*segmentation,*
*gradient methods,*
*polynomial approximation*

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# SEGMENTATION OF IMAGES USING GRADIENT METHODS AND POLYNOMIAL APPROXIMATION

The paper presents a method for segmentation of images using region growing, with modification through the use of a correction coefficient based on the variation of intensity (brightness) in the neighborhood of the pixel of the interest. A method for the quantification of variability is based on differences in intensity, as well as the differences in intensity gradients in the surrounding pixels [10]. Evaluation of the gradients were determined by means of numerical differentiation, using the polynomial approximation [11]. The article presents the effects of application of developed methods for segmentation of images of the brain, lungs and heart.

## 1. INTRODUCTION

The structures shown on the medical images are often characterized by a high degree of blurring which results in the separation of the two tissues is very problematic. There is a great need for proper and accurate separation particularly when object of interest is the neoplastic lesions. To obtain correct and accurate separation of diseased tissue from healthy, obtained during the test images are processed by a computer. The main tool is the segmentation, i.e. dividing the image into homogeneous, in terms of some established criterion, coherent areas associated with the objects presented in the image. Many segmentation algorithms are based on comparing the intensity (brightness) of the analyzed pixel with the global average intensity, which is too simple approach [7], [9]. The paper presents a segmentation algorithm using growth area and its modification based on the gradient method. The main task of the algorithm is to determine a pixel belonging to an object by comparing it with the average intensity of the pixels classified as an area, wherein the size of the acceptance interval is dependent on the intensity factor taking into account the variability of the environment. All image have been subject to segmentation in the Matlab environment. The region growing method requires specifying two parameters: the starting point, which is the initial object and the criterion of the proper intensity using during the process of adding new points (the homogeneity criterion was calculated based on seed points, previously provided by the user). It is also necessary to

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specify the type neighborhood for the pixels, which should be included in the desired object [3]. The method checks the point that is located the closest to the seed point. After the point is checked and it turns out that it has met the homogeneity criterion, it is added to the region of the verified object. In addition, applying a gradient-based methods of analysis are obtained derivatives of intensity values, which help to determine the intensity variation in the vicinity of the starting point. These methods are divided due to the row of derivatives that are used in the calculation. Most commonly used is a derivative of the first order, which assumes that the brightness of the point shown in the image is fixed [7]. In the gradient method the assessment of the intensity variation in the environment were considered as an indicator $||\widetilde{\nabla}||$ which is based on the values of the intensity gradients. In this case, there was exploited robust estimator using partial derivatives, aiming to reduce the impact of disturbances (noise). The estimator is based on an approximation of the intensity using polynomial of two variables, which derivatives are then determined symbolically. This leads to the square systems of linear equations of the exemplary dimensions: 3, 6, 10, 15, 21 and so on (depending on the degree of the approximating polynomial). For some degrees the paper presents symbolic design of the estimator $||\widetilde{\nabla}||$ depending on the radius surrounding the tested pixel.

The paper is divided into parts, which presents a method of region growing, the modification of the method using gradients and the results of exemplary image processing.

## 2. METHODS OF IMAGE SEGMENTATION

Among the different methods of segmentation two main group are [6], [8]:

- region growing methods, based on the similarities within regions, thereby providing a set of pixels with the same level of intensity,
- edge detection based on gradient method, a result of which it is received a set of edges across which the level of intensity of pixels is different.

During the analysis of medical images it is observed a similar degree of retention of X-rays on the surface of organs. And the emergence of varying intensity within one organ may suggest the presence of pathological changes. On the border of objects it can be observed change of photoelectric absorption, which is why there are large gradients of brightness [1]. This is a motivation for use the region growing segmentation methods with an additional criterion which takes into account value of the gradient of brightness, determined numerically in a neighborhood of the tested pixel. However, in many cases, the images containing artifacts (e.g. caused by the movement of the image-organ) is the phenomenon of "leak" that is incorrect, excessive assignment to the region pixels from outside. Inaccurate segmentation of the object is not a drawback of the method because the images from for example Computed Tomography scans one of the parameters of the image is the response function for a point source. This means that the object in the image, in fact, may be much smaller than that expected from the pictures. The degree of blurring of the object in the image is dependent on various factors [4]. Difficulties arising from the application of the criteria of gradient in image segmentation algorithms leads to modification of the methods of region-growing and to develop methods for the estimation of gradients, which are characterized by a higher robust to artifacts (noise and distortion) in the analyzed images [5].

