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AUTOMATED PANSHARPENING INFORMATION TECHNOLOGY OF SATELLITE IMAGES

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ABSTRACT

Context. Nowadays, information technologies are widely used in digital image processing. The task of joint processing of satellite image obtained by different space systems that have different spatial differences is important. The already known pansharpening methods to improve the quality of the resulting image, there are new scientific problems associated with increasing the requirements for high-resolution image processing and the development of automated technology for processing the satellite data for further thematic analysis. Most spatial resolution techniques result in artifacts. Our work explores the major remote sensing data fusion techniques at pixel level and reviews the concept, principals, limitations and advantages for each technique with the program implementation of research.

Objective. The goal of the work is analyze the effectiveness of the traditional pan-sharpening methods like the Brovey, the wavelet-transform, the GIHS, the HCT and the combined pansharpening method for satellite images of high-spatial resolution.

Method. In this paper we propose the information technology for pansharpening high spatial resolution images with automation of choosing the best method based on the analysis of quantitative and qualitative evolutions. The method involves the scaling multispectral image to the size of the panchromatic image; using histogram equalization to adjust the primary images by aligning the integral areas of the sections with different brightness; conversion of primary images after the spectral correction on traditional pansharpening methods; analyze the effectiveness of the results obtained for conducts their detailed comparative visual and quantitative evaluation. The technology allows determining the best method of pansharpening by analyzing quantitative metrics: the NDVI index, the RMSE and the ERGAS. The NDVI index for the methods Brovey and HPF indicate color distortion in comparison with the reference data. This is due to the fact that the Brovey and HPF methods are based on the fusion of three channel images and do not include the information contained in the near infrared range. The RMSE and the ERGAS show the superiority of the combined HSV-HCT-Wavelet method over the conventional and state-of-art image resolution enhancement techniques of high resolution satellite images. This is achieved, in particular, by preliminary processing of primary images, data processing localized spectral bases, optimized performance information, and the information contained in the infrared image.

Results. The software implementing proposed method is developed. The experiments to study the properties of the proposed algorithm are conducted. Experimental evaluation performed on eight-primary satellite images of high spatial resolution obtained WorldView-2 satellite. The experimental results show that a synthesized high spatial resolution image with high information content is achieved with the complex use of fusion methods, which makes it possible to increase the spatial resolution of the original multichannel image without color distortions.

Conclusions. The experiments confirmed the effectiveness of the proposed automated information technology for pansharpening high-resolution satellite images with the development of a graphical interface to obtain a new synthesized image. In addition, the proposed technology will effectively carry out further recognition and real-time monitoring infrastructure.

KEYWORDS: image fusion, satellite image, pansharpening, automating, WorldView, high resolution imaging, metanalysis.

ABBREVIATIONS

RGB is a multispectral image;
PAN is a panchromatic image;
NIR is a Near Infrared band;
GIHS is a generalized intensity-saturation-tone;
HPF is a high-frequency filter;
HCT is a hyperspherical conversion;
NDVI is a normalized vegetation index;
GUI is a graphical user interface.

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NOMENCLATURE

F_i is an i-th channel in the image after the pansharpening;

P is a panchromatic image;

$RGB_i\uparrow$ is an i-th image channel RGB after scaling to size P;

S is a synthesized image;

N is a total number of RGB channel;

$*$ is a convolution operator;

g is a high-frequency filter;

$P`$ is a detail coefficients of the software;

NIR is a near infrared light intensity value;

RED is a red reflection, which corresponds respectively to channel 8 for images obtained by satellite WorldView-2.

INTRODUCTION

In recent years satellites imaging systems have been developing rapidly. Nowadays, these satellites allow to obtain data with a spatial resolution of half a meter or less to monitoring the state of forests, sea areas, shelves, etc. Images of high spatial resolution are required to use of special methods of their processing [1].

Satellite imagery of high spatial resolutions is a source of geospatial information. One of the problems of using satellite images obtained by various space systems is the joint processing of a multispectral image with low spatial resolution (channels: Coastal, Blue, Green, Yellow, Red, Red Edge, NIR1, NIR2) and a panchromatic image (PAN) of high spatial resolution, which is monochrome. The PANs have a smaller pixel size and are fixed in a sufficiently wide spectral range of radiation intensity and have a significantly higher spatial disparity than the RGBs obtained in narrow spectral intervals [2]. The current level of requirements for the reliability of image interpretation makes it necessary to overcome the physical limitations of available satellite sensors, in particular, by fusion high spatial and spectral disparity indicators in one graphical object.

