



Method for Fusing Images Based on Different Resolution Remote Sensed Data

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Abstract: Study is dedicated to depict and grouping methods for combining multispectral low-resolution remote detected images with an all the more exceedingly settled panchromatic image to high-resolution images. The attributes of image handling quantitative estimation dependent on ex-footing method are depicted. Factual examinations are illustrated. The aftereffects of image geniuscessing completed by various methods are given.

INTRODUCTION

One of the problems of the integrated use of Earth Remote Sensing Data (RSD), obtained by different space systems is the joint processing of images formed in different spectral ranges with different spatial resolution. Such a problem arises when processing data of multispectral optical systems their integration with microwave radiometric and radar images (Ermakov and Smirnov, 2001; Weydahl *et al.*, 1995). A similar problem exists in the joint processing of remote sensing data, ground-based measurements and a priori information presented in the form of thematic layers of digital maps (Ermakov and Smirnov, 2005).

Most modern satellite systems that monitor the Earth, such as Landsat, SPOT, IRS, IKONOS, QuickBird and others are capable of obtaining multispectral and panchromatic images of different spatial resolution (Table 1).

In order to efficiently use these data a large number of methods have been developed for obtaining synthesized multispectral images with an increase in spatial resolution due to their combination with a high-resolution pan-chromatic image in a single color image. These methods also make it possible to combine,

in a single color image, data obtained in the microwave range using space-borne synthetic aperture radar (PCA) and multispectral images of the optical range. The term "Image fusion" (in English literature image fusion as well as image sharpening, resolution merge) (Chavez *et al.*, 1991; Wald, 2002; Ranchin *et al.*, 2003) is most often used to refer to this procedure.

The use of synthesized images greatly increases the possibility of thematic interpretation. However, this procedure often leads to impaired color rendering. The qualitative characteristics of the synthesized image often depend on the experience of the operator and their assessment is subjective. To reduce color distortion and improve the quality of merge results a variety of different strategies have been developed, each of which is designed for a specific merge method or source data set.

The problem of significant color distortions in the resulting image was aggravated with the advent of ultra-high resolution remote sensing data. Unlike the panchromatic images of the SPOT and IRS spacecraft sensors, the wavelength range of the shooting systems of the IKONOS, QuickBird and OrbView satellites is extended from the visible to the near infrared region of the spectrum (Table 1). This difference significantly changes the gray level values of such panchromatic images.

Table 1: Resolution of space systems for remote sensing optical range

Cosmic system/sensor	Landsat ETM+	SPOT HRGI	IRS PAN/LISS-III	IKONOS	Quick Bird BHRC-60	
Spatial resolution (m): panchromatic mode	15	5 (2,5)	5,8	1	0,61	8
Multispectral mode	30, 60	10	23	4	2,5	20
Spectral range of panchromatic image (μm)	0.52-0.90	0.48-0.71	0.50-0.75	0.45 -0.90	0.45 -0.90	0.51-0.85

Therefore, processing methods that have proven to be good for merging panchromatic SPOT images with other multispectral data cannot provide qualitative results when merging ultra-high resolution satellite images (Zhang, 2002). This factor stimulates the need for a comprehensive analysis of the many existing and the development of new fusion methods (Zhang, 1999; Chena *et al.*, 2003; Kundur and Hatzinakos, 2004).

This study discusses the main stages of the “Image fusion” procedure, provides an overview of the methods and algorithms underlying them, proposes a method for quantifying the characteristics of processed images based on the developed test and presents the results of processing satellite images by various methods.

MATERIALS AND METHODS

Image fusion methods: The first detailed review of image synthesis methods is given in the research of (Pohl and Genderen, 1998). Currently, a large number of algorithms for obtaining synthesized multispectral images with increasing spatial resolution have been developed (Ranchin *et al.*, 2003; Chena *et al.*, 2003; Pohl and Genderen, 1998). In the research of recent years, the emphasis is on improving the quality of the resulting image and on reducing color distortion. The variety of implementations of the method provides the adaptability of the procedure to the solution of specific problems of thematic interpretation.

When using the “Merge images” procedure, a high-resolution color image is obtained by successively performing the following steps.

