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Measuring methods of objects in CT images

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Abstract:
The problem of object's measuring in computer tomography requires the detection of object's edges. Usually, it is performed by operator, who picks the edge's points. This fact implicates the doubts for measuring accuracy and repeatability as well as the comparison possibility with another measuring results, obtained by another operator. The paper presents the analysis of automated edge detection methods and the application proposal of the method, which detects the edges by direct lamination analysis.

Introduction

Measuring of objects in computer tomography images is one of the essential element for the diagnostic procedure estimation. This element is important, when the variability of anatomical structure dimensions is required. It is performed during analysis of the illness process dynamics or the treat effectiveness. The measuring accuracy is very important in the science study because it is the base for the analyses and the conclusions. The fundamental task in described situations is accurately detection of the anatomical structures' borders. Partial volume artifact makes the borders' detection hard difficult, because the elements have not the clear edges. The measurements are done by the operator, who picks the edge points – it is the reason of measuring errors; the measuring results cannot be compared with other results, which was done by second operator.

The paper presents the analysis of the automated edge detection methods in computer tomography images and proposes the method, which is free of the described above faults.

Methods for edge detection

The notion "object's edge" is not precisely defined. We can tell, that it is the part of image with suddenly change of the lumination. Basing on above definition, the jump model of edge can be presented [11,21] (fig.1).

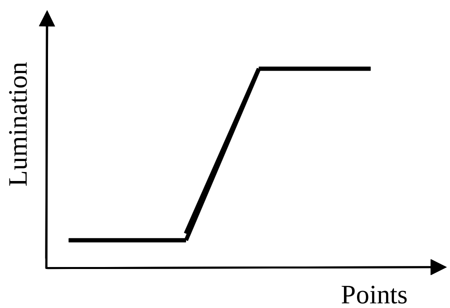

Fig.1. The jump model of edge

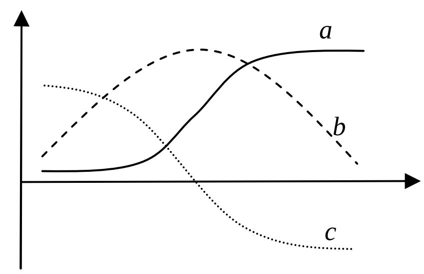

Fig.2. The umination (a), the first (b) and the second (c) derivates

The object’s edge can be defined by the first and the second derivates [11,14,21] (fig.2) – the edge is defined by maximum of the first derivate or the root of the second derivate.

Binarization

The typical solution of edge detection is using the binarization method [14], which requires the value of threshold. The binarization operation changes the greyscale image $L(x,y)$ into black and white (binary) image $B(x,y)$. The threshold value t defines the borderline.

$$B(x,y) = \begin{cases} 1, & L(x,y) > t \\ 0, & L(x,y) \le t \end{cases} \quad (1)$$

a) b)

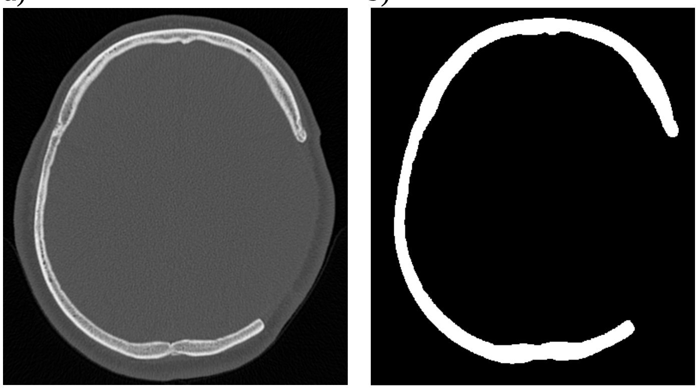

Fig.3. The human skull’s CT image (a) and the result of binarization (b)

All points with lumination less then threshold are changed to black and other points will be white. In this case the white shape in the binary image represents the digitized object. In the next step the shape’s edge have to be found. It can be done by one of the image analysis method – the thinning [14](fig.3, fig.4). The binarization is popular, simple and easy to use method of edge detection (e.g. in computer programs for analysis of CT images) but it has some faults. The binarization requires the threshold value, which can be arbitrary defined by an operator or it can be computed by one of the algorithms for automatic threshold finding (e.g. gradient analysis, clustering, entropy, metric, intervariance, Otsu [8,14]).
The described methods are global, that means they analyse the whole image. So, we can find the local methods (Bernsen, Chow and Kaneko, Eikvil [14]) which divide image into the subimages and choose the threshold for the each subimage.
The binarization method is sensitivity to local changes of edge’s lumination, so potentially it generates the errors of edge detection.