1 PROBLEM STATEMENT

The Data Fusion approach means that the resulting synthesized data combines the properties of both types of source data and carries more information than a simple combination of information sources considered separately from each other. These information sources contain heterogeneous data represented by different formats, structures and implemented on different types of platforms.

Eight-channel images from the WorldView-2 satellite are used as input data. The panchrome wavelength of this satellite was expanded from the visible to the near infrared range. An image can be expressed in matrix format by the formula (1):

$$A_{n,b} = \begin{pmatrix} a_{1,1} & \cdots & a_{1,n} \\ \vdots & \ddots & \vdots \\ a_{b,1} & \cdots & a_{b,n} \end{pmatrix}, \quad (1)$$

where n represents the number of the pixels and b is the number of bands. Considering each WorldView-2 band as a vector, the above matrix can be simplified by the formula (2):

$$A_b = \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_8 \end{pmatrix}. \quad (2)$$

The main requirements to satellite images for their processing are as follows:

1. PAN and RGB images should be of the same territory and taken in the same season.

2. Images should be done with the imaging systems of the same type and the spectral bands of the imaging systems are the same.

3. PAN and RGB images should be of the same or close resolution, otherwise the images will contain different information about objects.

Therefore, there is a need to investigate the effectiveness of existing techniques for pansharpening high spatial difference satellite imagery with automation of choosing the best method based on the analysis of quantitative and qualitative evolutions for synthesized images.

2 REVIEW OF THE LITERATURE

Over the past two decades, a large number of methods for pansharpening satellite imagery have been developed, which can be divided into: component replacement, multiscale analysis and combined methods [3–6]. Component replacement methods are the conversion of a RGB with the replacement of some components from the software and the conversion of the result to the primary view. IHS (intensity – brightness, hue – color tone, saturation – saturation) is a method in which the I-component of the RGB is replaced with software with high. This transformation can be applied to only three images; and for images with four channels, a modified GIHS method [7, 8] is used. Rahmani et al. proposed a modified IHS pansharpening method which provides good quality visual high resolution multispectral image [9]. This method allows an image adaptive coefficient for IHS was found. It obtained a more accurate spectral resolution for primary image. Work [10] proposed a pansharpening with multiscale normalized nonlocal means filter. This filter computes each pixel value as the weighted average of all pixels over a sliding window, and the final smooth fused image is obtained. All these approaches are fast and easy to implement but not efficient for the latest image generation.

Efficient algorithm is a multispectral image conversion algorithm that uses independent component analysis (PCA) method, in which the first main component (RS1) is replaced with PAN image [11]. Brovey transform and Gram-Schmidt conversions are also common methods for replacing components. They make it possible to obtain a

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new synthesized image with good visual quality, but disrupt spectral quality [12, 13]. The main disadvantage of component replacement methods is the appearance of spectral distortions. Multi-scale analysis methods provide images that will have a high spatial resolution (due to the software), a high spectral resolution (due to the RGB) and contain information that is not present in the primary data (due to images obtained using microwave shooting and active location). An example of such methods is the Laplace pyramid method [14] and the A-transform method [15]. In [16] authors suggested method which combines the Independent Component Analysis and optimization wavelet transform. The wavelet decomposition coefficients are determined as a result of solving the optimization problem by the criterion of maximizing the entropy. Wavelet transformations allow you to save spectral information of the image, but do not take into account a priori and expert information.

3 MATERIALS AND METHODS

The work developed an automated technology for comparing and the choosing the best method of pansharpening satellite images of high spatial. Satellite imagery obtained by satellite WorldView-2 has a spatial resolution of 1.84 m in the multispectral channel and 46 cm in the panchromatic channel, respectively. The scheme of the proposed algorithm is presented in Fig. 1 and consists of the following main stages:

1. Loading of primary input data different spatial resolution images of the same scene.
2. Preprocessing the snapshot. In this step, the RGB was scaled to the size of the panchromatic image, and the histogram was equalized to the multispectral image. This made it possible to adjust the primary images by aligning the integral areas of the sections with different brightness proposed [17] by the algorithm in operation (3):

$$v\,(x,y) = \sum_{i=0}^{3}\sum_{j=0}^{3} a_{ij} \cdot P_{ij}\ . \qquad (3)$$

3. Analysis of pansharpening methods. In the proposed algorithm, the following methods are analyzed at this stage: generalized intensity – saturation – tone, the "Brovey" method, the high-pass filter method, wavelet transformations and combined methods. These techniques are easy to process and can be applied with any number of selected input spectral channels.