Transformation of a low-resolution multispectral image from a Red-Green-Blue (RGB) basis to some three-coordinate basis in which one of the coordinates is equivalent to the distribution of brightness and can be replaced with a panchromatic high-resolution image.

Increasing the sampling frequency of the transformed image to the sampling frequency of the panchromatic image and the subsequent interpolation (linear, bicubic, according to the nearest neighbor rule, etc). Replacing the luminance component of the converted image with a panchromatic high resolution image.

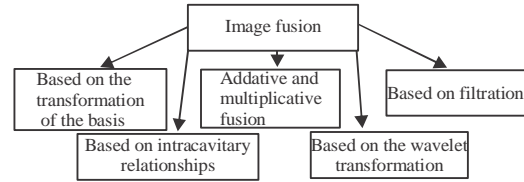


Fig. 1: Classification methods

Inverse conversion to the basis of RGB: Numerous fusion methods differ in the type of transformation of spectrozonal images used at the first stage of the procedure and accordingly, the method of replacing one of the components with a high-resolution image at the third stage and the interpolation algorithm used at the second stage. All the variety of methods of “Merging images” is usually classified according to the types of transformations of the blowing image (Fig. 1). The following is a brief description of these methods.

Fusion methods based on base transformation: The method of direct synthesis of color images. When using this method, instead of data corresponding to the intensity of one of the color channels of a low-resolution image, data of a Panchromatic channel of high resolution (Pan) is substituted. This method is the most easy to implement but it gives the greatest violation of color rendition. The scheme of image formation by the method of direct synthesis is presented in Fig. 2. R, G, B-denotes the intensities of the original color channels and R^* , G^* , B^* denotes the intensities of the high-resolution multispectral image channels (Chavez *et al.*, 1991).

Synthesizing based on the principal component method (PCA-Principal Component Analysis). The Principal Component method (PC) is used to determine statistically independent derived features of objects to isolate and display their spectral contrast.

When performing the transformation by the principal component method in the n-dimensional spectral space, the axes of the coordinates of the spectral space are rotated, so that, the new axes become parallel to the axes of the scattering ellipsoid. Therefore, the first main

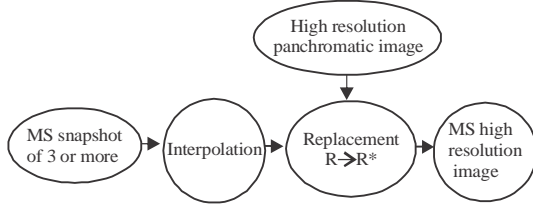


Fig. 2: Image fusion by direct synthesizing

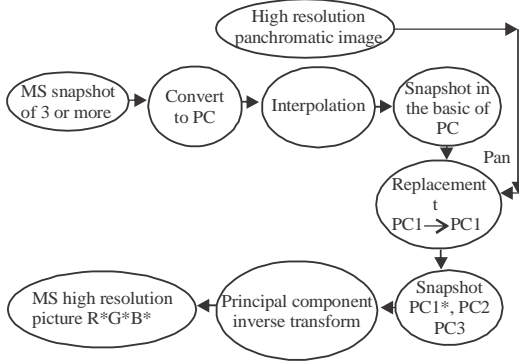


Fig. 3: Synthesis by the principal component method

rotated, so that, the new axes become parallel to the axes of the scattering ellipsoid. Therefore, the first main component corresponds to the largest axis of the ellipsoid the direction of the greatest variation in brightness values. The second main component corresponds to the largest cross section of the ellipse orthogonal to the first main component. It reflects the greatest value of variation in data that is not yet covered by the first major component. Each subsequent main component is one of the cross sections of the ellipsoid scattering, orthogonal to the previous sections (components) and characterizes the reducing value of the variations in the data that have not yet been taken into account by the previous main components. Therefore, the first of them reflect the greatest information contained in the transformed multispectral image. PCA conversion converts interconnected multispectral ranges into a new set of uncorrelated components (Shettigara, 1992):

$$\begin{bmatrix} PC1 \\ PC2 \\ PC3 \end{bmatrix} = W_{pc} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Where:

- PC1 : The matrix of the i-th main component
- W_{pc} : Transformation matrix
- R, G, B : Matrices of the brightness values of the image pixels in the original spectral channels

The first major component “Resembles” a Panchromatic image (Pan) image. Therefore, when merging, it is also replaced with high-resolution pan data. This image is combined with low-resolution multispectral channel data by performing inverse PCA conversion (Zhang, 2002; Chena *et al.*, 2003). The synthesis scheme for the GC method is presented in Fig. 3. The main operations are the following: transformation of the main component to transfer multi-spectral data (from three or more channels) to the category of main components, replacement of one main component usually the first with panchromatic high-resolution image, reverse transformation of the main components (together with replaced ones) to the mode original snapshot. After the reverse transformation, several synthesized multispectral images are obtained (since, the number of source channels may be more than three).

Intensity-Hue-Saturation (IHS) conversion. Using this method, the color image from the RGB (Red, Green, Blue) representation is transformed into 3 separate images, each of which has maximum characteristics according to Intensity (I) Saturation (S) and shades (H) colors. IHS conversion is described by the following relations (Zhang, 1999; Pellemans *et al.*, 1993; Chibani and Houacine, 2002):

$$\begin{aligned} I &= R+G+B \\ S &= 1 - \frac{3 \cdot \min(R, G, B)}{I} \\ H &= \begin{cases} 2 - \arccos \left\{ \frac{(R-G)+(R-B)}{2\sqrt{(R-G)^2(R-G)(G-B)}} \right\} & , B > G \\ \arccos \left\{ \frac{(R-G)+(R-B)}{2\sqrt{(R-G)^2(R-G)(G-B)}} \right\} & , B < G \end{cases} \end{aligned} \quad (2)$$

where I, H, S is the brightness value of a pixel in the channels intensity-tint-saturation, R, G, B the brightness value of the pixel of the image in the original spectral channels.

Since, the image with the maximum intensity I is “Similar” to the Panchromatic (Pan) image it is replaced when merging Pan with a high-resolution image. Then, the inverse IHS conversion of the Pan image is performed along with the H and S images, resulting in an RGB image.

The synthesis scheme by the IHS method is shown in Fig. 4. The main operations are as follows: transformation of a color image from RGB mode to IHS mode, replacement of components I (Intensity) with a

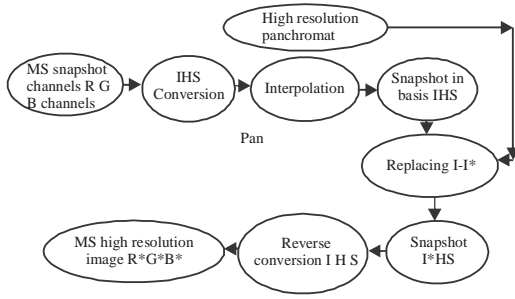


Fig. 4: Synthesis by IHS method

panchromatic high resolution image, reverse transformation of the replaced components from IHS mode into the original RGB mode to obtain a high synthesized image permissions.

Additive and multiplicative fusion: For image fusion, various methods were developed based on additive and multiplicative transformations of the original images: intensity modulation, Browning Transform (Brovey Transform), calculating the complex variable coefficient (SVR), calculating the improved coefficient (RE) and others and in the above methods based on baseline transformation, the procedure should be carried out to increase the number of samples of the data vectors of the multispectral channels R, G, B to the level of the number of samples of the data vector pan chromaticity image P. After increasing the sampling rate, the values of the resulting samples are interpolated by one of the methods already mentioned (Zhang, 1999). Let us dwell on the first two methods.

Intensity modulation: This method is one of the simplest. It is based only on visual perception and does not concern the physical properties of the obtained images. The main idea of the method is to multiply the panchromatic image by a low-resolution multispectral image, find the geometric mean and select empirically scaling coefficients a_i and b_i shift parameters b_i to improve visual characteristics. The following transformations of pixel intensities of multispectral and panchromatic channels are applied for transformation (Cliche *et al.*, 1985):

$$\begin{aligned} R^* &= a_R + b_R \sqrt{P \cdot R} \\ G^* &= a_G + b_G \sqrt{P \cdot G} \\ B^* &= a_B + b_B \sqrt{P \cdot B} \end{aligned} \quad (3)$$

