Jan MATUSZEWSKI, Marcin ZAJĄC

Wojskowa Akademia Techniczna, Wydział Elektroniki, Instytut Radioelektroniki

doi:10.15199/48.2019.11.30

Methods of picture segmentation in recognition digital satellite images

Abstract. *In the article for the recognition of digital satellite images, the method of segmentation of views by thresholding was chosen. Two algorithms were used: Laplasian of Gaussian and Canny. The Laplasian of Gaussian algorithm with Gauss low-pass filter smoothes the edges and Laplace's high-pass filter sharpens the image. Based on the calculations made, clear boundaries between individual areas were obtained. The presented application in the MATLAB environment effectively detects forest areas and lakes in the satellite images.*

Streszczenie. *W artykule do rozpoznawania cyfrowych zdjęć satelitarnych wybrano metodę segmentacji zobrazowań przez progowanie. Zastosowano dwa algorytmy: Laplasian of Gaussian i Canny'ego. Algorytm Laplasian of Gaussian z filtrem dolnoprzepustowym Gaussa wygładza krawędzie a filtr górnoprzepustowy Laplace'a wyostrza obraz. Na podstawie przeprowadzonych obliczeń otrzymano wyraźne granice między poszczególnymi obszarami. Przedstawiona aplikacja w środowisku MATLAB skutecznie wykrywa obszary leśne i jeziora na zdjęciach satelitarnych. (**Rozpoznawanie cyfrowych zdjęć satelitarnych metoda segmentacji**)*

Keywords: pattern recognition, pattern segmentation, algorithms Canny'ego and Laplasian of Gaussian
Słowa kluczowe: rozpoznanie obrazowe, segmentacja obrazu, algorytmy Canny'ego i Laplasian of Gaussian

Introduction

In recent years, the possibilities of image processing have developed to a large extent. Thanks to the new algorithms, we can get better and better results from the same satellite imagery [1, 2]. The information obtained from different sources is widely used in various areas of the economy, such as geodesy and cartography, forestry, electronic warfare systems water management [3-7]. They also make a significant contribution to rescue and the fight against the effects of natural disasters.

Various algorithms for processing and recognizing digital images can be found in the literature [8-10]. The first step is segmentation of the image, i.e. its division into disjoint areas that meet certain criteria of homogeneity. This approach allows us to skip individual pixel analysis and focus on the larger areas. These areas are internally uniform, which means that there are no clear boundaries between them, they have similar texture, color, brightness. There are many methods for segmenting digital images, such as thresholding, splitting and combining, area expansion and edge detection. Each of them has the task of extracting objects from the background, but using different image processing algorithms results in completely different results. To do this, select the appropriate segmentation method for the display in order to obtain the desired final result of the object recognition.

Image segmentation by thresholding

It consists in determining the threshold T, which defines the value on the brightness scale of the image, on the basis of which an analysis of individual pixels of the image is carried out [11]. Pixels that meet the condition: $f(x, y) \geq T$ are an object and pixels that do not meet it are the background. The result of the threshold operation can be represented by the following function

$$g(x,y) = \begin{cases} 1 \; dla \; f(x,y) \geq T \\ 0 \; dla \; f(x,y) < T \end{cases} \tag{1}$$

where: $g(x, y)$ - area of the image, $f(x, y)$ - brightness of the pixel, T - set threshold or set value of brightness of the pixel.

When the threshold value is set for the whole image, it is called the global. However, if the threshold value depends on the spatial coordinates (x, y) of the image, then the given threshold is called the dynamically determined. There are also local thresholds. These are the thresholds that depend on both the image content and the additional criterion, which may be, for example, the average brightness of the image in a given area.

For the segmentation of color images based on a three-dimensional histogram, created from three color components, the two-level thresholding is used. In order to minimize the total error of segmentation of the image, threshold values should be chosen so as to obtain the smallest possible sum of the number of image pixels belonging to the object and associated with the background and the number of background pixels included in the object [1, 8, 10].

Image segmentation based on edge detection

The easiest way to detect simple shapes in an image (e.g. points, lines, edges) is to determine the correlation of the image with the detection mask. The most common are square masks with dimensions: 3×3 and 5×5. The edge in the image is the place where the brightness changes rapidly. The size of the mask and the value of its co-efficients depend on the type of shape being detected [12].