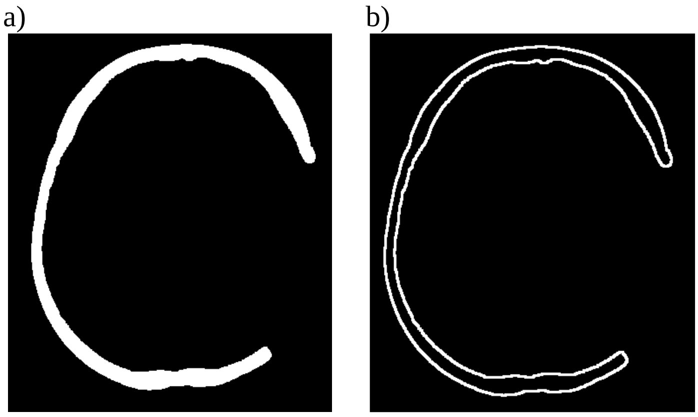

Fig.4. The results of binarization (a) and thinning (b) operations

Gradient filters

Another way for edge detection is using the gradient filters [14] (e.g. Sobel or Prewitt). The gradient filters analyse the changes of points' lumination in the image and change the greyscale image into another greyscale image which shown the lumination gradient (fig.5).

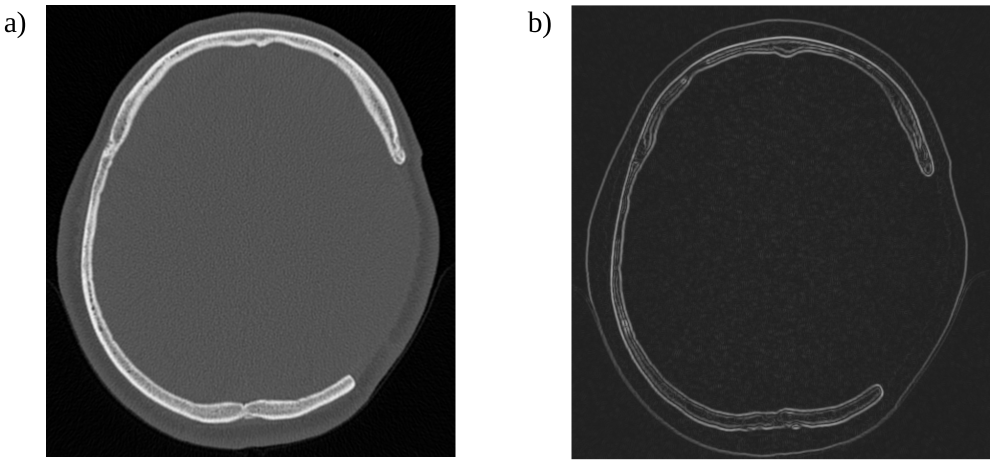

Fig.5. The human skull's CT image (a) an application of the Prewitt filter (b)

The image filtering can be described as the convolution of the image and the filter function [14,19]. In practice, the analog convolution is described as discrete convoluting of image $L(x,y)$ and the convolution kernel $K(x,y)$.

The popular convolution kernel is the 3 x 3 matrix [8]:

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

When the neighborhood of analyzed point is described as:

$$L = \begin{bmatrix} L(x-1, y-1) & L(x, y-1) & L(x+1, y-1) \\ L(x-1, y) & L(x, y) & L(x+1, y) \\ L(x-1, y+1) & L(x, y+1) & L(x+1, y+1) \end{bmatrix} \quad (3)$$

than the point's lumination after filtering is defined as:

$$L'(x,y)=\frac{1}{r}\sum_{\substack{i=x-1\ldots x+1\\ j=y-1\ldots y+1}} K(i,j)L(i,j) \qquad (4)$$

Factor r is used for image normalization. The normalization is required, because the solution of the product sum must be the value in range [0, 2^b-1] – b is the resolution of image lumination.
The gradient filters enable the directional filtering. The Prewitt and Sobel convolution kernels for detecting a horizontal and vertical edges are described below [8]:

Prewitt $$K_{horizontal}=\begin{bmatrix}1 & 1 & 1\\ 0 & 0 & 0\\ -1 & -1 & -1\end{bmatrix} \text{ and } K_{vertical}=\begin{bmatrix}-1 & 0 & 1\\ -1 & 0 & 1\\ -1 & 0 & 1\end{bmatrix}, \qquad (5)$$

Sobel $$K_{horizontal}=\begin{bmatrix}1 & 2 & 1\\ 0 & 0 & 0\\ -1 & -2 & -1\end{bmatrix} \text{ and } K_{vertical}=\begin{bmatrix}-1 & 0 & 1\\ -2 & 0 & 2\\ -1 & 0 & 1\end{bmatrix}. \qquad (6)$$

The above kernels can be compared – it gives a chance for finding the edges in various directions [8]:

- Prewitt:

$$\begin{aligned}L'(x,y)=\max\big[&|L(x+1,y-1)-L(x-1,y-1)+L(x+1,y)-L(x-1,y)+\\ &+L(x+1,y+1)-L(x-1,y+1)|,\\ &|L(x-1,y+1)-L(x-1,y-1)+L(x,y+1)-L(x,y-1)+\\ &+L(x+1,y+1)-L(x+1,y-1)|\,\big]\end{aligned} \qquad (7)$$

- Sobel:

$$\begin{aligned}L'(x,y)=\max\big[&|L(x+1,y-1)-L(x-1,y-1)+2L(x+1,y)-\\ &-2L(x-1,y)+L(x+1,y+1)-L(x-1,y+1)|,\\ &|L(x-1,y+1)-L(x-1,y-1)+2L(x,y+1)-\\ &-2L(x,y-1)+L(x+1,y+1)-L(x+1,y-1)|\,\big]\end{aligned} \qquad (8)$$

The main problem in using of gradient filters is the fact, that they do not create the 1-point edge of object, but they show areas for future edge detection.

Canny edge detector

The method for edge detection, which creates the 1-point edge basing on the lumination gradient analysis, is the Canny edge detector [3,4], so it means, that it is free from faults of the binarization and the gradient filters. Unfortunately, usually the Canny edge detector creates non-closed edges (fig.6).

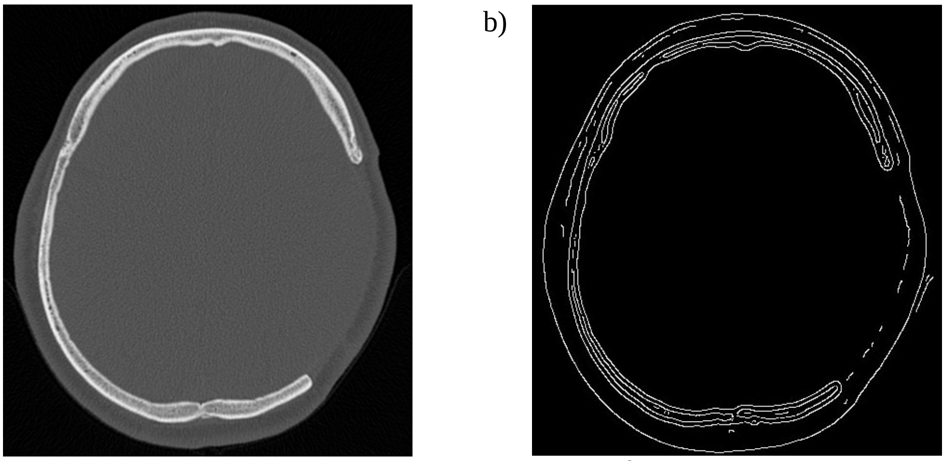

Fig.6. The human skull's CT image (a) an application of the Canny edge detector (b)

Another edge detectors

We can find another methods for edge detection, too.

Shih and Zhang [17] write, that an active contour model, called snake, can adapt to object boundary in an image. A snake is defined as an energy minimizing spline guided by external constraint forces and influenced by image forces that pull it toward features such as lines or edges. They present an improved snake model associated with new regional similarity energy and a gravitation force field to attract the snake approaching the object contours efficiently.

Pardo et al. [16] describe a deformable contour method for the problem of automatically delineating the external bone contours from a set of CT scan images. They introduced a new region potential term and an edge focusing strategy that diminish the problems that the classical snake method presents when it is applied to the segmentation of CT images.