### 2.1. METHODS USING REGION GROWING

The most common and also the simplest method of segmentation is thresholding using intensities (magnitudes, levels of gray) pixels of the image and is based on comparing their

values with a predetermined threshold value. The result of thresholding is a binary image with separate two areas, called the object and the background. But there are also more advanced thresholding techniques that result in extracting greater number of regions which is conceptually identical to the region growing (see Fig.1).
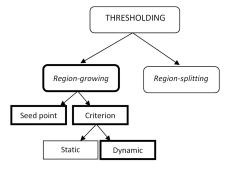


Fig. 1.    Different methods of thresholding.

The criterion for adding new pixels to the object can be called:
-   static, in which thresholding is performed with a fixed threshold;
-   dynamic, in which the intensity of the tested pixel is compared to the average intensity level of the region.

## 3.  PROPOSED ALGORITHM OF REGION GROWING METHOD

The proposed algorithm of region growing uses dynamic thresholding as an input parameter dynamic inclusion criteria pixels. By the fact that not all pixels are taken into account, and only those that have a certain level of intensity and surround the start point, time of the segmentation is reduced, and the object is precisely separated without the appearing the phenomenon of "leak". The start point is selected manually due to the need of identifying the appropriate level of intensity. For the analyzed images is used 4-neighborhood, which reduces the formation of the phenomenon of "leak". Proper selection of the input parameters determines correctly conducted segmentation. Execution region growing algorithm is divided into several stages: loading the image into the workspace, selecting the start point, performing image segmentation, displaying of the results obtained. The general idea of the algorithm is presented below.

**Step 1:** *Loading the image into the workspace*
The user can choose the type of image/sections, which are to undergo segmentation. Images for analysis should contain at least partially visible changes in the anatomical structures through which an indication of the starting point will be facilitated.

**Step 2:** *Selecting the start point*
The user indicates the point at the appropriate level of intensity (the start point) and he defines its coordinates.

**Step 3:** *Analysis of the start point*
In this step the start point is inserted on the front of the queue containing pixels of a appropriate level of intensity for further analysis. Next there are determined the extreme of intensity values (minimum and maximum) of the selected point and there level of intensity is compared with the pixel closest to the start point.

**Step 4:** *Analysis of the next point*

In this step it is checked whether the point has already been analyzed, if so back to **Step 3**, if not then:

- calculate the average intensity based on the intensity of the start point (average minimum and maximum intensity of the start point with new point),
- extension of the analyzed region of the 4-neighborhood (analyzed are start point with points contained in the 4-neighborhood),
- adding to the queue the pixel which has the appropriate level of intensity (the level of intensity is selected experimentally and the user may change the parameter values of the vector in algorithm),
- incrementing the counter of pixels, back to **Step 3**.

**Step 5:** *Obtaining a binary output image - the segmented image*

The algorithm is performed until all neighboring points are checked, so all points in the neighborhood of the seed point are verified. The points failing to meet the homogeneity criterion are not added to the region. After the verification process is completed, the images are displayed with the marked segmented region.

## 4. ROBUST METHOD OF GRADIENT ESTIMATION

The simplest, often used numerical method for determining the partial derivatives (i.e. components of the gradient) of the brightness of the test image consists in calculating the differences along a given coordinate, vertical or horizontal. This can be interpreted as a high-pass filtering operation, expressed by the mask with constants, depending on the square surrounding the analyzed pixel [11]. For example, the partial derivative with respect to the y (vertical coordinate) may be expressed by the following mask (expressed in matrix form):

$$\frac{3}{R(R+1)(2R+1)^2} \begin{bmatrix} R & \dots & R & \dots & R \\ R-1 & \dots & R-1 & \dots & R-1 \\ \vdots & \vdots & \vdots & & \\ 1 & \dots & 1 & \dots & 1 \\ 0 & \dots & 0 & \dots & 0 \\ -1 & \dots & -1 & \dots & -1 \\ \vdots & \vdots & \vdots & & \\ -R+1 & \dots & -R+1 & \dots & -R+1 \\ -R & \dots & -R & \dots & -R \end{bmatrix} \tag{1}$$

where $R$ is the radius of the square surrounding the pixel under test. Constant factor, common to all the elements of the matrix ensures the normalization of the resulting estimator of partial derivative. Similarly, the derivatives with respect to the x (horizontal coordinate) can be determined. But determining in this way has a relatively high sensitivity to noise in the test image and this is a motivated to develop a method which is a generalization of the above.