Brovey-merge the basic procedure of the brovey transform method is that first each low-resolution multispectral image range is multiplied by the high-resolution panchromatic image range and then each resulting piece is divided by the sum of the multispectral image ranges. The following relations apply for transformation (Zhou *et al.*, 1998):

$$\begin{aligned} R^* &= \frac{R}{(R+G+B)} \cdot P \\ G^* &= \frac{G}{(R+G+B)} \cdot P \\ B^* &= \frac{B}{(R+G+B)} \cdot P \end{aligned} \quad (4)$$

Merging based on filtering: The brovey transform method was developed to increase visual contrast in the lower and upper parts of the histogram (i.e., it allows for contrast in shade, water surfaces and in areas with high reflectivity). Therefore, this method is not suitable for maintaining high radiometric characteristics of the original image:

$$\begin{aligned} R^* &= FT^{-1} PF T(R) HPF T(P) \\ G^* &= FT^{-1} PF T(G) HPF T(P) \\ B^* &= FT^{-1} PF T(B) HPF T(P) \end{aligned} \quad (5)$$

Where LPF-low-pass, filter-low-pass filtering, HPF-high-pass, filter-high-frequency filtering, FT-direct two-dimensional Fourier transform, FT^{-1} -inverse, two-dimensional Fourier transform.

In-band merging based: Gram-Schmidt transformation (Gram-Schmidt Transformation). Procedure designed to obtain orthogonal channels from channels with known correlation (Chavez *et al.*, 1991; Wald, 2002; Ranchin *et al.*, 2003). In particular, for the data of the three channels R, G and B with a known correlation:

$$\rho_{RG} = E[R, G], \rho_{GB} = E[G, B], \rho_{RB} = E[R, B]$$

In the first step of the procedure, two vectors V_G^R, V_B^R orthogonal R are obtained but correlated with each other:

$$\begin{bmatrix} V_G^R \\ V_B^R \end{bmatrix} = \begin{bmatrix} -q_G^R & 1 & 0 \\ -q_B^R & 0 & 1 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (6)$$

Where the second step is to convert:

$$\begin{aligned} q_j^R &= p_{Rj} p_{RR}, j = G, B \\ v_B^G &= v_B^R - \frac{E[v_B^R v_B^R]}{E[v_G^R]} \cdot v_G^R \end{aligned} \quad (7)$$

The result is three orthogonal vectors R , V_G^R , V_B^R , one of which is replaced by the data of the high-resolution channel P and the inverse transform is performed. Regressive fusion. Due to the high correlation of multispectral and panchromatic images, the regressive merge method (Price, 1999) allows to calculate the shift parameter and scaling coefficient and then calculate:

$$\begin{aligned} R^* &= a_R + b_R P \\ G^* &= a_G + b_G P \\ B^* &= a_B + b_B P \end{aligned} \quad (8)$$

The difference of this method from the intensity modulation method is that the parameters a_i and b_i are determined from the conditions of image correlation and not the required clarity. This method is not suitable for infrared imagery as in this case the correlation of multispectral and panchromatic images is weak.

Merging on the basis of wavelet transformations: The merging of images on the basis of wavelet transformations (Wavelet transformation) is as follows (Fig. 5).

A high resolution panchromatic image is decomposed into low resolution panchromatic images and detail coefficients. Then the panchromatic image of low resolution is replaced by a multispectral image with the same resolution. The inverse transform is performed to convert the composite and replaced parts of the panchromatic image to the original resolution level of the panchromatic image. Replacement and reverse transformation are carried out three times, one time for one multispectral image. Thus, high-resolution spatial details are introduced into each Multispectral (MS) range by performing an inverse wavelet transform for each MS range in conjunction with the corresponding wavelet coefficients (Chibani and Houacine, 2002; Price, 1999; (De and Chanda, 2006; Tseng and Chen, 2001). Among the whole variety of image transformation methods, the most common are:

- Intensity-hue-saturation conversion
- Principal component method
- The arithmetic combination method based on the brouvi transformation
- Gram-Schmidt transform
- Wavelet transform

Software systems that implement the procedure for merging images: In the most common software systems

(PCs) of remote sensing data processing such as ENVI, PCI geomatica, ERDAS, scanEx image processor, etc., various methods of image fusion are implemented. ENVI 4.2 uses 5 algorithms (labeled transforms-image sharpening): IHS, color normalized (Brovey), Gram-Schmidt transform, PCA and CN spectral.