Yuan and Li [22] describe a new method for edge detection based on directional space. The principle of method is that: firstly, the directional differential space is set up in which the ridge edge pixels and valley edge pixels are abstracted with the help of the method of logical judgments along the direction of differential function, forming a directional roof edge map; secondly, step edge pixels are abstracted between the neighboring directional ridge edge and directional valley edge along the direction of differential function; finally, the ridge edge map, valley edge map and step edge map gained along different directions are combined into corresponding ridge edge map, valley edge map and step edge map.

Wang and Wang [20] present an image edge detection method based on multi-fractal spectrum. The coarse grain Holder exponent of the image pixels is first computed Then, its multi-fractal spectrum is estimated by the kernel estimation method. Finally, the image edge detection is done by means of different multi-fractal spectrum values. Simulation results show that this method is efficient and has better locality compared with the traditional edge detection methods such as the Sobel method.

Nezamabadi et al. [15] proposed an edge detection method, which uses the ant colony search. The problem is represented by a directed graph in which nodes are the pixels of an image. To adapt the problem, the authors applied some modifications on original ant colony search algorithm (ACSA).

He and Zhang [5] propose a new edge detection algorithm for image corrupted by White-Gaussian noise that can reasonably consider White-Gaussian noise reduction and correct location of edge, and provides its specific arithmetic process.

Yuksel [23] describes a neuro-fuzzy operator for edge detection in digital images corrupted by impulse noise. The proposed operator is constructed by combining a desired number of neuro-fuzzy subdetectors with a postprocessor. Each neuro-fuzzy subdetector in the structure evaluates a different pixel neighborhood relation.

Lu et al. [13] present a fuzzy neural network system for edge detection and enhancement. The system can obtain edges and enhance edges by recovering missing edges and eliminate false edges caused by noise.

Hu et al. [7] show an edge detector based on fuzzy If-Then inference rules and edge continuity. The fuzzy If-Then rule system is designed to model edge continuity criteria. The maximum entropy principle is used in the parameter adjusting process.

Heric and Zazula [6] present an edge detection algorithm, using Haar wavelet transform and signal registration.

Sun et al. [18] describe the original method for edge detection which based on the law of universal gravity. The algorithm assumes that each image pixel is a celestial body with a mass represented by its grayscale intensity. Accordingly, each celestial body exerts forces onto its neighboring pixels and in return receives forces from the neighboring pixels. These forces can be calculated by the law of universal gravity. The vector sums of all gravitational forces along, respectively, the horizontal and the vertical directions are used to compute the magnitude and the direction of signal variations. Edges are characterized by high magnitude of gravitational forces along a particular direction and can therefore be detected.

Diao et al. [2] propose an edge detection scheme which is deduced from Fresnel diffraction. Analysis shows that Fresnel convolution kernel function performs well on edge enhancement when images are transformed into complex functions. Due to its mathematical complexity, the method is simplified into a linear convolution filter. The new edge detector is designed based on the simplified linear filter. Experimental results indicate that the new detector gives quantitative results equal to the Canny detector while it is more simple to be implemented.

Edge detection by directional lumination analysis

Most methods described above are used for edge detection in image, but the image analysis finishes the process – it means, that the result of edge detection is not used for preparing the model of object, which is acquired in the image. This process is not enough in reverse engineering. The author proposes the using of the edge detector, which is proven in manufacturing processes during the measuring of the objects. This edge detector is implemented in Vision module of LabView system [8].