3.1 The generalized intensity-saturation-tone (GIHS) method is a modified IHS method in which the number of channels can be selected. Channel I contains information about bright component of image, others – information about spectral components. The method can be represented according to [18] the following expressions (4):

$$F_i = RGB_{i\uparrow} + (P - S)\,, \qquad S = \frac{1}{N}\sum_{i=1}^{N} RGB_{i\uparrow}\ . \qquad (4)$$

3.2 Method "Brovey" [19]. This method is based on formation of new spectral components of software in accordance with the following expression (5):

$$F_i = \frac{P}{S} RGB_{i\uparrow}\ ,\ S = \frac{1}{N}\sum_{i=1}^{N} RGB_{i\uparrow}\ . \qquad (5)$$

3.3 High-frequency filter (HPF) method [20] increases image information content based on transfer of high-frequency components of panchromatic channel to spectral channels in accordance with the following expression (6):

$$F_i = \frac{[P * g] + RGB_{i\uparrow}}{2}\ . \qquad (6)$$

3.4 Hyperspherical conversion (HCT) is a transformation between a native color space with Cartesian coordinates into a hyperspherical color space that effectively works with any number of RGB input channels [21] in the sample (7):

$$F_i^2 = \sum_{i=1}^{N} RGB_i^2\ ,\ \ P^2 = (Pan)^2\ . \qquad (7)$$

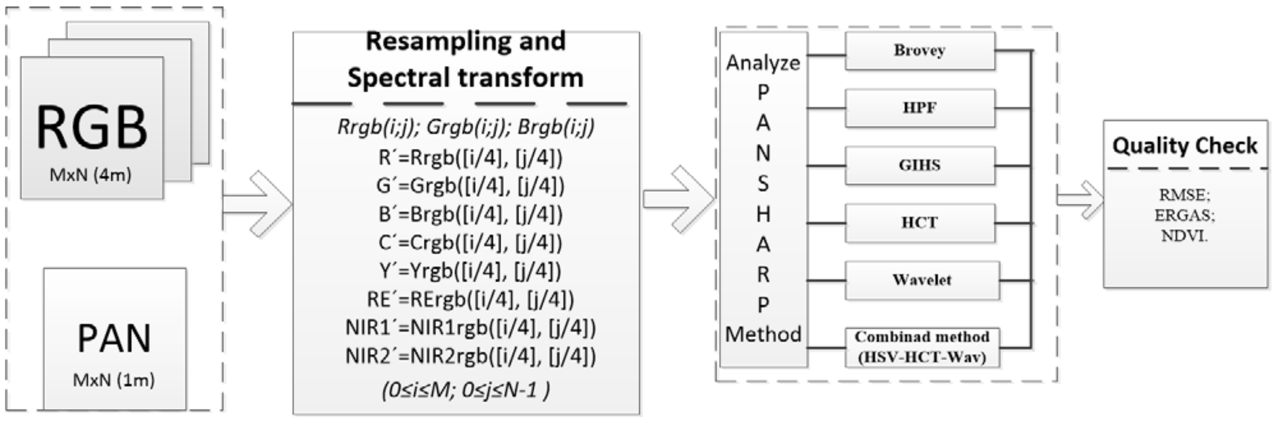

Figure 1 – Algorithm scheme

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3.5 Methods on the basis of wavelet transform are implemented by convolution of signal with several bandpass filters and decimation of result [22]. To perform the reverse operation (synthesis), an operation is performed to interpolate subband signals, filter and add them. The synthesis uses the same filters as the analysis, but the coefficients are presented in reverse order by the formula (8):

$$F_i = RGB_{i\uparrow} + \frac{RGB_{i\uparrow}}{\sum_{i=1}^{N} RGB_{i\uparrow}} \cdot P' . \qquad (8)$$

3.6 Combined methods combine the advantages of existing pansharpening methods with the minimization of color distortions and taking into account physical mechanisms for capturing species information [5, 6]. In [18] proposes an HSV conversion method, hyperspherical conversion, and a packet-type HSV-HCT transformation, which improves the spatial capability of the primary digital image and avoids spectral distortion in local regions.