In the basic delivery of the ERDAS software, 3 types of such algorithms (PC, multiplicative and brovey transform) are implemented.

An algorithm based on the combination of the principal component method and the wavelet transform method is implemented in the ScanEx Image Processor Software package.

Unlike ENVI which allows you to select a technology for processing, PCI geomatica 10.0 in a special module PANSHARP uses a new technology of image fusion based on statistical methods that has two fundamental differences: To reduce color distortions, the least squares method is used when finding the best match between the values of the gray levels of the synthesized images and adjusting the contribution of each individual range to the resulting image.

To eliminate dependence on the source data set (that is to reduce the impact of changes in the source data) and to automate the merge process a statistical approach is used to estimate the ratio of gray level values between all incoming channels

Research methods: In the present research, the comparison of existing options for implementing the merge method implemented in various software complexes for processing remote sensing data was carried out by analyzing the characteristics of resolution and color distortion (Visual method and cross section diagrams method). The studies were carried out both on the basis of processing special test images and by processing real satellite images.

Test image analysis: To obtain test images we used a software module developed by the researchers that allows forming an image for panchromatic and a specified number of spectrozonal channels. The structure of the test image for all channels is the same and includes the following elements (Fig. 6).

Single and double brilliant points with increasing distance between them by 1, 2, 3, 4 pixels for single points and on; 2, 4, 6, 8 pixels for double points (analog

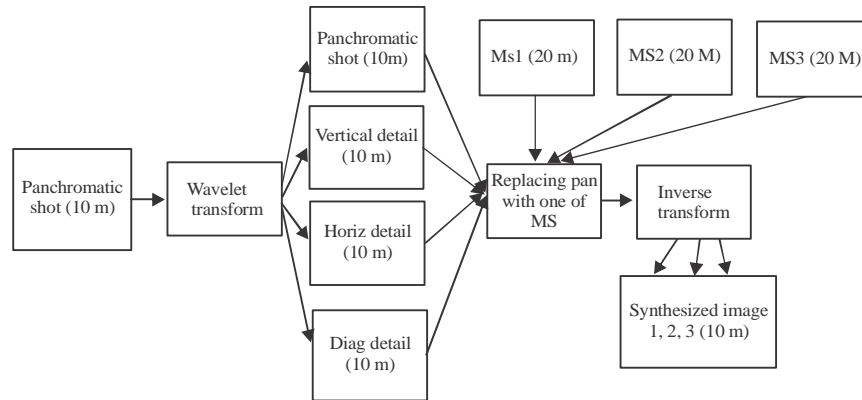


Fig. 5: Synthesis scheme based on the wavelet- transformation method

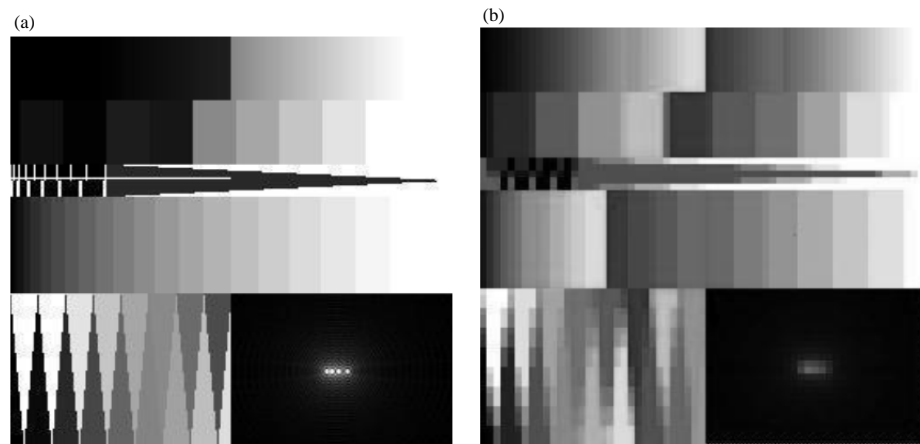


Fig. 6 (a, b): Test image, (a) “panchromatic” channel and (b) the “spectral” channel with a resolution 4 times lower than the initial one