Most of edge detection methods are based on the determination of local image derivatives (so-called gradient operators). Therefore, in order to detect them, derivatives of functions that find sudden brightness jumps are often used. The basic properties of gradient operators are as follows:

- the first image derivative can be used for edge detection and its direction,
- the change point of the second derivative mark, i.e. the zero image location, can be used to determine the location of the edge occurrence.

The disadvantage of gradient operators is to emphasize impulse interference in images. It may cause deterioration of image quality or detection of false edges [8]. It should be noted that the derivative of the function is determined for continuous functions, and when working with digital images we deal with the discrete data. Therefore, a simple generalization of discrete functions should be constructed.

Let us assume the following one-dimensional function f, whose derivation is determined at the point x_0 from the formula [11]

$$\frac{\partial f}{\partial x}(x_0) = \lim_{h\to 0}\frac{f(x_0 + h) - f(x_0)}{h} \tag{2}$$

For digital images, the jump is made by h=1. With this assumption, we get the following relationship

(3) $$\frac{\partial f}{\partial x}(x_0) = f(x_0 + 1) - f(x_0)$$

We will similarly determine the second derivative (counting it from the first derivative) assuming that h=1

(4) $$\frac{\partial^2 f}{\partial^2 x}(x_0) = f(x_0 + 1) + f(x_0 - 1) - 2f(x_0)$$

For two-dimensional space, we define partial derivatives, which are described by the following relations:

(5) $$\frac{\partial^2 f}{\partial^2 x}(x, y) = f(x + 1, y) + f(x - 1, y) - 2f(x, y)$$

(6) $$\frac{\partial^2 f}{\partial^2 y}(x, y) = f(x, y + 1) + f(x, y - 1) - 2f(x, y)$$

The values of the first and second derivative of the function indicate the brightness of the pixels. They can be used to detect edges on images. The above-described methods using derivatives determine sudden changes in color, and hence the edge. This can be equated with finding the gradient of the function f given by the formula [11]

(7) $$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$

Using the gradient, the direction of the fastest brightness of the image is presented, and the angle of the gradient determines the speed of the gradient as follows

(8) $$\measuredangle = arctag\left(\frac{\partial f}{\partial x} \Big/ \frac{\partial f}{\partial y}\right)$$

The edge center point is selected for each point using the gradient orientation information. The gradient value of a given pixel is compared to the neighboring pixel gradient values. When it is smaller than them, the value for a given point is suppressed.

Laplace filter

This filter is based on the determination of second derivatives. In contrast to the first derivatives that are looking for places of rapid increase/decrease in brightness. The second derivatives focus on finding places of color changes. The Laplace algorithm uses the following relationship [12]

(9) $$\nabla f = \left[\frac{\partial^2 f}{\partial^2 x} + \frac{\partial^2 f}{\partial^2 y}\right]$$

To be able to perform an operation on the image, one of the following masks can be used [9]:

(10) $$L_1 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 0 \end{bmatrix}, \quad L_2 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 8 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

Canny's algorithm

The Canny's edge detection algorithm uses first- and second degree derivatives [12]. As a result, the direction and speed of gradient decrease is obtained. Canny's algorithm fulfills three assumptions:

- accurately locates points forming the edges,
- edges generated by this method have a thickness of one pixel,
- the number of false edge detection is minimized.

The most common method of edge detection is the use of a gradient operator. For digital images, this algorithm boils down to determining the differences between adjacent pixels.

The implementation of Canny's algorithm takes place in four stages [9, 10]:

1. Using the Gauss filter to smooth the image.
2. Calculation of the gradient value and direction for each pixel.
3. Reduce the edge thickness by reducing pixels with non-maximal values.
4. Making a threshold with hysteresis, which reduces the probability of detecting the false edges.

For processing of satellite images in the first phase, the noise is reduced using the Gauss filter. The value of parameter σ of the standard deviation is specified, on the basis of which the mask size is determined. The mask of this filter is described by the dependency[12]:

(11) $$G(t) = e^{\frac{\frac{-t^2}{2\sigma^2}}{2\pi\sigma^2}}$$

For σ = 0,5 a one-dimensional matrix is generated that is the following form:

(12) $$t = [-2 \quad -1 \quad 0 \quad 1 \quad 2]$$

The mask, which is an approximation of the expression (12) for σ = 0,5, is as follows [11]:

(13) $$G(t) = [0{,}0002 \quad 0{,}0862 \quad 0{,}6366 \quad 0{,}0862 \quad 0{,}0002]$$

Then, the algorithm determines the direction of the Gaussian derivative. This function is two-dimensional. The derivative along the axis x is found, and the derivative for the axis y is obtained by transposing the obtained result.