4. The next stage is the analysis of the qualitative and quantitative characteristics of the pansharpening methods for satellite imagery considered in the work in order to determine their state and significance.

4.1 The RMSE criterion determines the deviation of the position of the point on the shot relative to its position in space [23].

4.2 ERGAS is a quality index that calculates the "number" of spectral distortions of a synthesized image [21]. An ERGAS value higher than three corresponds to the resulting low-quality image. If ERGAS is less than three, then the image quality is considered satisfactory.

4.3 One of the criteria for checking spectral properties of synthesized images is calculation of spectral index, in particular normalized vegetation index (NDVI) [24] was calculated in the sample (9):

$$NDVI = \frac{NIR - RED}{NIR + RED} . \qquad (9)$$

4 EXPERIMENTS

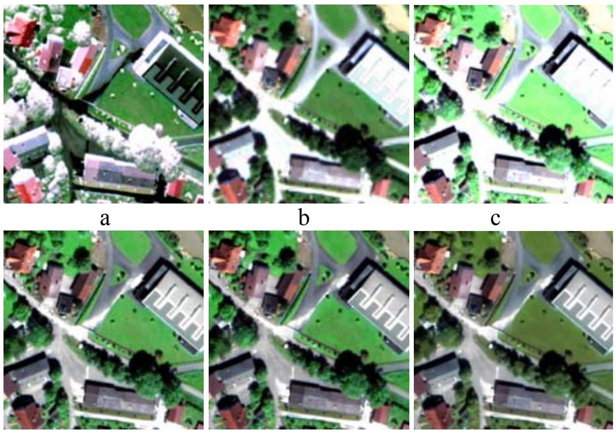
Research of influence of fusion methods was performed on the primary satellite images by WorldView-2 of 400x400 pixels, images are shown in Fig. 2.

We have selected the whole scene, which constitutes buildings, trees, grass, and roads. Fig. 2a shows the original multispectral image, Fig. 2b – panchromatic image. After image fusion by pansharpening methods discussed above, images are shown in Fig. 3.

a

b

Figure 2 – Fragments of multispectral image:
a – input RGB after resampling; b – input PAN



a b c

d e f

Figure 3 – Image fragments by methods: a – Brovey; b – HPF, c – GIHS; d – HCT; e – Wavelet; f – combined method

5 RESULTS

We created the graphical user interface for comparing and the choosing the best method of pansharpening satellite images of high spatial resolution. To use the GUI we have defined set of instructions:

Step 1: Click on Load Button. At first program propose to select panchromatic image, then multispectral

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image. We need to be careful as the input data must be of the same scene and size.

Step 1.1: Choice the visible Bands for RGB image.

Step 2: Preprocessing the snapshot click on Scans Button and Resampling Button.

Step 2.1: Scans Button analyzed your primary input data: spectral and spatial resolution of the same scene.

Step 2.1: Resampling Button – scaled to the size of the panchromatic image and equalized the histogram to the multispectral image.

Step 3: Pansharpening Button analysis of the methods and show results. Then, we can automatically see the result in the Pansharpened image block for this you need click on Visible Button. All images are displayed in their stated blocks.

Step 4: Button Quantitative Metrics show the quantitative characteristics of the pansharpening methods for satellite imagery.

Result: Pansharpened Image and quantitative values for synthesized multispectral images.

Image quality assessment plays an important role in the processing of satellite images to determine their state and significance, especially when using image quality enhancement techniques. The first step of quality assessment is the visual analysis of the fused images. After the pansharpening of images according to the above methods, images were obtained that, even visually compared to the reference RGB, are more clear, but have significant color distortions (Figure 3). Figure 5a shows the multispectral image details containing two targets before and after pansharpening (Fig. 5b, Fig. 5c, Fig. 5d, Fig. 5e, Fig. 5f). The synthesized multispectral image by the Brovey method has many artifacts due to colors. Image is too noisy and colors are not well synthesized as a whole and locally. Green trees are not green enough. Shapes are not well defined; they are sometimes underlined by black lines. Too large bias is observed.