worlds). Four bright dots with varying brightness when removed according to, the law $\sin(x)$ and located at a distance of 3, 4 and 9 lengths of the element of resolution. An area with uniformly varying brightness. An area with brightness varying according to a stepwise law and equal to standing between the boundaries. A region with brightness varying according to, a stepwise law and uniformly increasing distances between the boundaries. Areas with tapering borders.

The relationship of the intensity of the test images in the “Panchromatic” and “Spectral” channels are set either by the user or automatically in accordance with the spectral characteristics of reflections of typical surfaces (water, snow, vegetation, soil, etc.) and taking into account the values of the transfer coefficient of the imaging equipment. The initially formed test images of

the “panchromatic” and “spectrozon” channels have the same resolution. To carry out research on the merging of images, the resolution of the “spectral” channels is reduced by performing a direct wavelet transform and then reversing with the removal of detail coefficients. For the direct and inverse wavelet transformations, two types of wavelets are used in the program module: haar and Daubechi-4. This test structure allows determining the parameters of the spatial resolution quantify and conduct a quantitative analysis of color impairment.

Image processing was carried out in ENVI 4.2 PC using IHS, color normalized (Brovey), Gram-Schmidt transform, PCA algorithms and also in PC in PCI geomatica 10.0.

To evaluate the resolution of the images before and after the merge procedure a slice analysis of the test image