The Gauss function described above has the form [12]

(14) $$G(x, y) = -xe^{\frac{\frac{-(x^2+y^2)}{2\sigma^2}}{\pi\sigma^2}}$$

where x and y have the following values [12]:

(15) $$x = \begin{bmatrix} -2 & -1 & 0 & 1 & 2 \\ -2 & -1 & 0 & 1 & 2 \\ -2 & -1 & 0 & 1 & 2 \\ -2 & -1 & 0 & 1 & 2 \\ -2 & -1 & 0 & 1 & 2 \end{bmatrix}, \quad y = \begin{bmatrix} -2 & -2 & -2 & -2 & -2 \\ -1 & -1 & -1 & -1 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 2 & 2 & 2 & 2 & 2 \end{bmatrix}$$

The Gauss filter mask after the approximation of (14) has the following form [12]:

(16) $$G = \begin{bmatrix} 0{,}0000 & 0{,}0001 & 0 & -0{,}0001 & -0{,}0000 \\ 0{,}0001 & 0{,}0233 & 0 & -0{,}0233 & -0{,}0001 \\ 0{,}0009 & 0{,}1723 & 0 & -0{,}1723 & 0{,}0009 \\ 0{,}0001 & 0{,}0233 & 0 & -0{,}0233 & -0{,}0001 \\ 0{,}0000 & 0{,}0001 & 0 & -0{,}0001 & -0{,}0000 \end{bmatrix}$$

In the next phase, the algorithm performs an entanglement of the input image with the Gauss filter in two dimensions and determines the derivative of the Gaussian function. Thanks to the symmetry of this filter, the operations are simplified and can be brought to the weave with a one-dimensional Gauss filter along the lines and then along the columns and then we will get the final result.

The next stage of Canny's algorithm is the suppression of non-maximal pixels. It is based on finding the center point of the edge. As the center point of the edge, the pixel for which the gradient value will be maximal is considered. The remaining edge pixels are discarded. In this way, the goal of proposed algorithm, which is the edge thickness of one pixel, is achieved. The final stage of the algorithm is thresholding with hysteresis. It determines the detail of edge detection. It requires two input parameters, which are the T_W high threshold T_W and the low threshold T_N. For images subjected to gradient filtration, the points on the edge of the image are the brightest.

To unambiguously determine the points belonging to the edge, select the appropriate threshold value and perform the binarization operation. When the threshold value is chosen too low, the correct determination of the object edges will be disturbed by the noise and small features that intersect them. However, the selection of the too high threshold value results in edge divisions and will complicate further segmentation.

Laplacian of Gaussian algorithm

In the first phase of this algorithm, the output image is subjected to a knot with a Gauss filter, thanks to which the noise from the image is reduced. It is necessary to apply this operation, because then the used Laplace filter significantly amplifies the noise. The Gauss function has the form [12

$$G_1(x,y) = e^{\frac{-(x^2+y^2)}{2\sigma^2}} \tag{17}$$

where: σ - standard deviation in Gaussian distribution.

The weave operation of the above function was performed with a h mask about dimensions 5x5, which has the following form [11]

$$h = \begin{bmatrix} 0{,}0000 & 0{,}0000 & 0{,}0002 & 0{,}0000 & 0{,}0000 \\ 0{,}0000 & 0{,}0113 & 0{,}0837 & 0{,}0113 & 0{,}0000 \\ 0{,}0002 & 0{,}0837 & 0{,}6187 & 0{,}0837 & 0{,}0002 \\ 0{,}0000 & 0{,}0113 & 0{,}0837 & 0{,}0113 & 0{,}0000 \\ 0{,}0000 & 0{,}0000 & 0{,}0002 & 0{,}0000 & 0{,}0000 \end{bmatrix} \tag{18}$$

The image obtained in this way is processed using the mask L_1 for Laplace operator [11]:

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \tag{19}$$

The mask L_1 has the following form 11]:

$$L_1 = \begin{bmatrix} 0{,}3333 & 0{,}3333 & 0{,}3333 \\ 0{,}3333 & -2{,}6667 & 0{,}3333 \\ 0{,}3333 & 0{,}3333 & 0{,}3333 \end{bmatrix} \tag{20}$$

The next stage of the algorithm is the determination of zero places. It is made using the mask L_2 in the form [12]:

$$L_2 = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \tag{21}$$

It can be seen that the obtained edges in masks L_1 and L_2 are double. In order to remove this phenomenon, the image should be binarized with the threshold determined on the basis of the histogram.

