution - 1 m, multispectral spatial resolution – 4 m). Examples of primary panchromatic, multispectral, and fused images (using Daubechies wavelet basis of level 4 decomposition) are shown in Figs 2 – 4.

The results indicate an increasing dynamics of signal entropy depending on the decomposition level, starting from the second level, regardless of the type of wavelet decomposition (Fig. 5).

Based on visual and numerical analysis, it was determined that the minimum-optimal decomposition level should be higher than the third level.

The use of decorrelation of MSI significantly reduced the computational complexity.

The optimal method of MSI channels decorrelation was determined from the perspective of "signal entropy".

Fig. 2. Primary panchromatic image

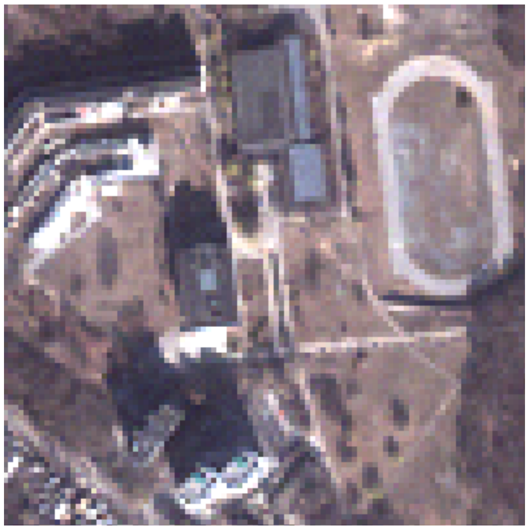

Fig. 3. Primary multispectral image

Fig. 4. Fusion image

V. CONCLUSIONS

The proposed linear mathematical model of fusing MIS and PI provides an increase in the informativeness of primary species-specific data from the standpoint of their thematic interpretation and analysis. Further development of this model involves its adaptation for processing hyperspectral images get by remote sensing.

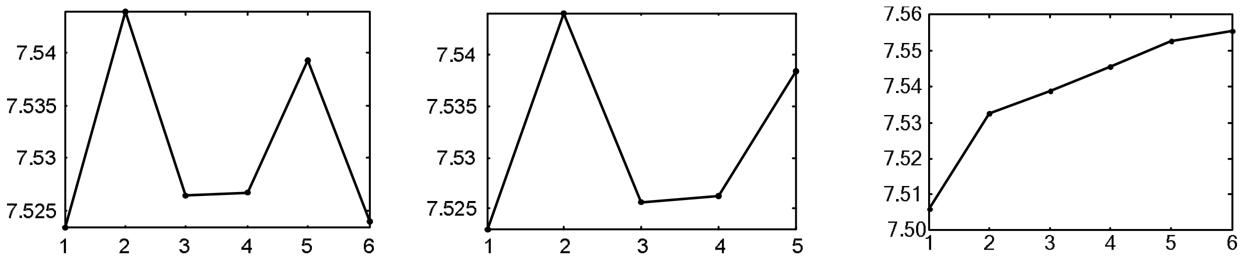

Fig. 5. Dynamics of signal entropy depending on the level of decomposition
(From left to right: wavelet bior 2.4, bior 5.5, db4)

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О. М. Гордієнко. Об'єднання зображень дистанційного зондування за допомогою вейвлет-перетворень

Статтю присвячено розвитку математичних моделей, покладених в основу об'єднання зображень, отриманих дистанційними засобами зондування з різними просторовими та радіометричними розрізненостями. Проведено аналіз сучасних засобів дистанційоного зондування, які формують зображення, що фіксуються при однакових позиційних умовах проекціювання, у різних спектральних діапазонах випромінювання. Зображення сформовані у широкому спектральному діапазоні і мають вищу лінійну розрізненність, ніж зображення сформовані у більш вузьких діапазонах, однак останні містять спектральну інформацію. Розроблено прикладну модель об'єднання зображень, зафіксованих в різних спектральних діапазонах з використанням пірамідального вейвлет-перетворення. Визначено оптимальну модель декорреляції спектральних каналів багатоспектральних зображень за сигнальною ентропією.

Ключові слова: дистанційні засоби зондування; багатоспеткральне зображення; синтезоване зображення; панхромне зображення; вейвлет-декомпозиція; вейвлет-синтез; декорреляція; сигнальна ентропія.

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