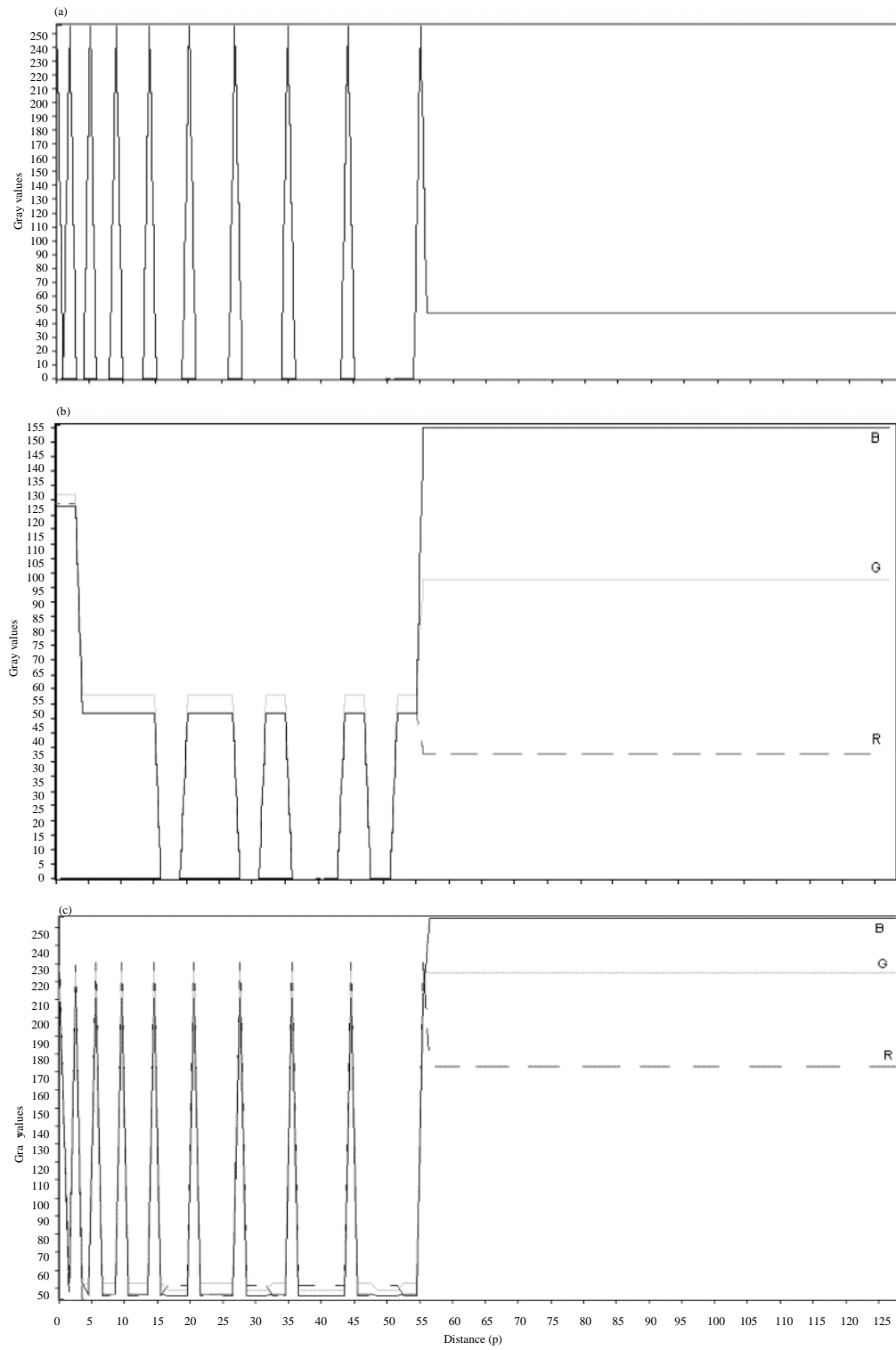


Fig. 7 (a-c): Slices of the test image

was performed. A slice is a graph of pixel brightness versus distance along a section line. Figure 7 shows the image slices along the straight line shown in Fig. 6 and the light line for the “Panchromatic”, three spectrozonal R, G, B channels with a resolution 4 times> the “Panchromatic” image and the high-resolution color image synthesized by the Gram-Schmidt method.

Studies have shown that for all methods it is possible to fully restore the image of shiny dots with increasing distance according to, two laws and four shiny dots with varying brightness when removed according to when analyzing the possibilities of restoring the border we calculated the average number of pixels belonging to the boundary between regions. The results are summarized in Table 2.

The violation of color rendition can be judged by the level of the cross section between peaks corresponding to the image of bright stripes in Fig. 7c. An analysis of the characteristics of color disturbances revealed that all the methods described introduce distortions. However, areas belonging to the same type of natural formations are

uniquely distinguished by color which makes it possible to successfully carry out the procedure for thematic interpretation of the high-resolution synthesized color image.

RESULTS AND DISCUSSION

The results of the processing for space images: In analyzing the fusion algorithms we used a fragment of the image of the industrial zone obtained by the QuickBird satellite in the panchromatic and three spectroson channels (Fig. 8). To estimate the resolution of the images before and after the processing procedure as in the case of test images we analyzed the slice diagrams given in Fig. 9. The image was cut along a straight line intersecting images of buildings, roads and technical structures of various sizes.

It is clearly seen that in the synthesized color image in contrast to the initial spectrozonal image, three elements of the industrial structure in the area of the mark of 20 m and elements of the three blocks in the area of marks of 120, 140 m and 180 m are resolved.

As a result of the processing of real images, it was found that all the investigated methods allow us to solve the problem of increasing the spatial resolution, however, they all to a greater or lesser extent, introduce color distortion. The least distortion was observed when using

Table 2: Blurring the borders of homogeneous areas of the text (in pixels)

Resolution of MS-image in relation to panchrome	MS-images	Synthesized image			
		1	1	1	1
0.25	4	2	2	3	3
0.5	2	1	1	1	1



Fig. 8: Fragment of the quickbird space image panchromatic channel.