A specialized Laplacian of Gaussian filter can be used for edge detection. Its operation is based on functions (17) and (19). Edge detection is performed using the Laplace operator, which changes the second derivative mark for the center point of the edge. The high frequency components are suppressed using the Gauss filter. As a result of applying these two algorithms we will get [12.

$$\nabla^2 G_1(x,y) = \frac{\partial^2 G_1(x,y)}{\partial x^2} + \frac{\partial^2 G_1(x,y)}{\partial y^2} \tag{22}$$

$$\nabla^2 G_1(x,y) = \left[\frac{x^2+y^2-2\sigma^2}{\sigma^4}\right] + e^{\frac{-(x^2+y^2)}{2\sigma^2}} \tag{23}$$

Expression (23) is called Laplasjan of Gaussian and is usually supplemented with the normalization factor: $1/(2\pi\sigma^2)$, which is responsible for the elements of the mask. The sum of all elements of this mask is 0.

The appropriate selection of thresholds used in the thresholding process with hysteresis is also important here, because for incorrectly selected values of these thresholds, the obtained edges do not maintain continuity.

Software application for image segmentation in recognition of digital satellite images

The comparison of the quality of image segmentation using these two algorithms was made using a specially developed computer application in the MATLAB environment. The main task of this application is the ability to determine from the area of the entire satellite imagery places where there are forests [2]. To achieve this goal the analyze the colors and the image segmentation is needed. Objects separated in this way will be highlighted in color. The application uses the automatic color segmentation in the space: L^*a^*b, Fig.1.

The following four stages are distinguished in the developed computer application [2]:

1. Downloading the selected satellite image to the program and then converting it from the RGB color space to the L^*a^*b [13] color space, which allows the visual differences between the different colors to be determined using specific values. This space consists of the brightness layer L, the chromatic layer *a* (indicating the color gradation along the red-green axis) and the chromaticity layer *b*, indicating the color gradation along the blue-yellow axis. All color information is in the layers *a* and *b*. The difference between colors is determined by the Euclidean distance measure.

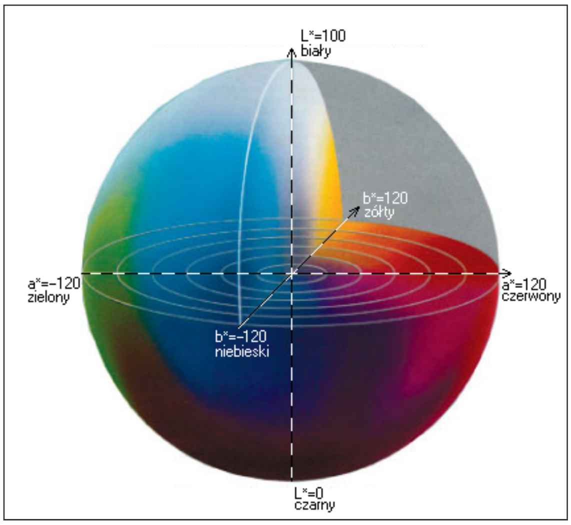

Fig.1. Graphic image of the model *L*a*b** [6, Rys. 3.2.7]

2. The division of colors in space a^*b into clusters using the *kmeans* function. Clustering is the method of dividing objects into clusters (groups) in such a way that objects located in one cluster will be located as close as possible to each other, and objects located in the different cluster as far as possible from each other [14]. The color information located in spaces a and b are grouped into three sets by means of the Euclidean distance measure [8]. The threshold value c should be appropriately selected, based on which the data is grouped in cluster and the number of duplicates of clusters divisions using the new initial positions.

3. Separation of the part of the image that interests us in a separate picture. You can see that there are dark and light green objects in satellite images that are found in one cluster. They can be separated using the layer L. The forests are dark green. The layer L contains the brightness values of each color. Then we find a cluster containing green objects, we extract the pixel brightness value in this cluster and perform a threshold operation with a global threshold on them. Areas designated in this way will be presented in the separate image.

Calculation results

Figure 2 shows the view of the interface for recognizing satellite images with the selected test image [2].