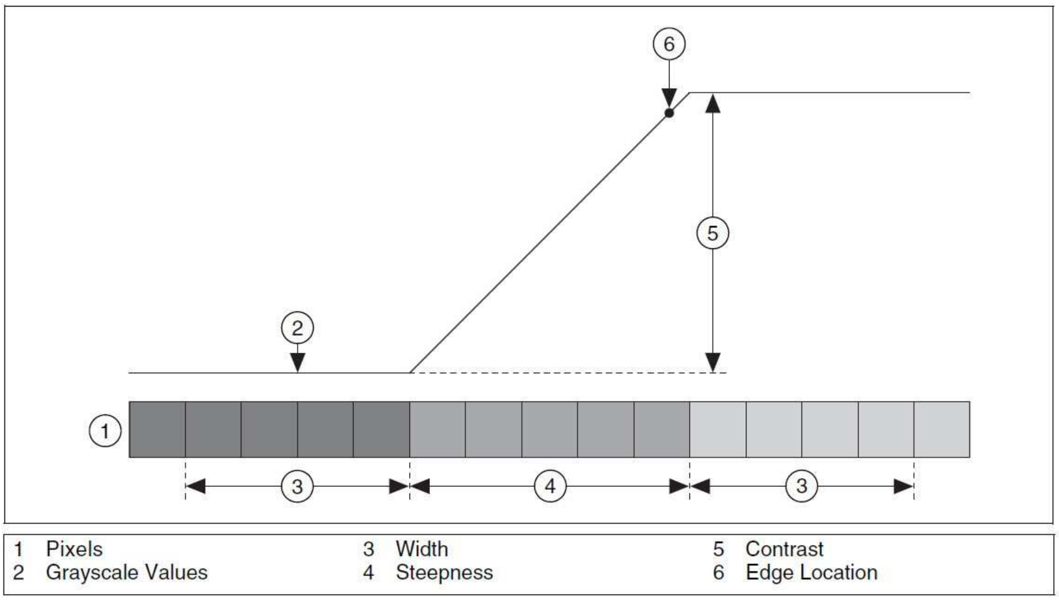

Fig.7. The schema of edge detection [8]

To find the edge, the detector scans across the 1-dimensional grayscale profile pixel by pixel. At each point, the edge strength, or contrast, is computed. If the contrast at the current point is greater than the user-set value for the minimum contrast for an edge, the point is stored for further analysis. Starting from this point, successive points are analyzed until the contrast reaches a maximum value and then falls below that value. The point where the contrast reaches the maximum value is tagged as the start edge location. The value of the steepness parameter is added to the start edge location to obtain the end edge location. The first point between the start edge location and end edge location—where the difference between the point intensity value and the start edge value is greater than or equal to 90% of the difference between the start edge value and end edge value—is returned as the edge location (fig.7). To compute the edge strength at a given point along the pixel profile, the detector averages pixels before and after the analyzed point. The pixels that are averaged after the point can be a specific pixel distance from the point, which can be defined by setting the steepness parameter. This number corresponds to the expected transition region in the edge profile. Additional parameter of the detector is the width parameter – it is the number of pixels averaged on each side. After computing the average, the detector computes the difference between these averages to determine the contrast. Filtering reduces the effects of noise along the profile.