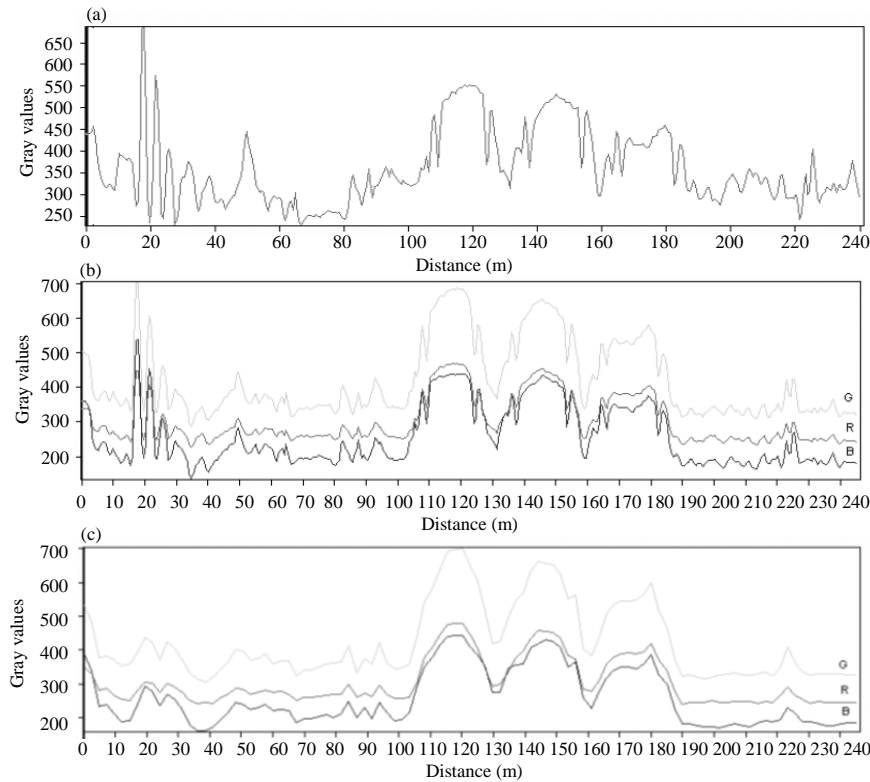


Fig. 9 (a-c): Cross-section of a fragment of a space image before (a, b) and after (c) processing by the method of merging images, (a) Panchromatic channel (resolution 0.61 m), (b) Red R, blue B and green G Channels (resolution 2.4 m), (c) Synthesized high resolution image Red, blue and green channels

the color normalized (Brovey) and IHS merge methods. In these cases, the violation of color did not cause the transition of pixels from one class of objects to another. Thus, when solving the classification problem these methods do not introduce an additional error. Synthesizing an image using the color normalized (Brovey) method allowed us to obtain images that are closest to the original multispectral images which makes this method stand out from the rest when it comes to solving clustering problems.

When synthesizing images using the Gram-Schmidt methods and the main components it was found that in some cases, after processing there is some difference in color for pixels that did not differ in color before processing.

Despite the fact that the color normalized (Brovey) method has demonstrated the best color reproduction, it should be noted that the processing results strongly depend on the combination of synthesized channels which means that the operator's experience will play the greatest role in its use. In the case of using the IHS merge algorithm, it should be noted that this method, although,

it does not lead to a violation of color rendition within the class, causes distortion in the color transfer of objects of different classes and can be used to solve classification problems only with significant restrictions. For synthesizing using the principal component method, it should be noted that the images obtained using this method often have weak colors and carry much less color information than the original multi-spectral images. This is due to the fact that the panchromatic image is replaced by the main component which has the most information and therefore, the characteristics of the panchromatic image dominate in the synthesized image.

CONCLUSION

This study provides a classification and brief overview of the methods and algorithms for processing remote sensing data that underlie the "Image fusion" procedure which allows synthesizing high-resolution color images based on combining data from multispectral and panchromatic channels of various resolutions as well as combining them with

radar images. A method is proposed for comparing the “Image fusion” methods based on the analysis of cross-section diagrams of a special test image.

The results of the processing of test images and fragments of real space images allowed us to determine methods that increase the resolution of the synthesized image and introduce the least distortion of color rendition. The best method for these indicators was the color normalized (Brovey) method, followed by the IHS method, the Gram-Schmidt method and the principal component method.

As a result of research, it was revealed that regardless of the method there is a disturbance in the color rendition of the final image. These distortions in solving many problems can be ignored and where color rendition plays a significant role, the use of additional processing algorithms is necessary. Despite this, the “Image fusion” method is a flexible and convenient tool for the preliminary processing of remote sensing data in case of thematic interpretation of images.

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