So, there is too much variance introduced by Brovey method, the resulting image are shown in Fig.5b. Fig. 5c illustrates the fused image of HPF method. The result has colors that are not synthesized well enough. Contours are not sharp enough. Small objects, are white and not colored. Other colors are missing in detail, thus preventing an accurate reading of small objects. GIHS – colors are not correctly synthesized enough. Small colored objects are missing, particularly in blue and red. Contours are blurred and not sharp enough, the fused images after GIHS method are shown in figure 5d. Figure 5e illustrates the fused image after HCT method this image is nice as a whole. Colors should be better synthesized. This would enhance the legibility of the image. Details are there, except for the most colored (blue, red). Errors in colors lead to interpretation errors. Contours should be sharper. Wavelet transform – pretty nice as a whole. Efforts to do with colors. Small size objects are missing, particularly those in red or blue. It can be seen from the Fig. 5f. Combined method (HSV-HCT-Wavelet) – have better contrast and clarity on the boundaries of the "object of interest – the background". Contours are sharp enough and colors are well synthesized. It can be seen from the Fig. 5g.

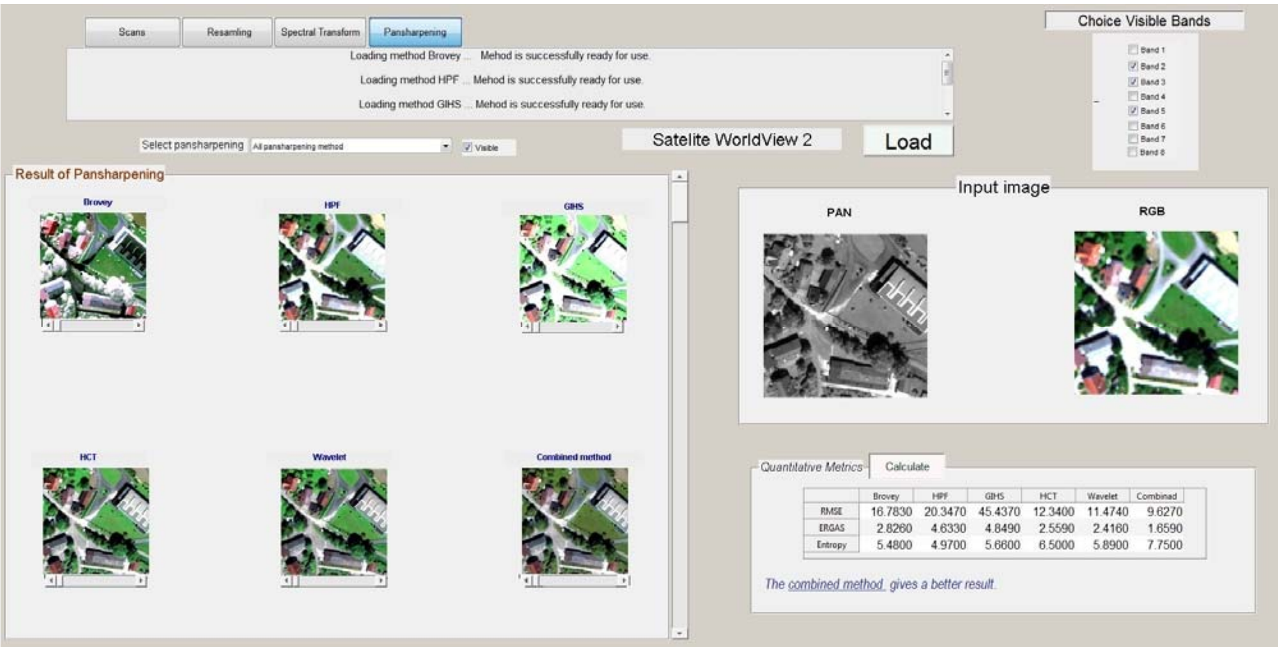

Figure 4 – Graphical user interface of proposed technology

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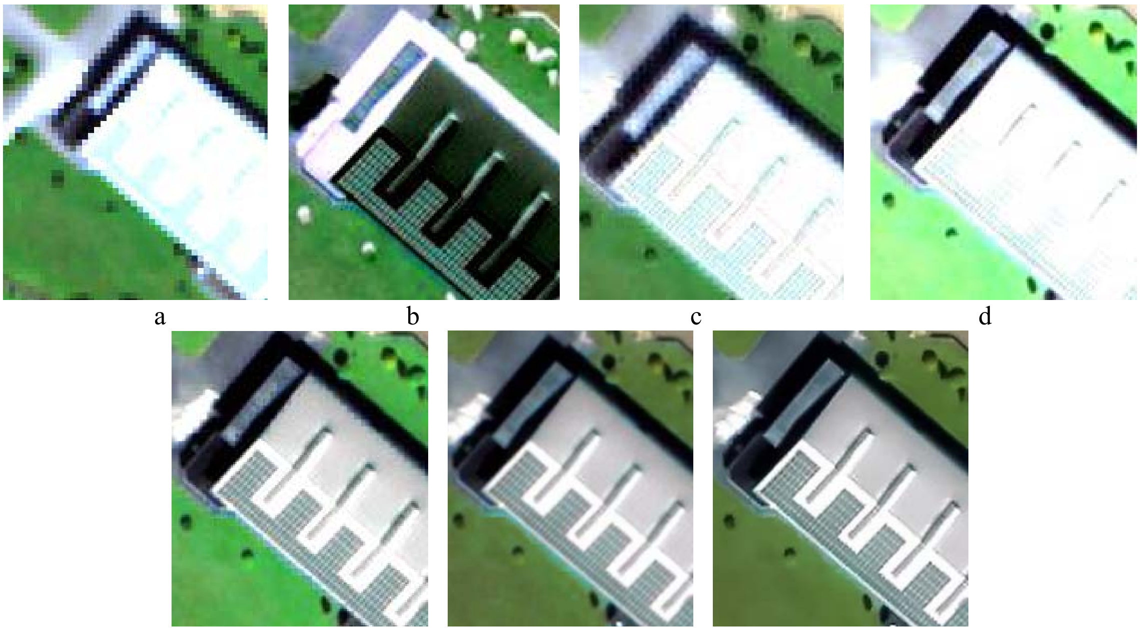

Figure 5 – The results of different classic fusion methods:
a – Input RGB; b – Brovey; c – HPF, d – GIHS; e – HCT; f – Wavelet; g – combined method

At the same time, due to the subjectivity of human perception, the visual system perceives artifacts on the image differently, much depends on the experience of experts. Therefore, in order to determine the effect of each method on the quality of a multispectral image, a quantitative analysis of the information content of the primary and synthesized multispectral was carried out in the work, namely, found RMSE, relative dimensionless global error (ERGAS) and normalized vegetation index (NDVi).