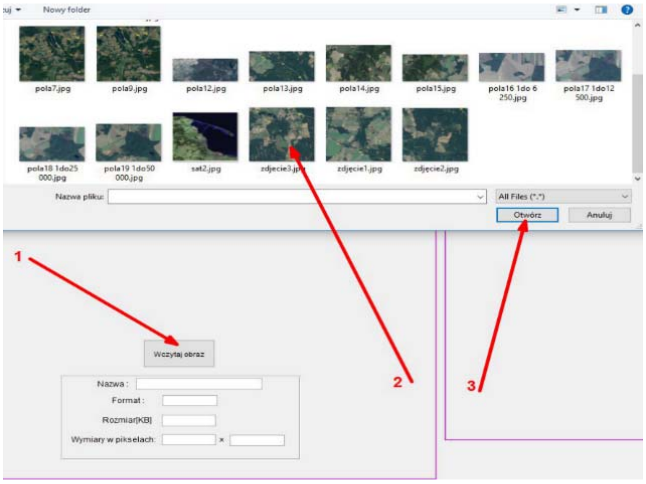

Fig.2. Image selection window

The second stage of the program is to process the loaded image after pressing the "select forests" button, (Fig.3). The resulting image loaded into the field on the right in Figure 4 is a comparison of the initial image with the image obtained as a result of the process of segmentation and separation of forest areas from the entire image [2].

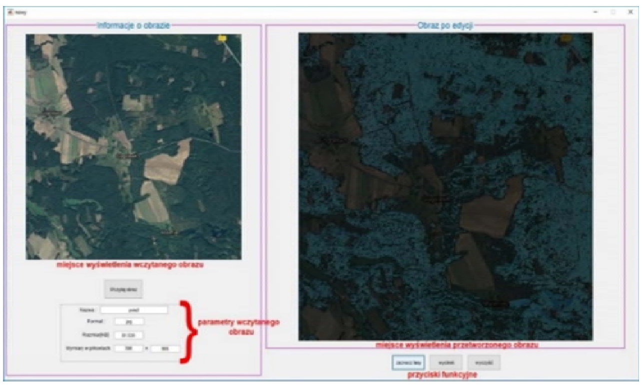

Fig.3. An interface view for recognizing satellite images

The final result of the program with marked forests and lakes is shown in Figure 4.

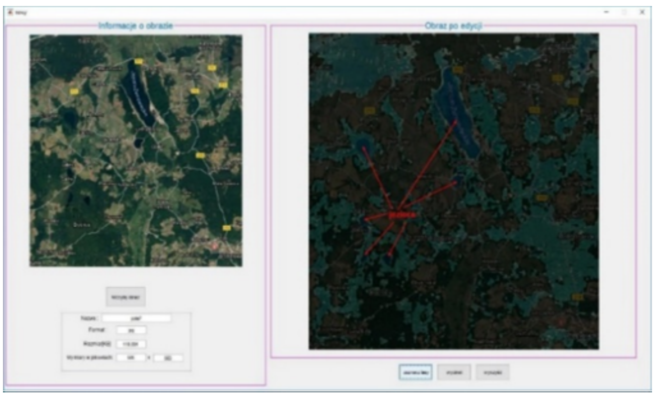

Fig.4. Image with marked forests and lakes

Conclusions

The article presents the method of detecting objects in satellite imagery. Its basis is the image segmentation. An important role in this algorithm is played the edge detection, and its effective operation should be pre-filtered.

For detection of objects in the satellite imagery, the better results from the Gauss filter were obtained for the Canny's algorithm. The edges detected by him are clear and thin, making the picture transparent. It is also characterized by the lower susceptibility to the impact of noise and thus is more likely to detect the image correctly than the Laplasian of Gaussian algorithm.

In recent years, the rapid development of various methods of processing digital images has been observed. More complicated methods of filtration and image processing by combining different methods, however, require devices with increasingly better parameters, which are characterized by faster information processing.

An important aspect during the extracting information from satellite imagery is also the resistance of this process to external factors. Therefore, it is important that the information obtained from the satellites is immune to interference. It is therefore necessary to direct the development of image processing also to the development of algorithms that are effective through the use, among others, filters with the better and better properties.

Authors:*dr inż. Jan Matuszewski, Wojskowa Akademia Techniczna, Wydział Elektroniki, Instytut Radioelektroniki, ul. gen. S. Kaliskiego 2, 00-908 Warszawa, E-mail: jan.matuszewski@wat.edu.pl*;

mgr inż. Marcin Zając, Wojskowa Akademia Techniczna, Wydział Elektroniki, ul. gen. S. Kaliskiego 2, 00-908 Warszawa, E-mail: avo0246@wp

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