The general idea of the proposed methods for estimating the brightness gradient involves the determination of the polynomial of two variables which is an approximation of the brightness of the image in the vicinity of the test pixel:

$$g_A(x,y) = \sum_{\substack{i,j=0 \\ i+j \leqslant D}}^{D} a_{i,j} x^i y^j \tag{2}$$

where D is the degree of the polynomial, and its coefficients can be written in matrix form:

$$\mathbf{A} = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,D-1} & a_{0,D} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,D-1} & 0 \\ \vdots & \vdots & \ddots & 0 & 0 \\ a_{D-1,0} & a_{D-1,1} & 0 & \ddots & \vdots \\ a_{D,0} & 0 & 0 & \cdots & 0 \end{bmatrix} \tag{3}$$

Without loss of generality it can be assumed that the tested pixel is located at the origin, and the coordinates of pixels in its surroundings have indices varying from $-R$ to $+R$. The next step is to determine the function – approximation criterion [10], which will allow the numerical evaluation of the polynomial coefficients.

$$\mathbf{S} = \begin{bmatrix} s_0^2 & s_1 s_0 & s_0 s_1 & \cdots & s_D s_0 & \cdots & s_0 s_D \\ s_1 s_0 & s_2 s_0 & s_1^2 & \cdots & \vdots & & \vdots \\ s_0 s_1 & s_1^2 & s_0 s_2 & \cdots & & & \\ \vdots & \vdots & \vdots & \ddots & & & \\ s_D s_0 & \cdots & & & s_{2D} s_0 & \cdots & s_D^2 \\ \vdots & & & & \vdots & \ddots & \vdots \\ s_0 s_D & \cdots & & & s_D^2 & \cdots & s_0 s_{2D} \end{bmatrix} \tag{4}$$

It is worth noting that the $S$ matrix inversion operation is performed only single time, once the parameters of the method (the degree of the approximating polynomial and the square of the window) are fixed. For each pixel it is only required to evaluate the vector that depends on the brightness of pixels in its neighborhood, and the calculation of the respective products of the matrix. This allows for shortening time implementation of the proposed method, without the need for explicit determination of all the coefficients of the approximating polynomial. Moreover, for polynomials of degrees 1 and 2, obtained estimates of partial derivatives are identical with the simplest method of the mask represented by formula 1. However, for a polynomial of degree 3 it yields the method which is an important generalization of simple high-pass filtering. In this case, the $S$ matrix has a dimension of 10 and takes the following form:

$$\mathbf{S} = \begin{bmatrix} s_0^2 & 0 & 0 & s_2 s_0 & 0 & s_0 s_2 & 0 & 0 & 0 & 0 \\ 0 & s_2 s_0 & 0 & 0 & 0 & 0 & s_4 s_0 & 0 & s_2^2 & 0 \\ 0 & 0 & s_0 s_2 & 0 & 0 & 0 & 0 & s_2^2 & 0 & s_0 s_4 \\ s_2 s_0 & 0 & 0 & s_4 s_0 & 0 & s_2^2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & s_2^2 & 0 & 0 & 0 & 0 & 0 \\ s_0 s_2 & 0 & 0 & s_2^2 & 0 & s_0 s_4 & 0 & 0 & 0 & 0 \\ 0 & s_4 s_0 & 0 & 0 & 0 & 0 & s_6 s_0 & 0 & s_4 s_2 & 0 \\ 0 & 0 & s_2^2 & 0 & 0 & 0 & 0 & s_4 s_2 & 0 & s_2 s_4 \\ 0 & s_2^2 & 0 & 0 & 0 & 0 & s_4 s_2 & 0 & s_2 s_4 & 0 \\ 0 & 0 & s_0 s_4 & 0 & 0 & 0 & 0 & s_2 s_4 & 0 & s_0 s_6 \end{bmatrix} \tag{5}$$

## 5. RESULTS OF PROPOSED METHOD

For the segmentation process was used images available in the database of medical images EURORAD. Mainly segmentation was subjected to images of changes in the structures of the brain, but to compare the results of the algorithm were also performed experiments on the

images presenting the structures of the heart and lungs [2]. The analyzed images were:

- made during the MRI scan, showing the structures of the brain (the pictures present poorly visible subacute hematoma located in the rear of the brain), Fig.2a;
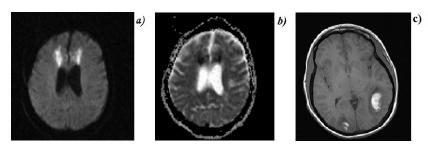


Fig. 2.   Haemorrhagic transformation in preeclampsia.