Entropy is a measure of image information richness is an important indicator of the size of the entropy reflects the amount of information contained in the image number (entropy for PAN=7.51, RGB=7.299).

The obtained entropy, RMSE, ERGAS and NDVI values for synthesized multispectral images are shown in Table 1. We see that the combined method (HSV-HCT) compared to classical fusion methods gives a better result.

Table 1 – Comparison of fusion methods

Image/Method	**RMSE**	**ERGAS**	**Entropy**
PAN	–	–	7.51
RGB	–	–	7.299
GIHS	16.783	2.826	5.48
Brovey	20.347	4.639	4.97
HPF	15.437	4.849	5.66
HCT	12.311	2.659	6.05
Wavelet transform	11.474	2.416	5.89
Compiled method (HSV-HCT-Wavelet)	**9.627**	**1.659**	**7.78**

The efficiency of the combined method is also evidenced by the NDVI index values obtained in Table 2.

Table 2 – The results of the normalized vegetation index

Image/ Method	**NDVI**	**NDVI for RMSE**	**NDV for ERGAS**
Reference image of the satellite WorldView-2	1	0	0
GIHS	0.9614	0.0586	12.6028
Brovey	0.9725	0.2125	45.7155
HPF	0.9569	0.1526	32.8356
HCT	0.9578	0.0578	12.4439
Wavelet transform	0.9573	0.0603	17.568
Compiled method (HSV-HCT-Wavelet)	**0.9924**	**0.0533**	**11.4107**

6 DISCUSSION

The proposed technology of spatial resolution of satellites images is automatically improving the spectral quality of the sharpened image choosing the best result of the pansharpening method. As it evident from the Table 1 the quantitative evolutions of entropy for PAN is 7.51, for RGB – 7.299, after combined method – 7.78. Indicator of the size of the entropy reflects the amount of information contained in the image number, under normal circumstances, the greater the entropy of fusion images, the amount of information it contains, the more the better integration. The other quantitative evolutions of RMSE, ERGAS and NDVI have better result for the combined method with compared to classical fusion methods. This

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is indicated by the value of the dimensionless global error and root mean square Error, which are the smallest (ERGAS = 1.659, RMSE = 1.659) compared to existing methods and indicates a minimum "number" of spectral distortions of satellite images and value entropy of the image pansharped by proposed technology is higher than others.