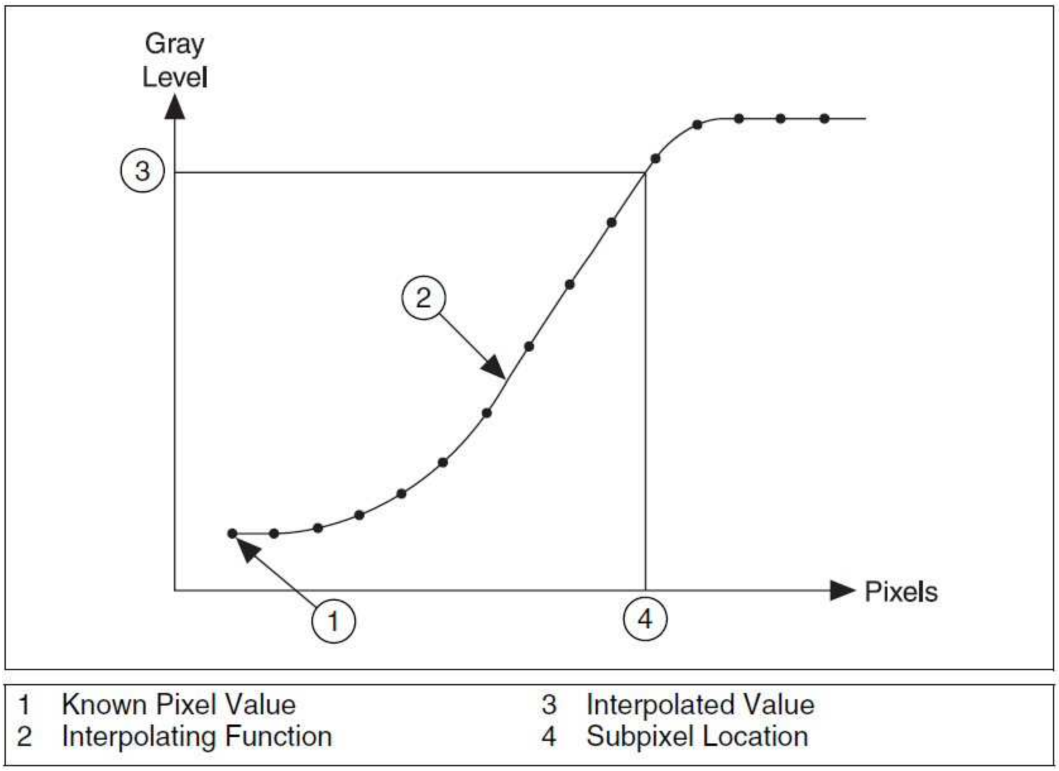

Fig.8. Obtaining subpixel information using interpolation [8]

When the resolution of the image is high enough, most measurement applications make accurate measurements using pixel accuracy only. However, it is sometimes difficult to obtain the minimum image resolution needed by a machine vision application because of the limits on the size of the sensors available or the price. For example, in the computer tomography the typical image resolution is 512 x 512 points. In these cases, we need to find edge positions with subpixel accuracy. Subpixel analysis is an algorithm that estimates the pixel values that a higher resolution imaging system would have provided. To compute the location of an edge with subpixel precision, the edge detector first fits a higher-order interpolating function, such as a quadratic or cubic function, to the pixel intensity data. The interpolating function provides the edge detection algorithm with pixel intensity values between the original pixel values. Then the algorithm uses the intensity information to find the location of the edge with subpixel accuracy.
Figure 8 illustrates how a cubic spline function fits to a set of pixel values. Using this fit, values at locations in between pixels are estimated. The edge detection algorithms use these values to estimate the location of an edge with subpixel accuracy.

The described methods can be used for measuring of the object in CT images.
The directional edge detector analyzes the 8-bits images (256 lumination levels). It means that the 8-bits lumination must be substituted by 12-bits Hounsfield scale. So, the presented algorithm analyzes the results at CT reconstruction in full 12-bits scale – not the windowed images, which are manually measured by an operator.
The figure 9 shows the brain tumour and the measuring method. The operator have to outline the direction of lumination analyses – the detection of tumour edges is realised automatically by special software, which was constructed using LabView enviroment [12].

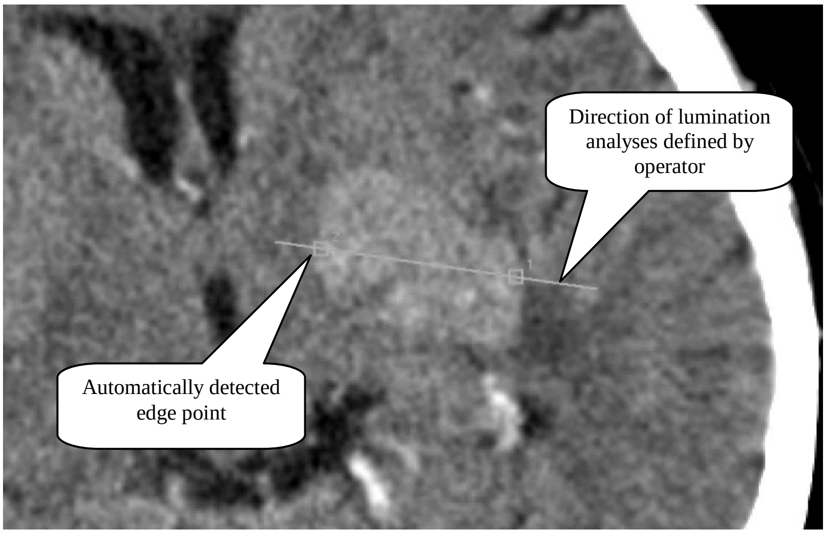

Fig.9. Brain tumour measuring. Algorithm parameters: width=4; steepness=3; contrast=40;

The presented algorithm was tested by authors for detecting of the skull's edges [1,9,10,24]. The edge detecting results gave a chance for building the medical models of the skulls. This models were used for preparing the craniofacial prosthesis for cranioplasty.

Conclusions

A one of the fundamental requirement for the measuring methods is the repeatability of results. The described algorithm eliminates the operator in the edge detection process, which is realized automatically – it provides the repeatability of results. The lumination analyses is worked out in the full Hounsfield scale – not in 256 greyscale, which can be projected in the computer display.

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