- made during the HRCT scan, showing the structures of the lung with fibrotic changes, Fig.3a;
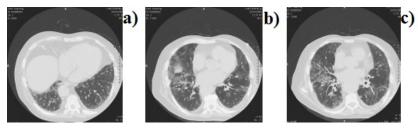


Fig. 3.   Methotrexate-affected lungs in the case of rheumatoid arthritis.

- made during the study contrast-enhanced CT showing pericardial effusion, Fig.4a.
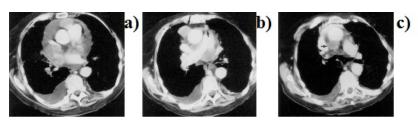


Fig. 4.   Metastatic tumor of the heart.

On available images changes in the structures are hardly visible, so there was decided to use the segmentation method to check how visibility of the diseased tissues will be improved.

## 6.  ILLUSTRATION OF THE EFFECTS OF PROPOSED METHOD

The aim of the applied algorithm was accurate segmentation of objects visualized on medical images from computer tomography examination and magnetic resonance imaging. For each type of images it were obtained different results, this is related to the intensity of pixels to the different layers of images. Images that show minor changes in the structure were subjected to segmentation several times to verify the correctness of the algorithm and comparing the results. During the experiments did not change the parameters: the counter of pixels and neighborhood, because in previous analyzes have been checked and typed values that bring the best results. Below are the results of segmentation region growing method and gradient method for each image.

The result of segmentation changes in the brain shows Fig.5. The figure presents images of the same structures obtained during segmentation by region growing and with gradient method. It can be observed that the use of gradient method for segmentation of poorly visible elements give better results, the pixels are precisely classified and the object does not contain extra pixels.
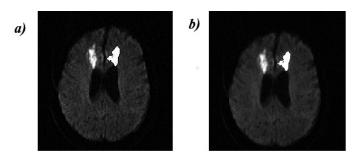


Fig. 5.   The brain segmentation using a) region growing method and b) gradient method.

Similar effects as in the case of segmentation changes in the brain are obtained during segmentation fibrous changes in lungs (see Fig.6). The region is precisely specified.
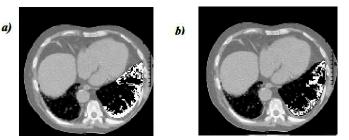


Fig. 6.   The segmentation of fibrotic changes in the lung using a) region growing method and b) gradient method.

Changes in the heart are small therefore in the process of segmentation it was necessary to accurately indicate the start point, that is why the process of segmentation in this case was carried out several times. As seen in Fig.8 obtained results are satisfactory.
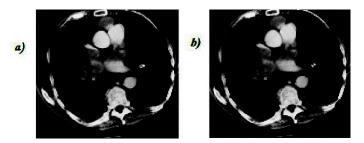


Fig. 7.   The segmentation of changes in the heart using a) region growing method and b) gradient method.

Presented algorithm is based on an analysis of the gradient surrounding the evaluated pixel. It is worth remembering also that depending on the classification of the pixel as located at the edge between two objects or not it is an increase or decrease in the acceptance intensity pixel interval. Where a pixel is treated as located inside the object the interval can be much larger. Obtained region increases with an increase in the acceptance interval. Segmentation was successful for all test rounds. Using gradient method the tumor region was isolated and its boundaries were precisely marked. Region growing method and gradient presented in article was also compare with standard segmentation method. Using standard method with 8-neighborhood appear d'ż″pixel overflowd'ż″ outside the tumor region, Fig.8.
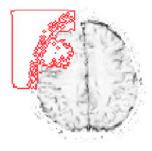
Fig. 8. Pixel overflow.

## 7. Summary

The region growing method and gradient method enables precise tumor segmentation; however, the selection of an appropriate homogeneity criterion is a prerequisite for correct segmentation. As a result both of the algorithm application it was obtained relatively correctly segmented regions which provide information about the size and location of the analyzed object. Condition of correct segmentation is to choose an appropriate criterion of homogeneity. When the algorithm uses the method of region growing combined with the gradient method, it works relatively correctly. The accuracy of the segmentation process depends on the accuracy of the selection criterion for the homogeneity and the quality of images prepared for analysis.

Images of segmented objects with gradient method give good prognosis for the future, in the absence of the need for mathematical morphology operations for final processing of the image. In result of the algorithm application user obtain a homogeneous areas, which do not have additional pixels that are often mistakenly classified during the use of other methods of segmentation.

In the future, it is planned to perform a quantitative statistical analysis determining the effectiveness of the method consisting in identifying the pixels which are correctly assigned to the object and which not, including the pixels which are classified as "leak" and which in general have not been taken into account in the process segmentation. The obtained results are good, but further study is needed to improve the accuracy of the algorithm.

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