As it evident from the Table 2 the NDVI index values is efficiency of the combined method too. Obtaining a normalized vegetation index value for the Brovey and HPF methods indicates color distortion compared to the reference data. This is due to the fact that the Brovey and HPF methods are based on the fusion of three channel images and do not take into account information contained in the near infrared range, which affects the quality of spectral information of the synthesized image.

The results according to these criteria make it possible to establish a rating range of pansharpening methods from the worst result: Brovey, HPF, GIHS, soundet conversion, HCT and the combined HSV-HCT method. In addition, separate use of these methods leads to the appearance of spectral artifacts on the synthesized image compared to the reference one. The "ideal" pansharpening method is a method that increases spatial difference with minimization of color distortion.

The proposed automated technology increases the spatial resolution of multi-spectral aerospace images without color distortion.

CONCLUSIONS

The actual problem of automated increase of spatial resolution of primary multichannel images is solved in the work.

The scientific novelty of obtained results is that the proposed information technology can to increase the spatial resolution of multispectral satellite images with automation of a choice of the best pansharpening method on the basis of the analysis of quantitative and qualitative indicators is offered.

The practical significance of obtained results is that they can effectively carry out further recognition and construction of infrastructure facilities, etc. Testing showed that a synthesized image of high spatial resolution with maximum information content is achieved with the integrated use of fusion methods, which allows increasing the spatial fragmentation of a multi-channel image without significant color distortions.

Prospects for further research are to research the influence of factors that significantly affect the spatial and radiometric diversity of multichannel satellite image. Further research involves the use of a mechanism for selecting the most informative image channels. Note that the definition of criteria for assessing such informativeness and quality of the results is a separate unresolved issue.

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АВТОМАТИЗОВАНА ІНФОРМАЦІЙНА ТЕХНОЛОГІЯ ЗЛИТТЯ СУПУТНИКОВИХ ЗНІМКІВ

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АНОТАЦІЯ

Актуальність. На сьогоднішній день інформаційні технології широко використовуються при цифровій обробці зображень дистанційного зондування Землі. Актуальною є задача сумісної обробки супутникових зображень, отриманих різними космічними системами, які мають різне просторове розрізнення. Одними із найсучасних супутників є WorldView-2 та WorldView-3, що дозволяють отримати восьмиканальне зображення високого просторового розрізнення. Незважаючи на розроблені методи, призначені для поліпшення якості результуючого зображення, з'являються нові наукові проблеми, які пов'язані із підвищенням вимог до результатів обробки знімків високого просторового розрізнення та розробкою автоматизованої технології обробки цих даних для подальшого їх тематичного аналізу. В роботі розглянуто концепції, принципи, обмеження та переваги традиційних методів злиття з програмною реалізацією.

Мета. Метою роботи є аналіз ефективності традиційних методів злиття, таких як Brovey, вейвлет-перетворення, GIHS, HCT та комбінованого методу для супутникових зображень високого просторового розрізнення.

Метод. У роботі запропоновано інформаційну технологію злиття знімків високого просторового розрізнення з автоматизацією вибору найкращого методу злиття на основі аналізу кількісних та якісних показників. Запропонована технологія включає: масштабування мультиспектрального зображення до розміру панхроматичного зображення; використання еквалізації гістограми для коригування первинних зображень шляхом вирівнювання інтегральних областей з різною яскравістю; перетворення первинних зображень після спектральної корекції за традиційними методами «паншарпінг»; аналіз ефективності отриманих результатів. Технологія дозволяє визначити кращий метод злиття шляхом аналізу кількісних метрик: індексу NDVI, RMSE та ERGAS. Індекс NDVI для методів Brovey та HPF вказує на спектральні спотворення у порівнянні з еталонними даними. Це пов'язано з тим, що методи Brovey та HPF засновані на злитті трьохканальних зображень і не включають інформацію, що міститься в ближньому інфрачервоному діапазоні. Отримані значення RMSE та ERGAS демонструють перевагу комбінованого методу HSV-HCT-Wavelet над традиційними та найсучаснішими методами підвищення просторового розрізнення супутникових зображень. Це досягається, зокрема, попередньою обробкою первинних зображень, обробкою даних локалізованих спектральних компонент та використанням інформації, що міститься в інфрачервоному каналі зображення.

Результати. Розроблено програмне забезпечення, що реалізує запропонований підхід. Експериментальна оцінка проведена на восьмиканальних первинних супутникових знімках високого просторового розрізнення, отриманих супутником WorldView-2. Експериментальні результати показують, що синтезоване зображення з високою просторовою роздільною здатністю з високим інформаційним вмістом досягається за допомогою комплексного використання методів злиття, що дозволяє збільшити просторову роздільну здатність вихідного багатоканального зображення без спектральних спотворень.

Висновки. Проведені експерименти підтвердили ефективність запропонованої автоматизованої інформаційної технології, що дозволяє рекомендувати її при подальшому дослідженні таких задач як розпізнавання й оперативний моніторинг об'єктів інфраструктури.

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КЛЮЧОВІ СЛОВА: злиття зображень, супутникове зображення, паншарпенінг, автоматизація, WorldView, зображення високого просторового розрізнення, метааналіз.

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АВТОМАТИЗИРОВАННАЯ ИНФОРМАЦИОННАЯ ТЕХНОЛОГИЯ СЛИЯНИЯ СПУТНИКОВЫХ СНИМКОВ

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АННОТАЦИЯ

Актуальность. На сегодняшний день информационные технологии широко используются при цифровой обработке изображений дистанционного зондирования Земли. Актуальной является задача совместной обработки спутниковых изображений, полученных различными космическими системами, которые имеют разное пространственное разрешение. Одними из самых современных спутников являются WorldView-2 и WorldView-3, которые позволяют получить восьмиканальное изображение высокого пространственного разрешения. Несмотря на разработанные методы слияния, предназначенные для улучшения качества результирующего изображения, появляются новые научные проблемы, связанные с повышением требований к результатам обработки снимков высокого пространственного разрешения и разработкой автоматизированной технологии обработки этих данных для дальнейшего их тематического анализа. В работе рассмотрены концепции, принципы, ограничения и преимущества традиционных методов слияния.

Цель. Целью работы является анализ эффективности традиционных методов слияния, таких как Brovey, вейвлет-преобразования, GIHS, HCT и комбинированного метода для спутниковых изображений высокого пространственного разрешения.

Метод. В работе предложена информационная технология слияния снимков высокого пространственного разрешения с автоматизацией выбора наилучшего метода синтеза на основе анализа количественных и качественных показателей. Предложенная технология включает: масштабирование мультиспектрального изображения до размера панхроматические изображения; использование эквализации гистограммы для корректировки первичных изображений путем выравнивания интегральных областей с различной яркостью; преобразование первичных изображений после спектральной коррекции с традиционными методами паншарпинга; анализ полученных результатов. Технология позволяет определить лучший метод слияния путем анализа количественных метрик: индекса NDVI, RMSE и ERGAS. Индекс NDVI для методов Brovey и HPF указывает на искажение цвета по сравнению с эталонными данными. Это связано с тем, что методы Brovey и HPF основанные на слиянии трехканальных изображений и не включают информацию, содержащуюся в ближнем инфракрасном диапазоне. RMSE и ERGAS демонстрируют преимущество комбинированного метода HSV-HCT-Wavelet над традиционными и современными методами повышения пространственного разрешения спутниковых изображений. Это достигается, в частности, предварительной обработкой первичных изображений, обработкой данных локализованных спектральных компонент и использованием информации, содержащейся в инфракрасном канале изображения.

Результаты. Разработано программное обеспечение, реализующее предложенный подход. Экспериментальная оценка, проведенная с использованием восьмиканальных первичных спутниковых снимков с высоким пространственным разрешением, полученных спутником WorldView-2. Экспериментальные результаты показывают, что синтезированное изображение высокого пространственного разрешения с высокой информативностью достигается с помощью комплексного использования методов синтеза, что позволяет увеличить пространственное разрешение исходного многоканального изображения без спектральных искажений.

Выводы. Проведенные эксперименты подтвердили эффективность предложенной автоматизированной информационной технологии, что позволяет рекомендовать его при дальнейшем исследовании таких задач как распознавание и оперативный мониторинг объектов инфраструктуры.

КЛЮЧЕВЫЕ СЛОВА: слияния изображений, спутниковое изображение, паншарпенинг, автоматизация, WorldView, изображение высокого пространственного разрешения, метаанализ.

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