EDGE DETECTION IN REVERSE ENGINEERING SYSTEM

Krzysztof Karbowski

Summary

The paper characterizes the methods of edge detection in the images, which can be used in the reverse engineering system. The method of edge detection by the directional illumination analysis has been shown. Described method is used in the reverse engineering system for preparing the models of the human skulls with holes after the craniotomy, and for designing the skull's prosthesis for cranioplasty surgical operations.

Keywords: reverse engineering, edge detection

Detekcja krawędzi w systemie inżynierii odwrotnej

Streszczenie

W pracy przedstawiono metody detekcji krawędzi obiektów na obrazach, mające zastosowanie w systemie inżynierii odwrotnej. Omówiono oryginalną metodę detekcji krawędzi, wykorzystującą kierunkową analizę gradientu luminancji. Metoda ta jest stosowana w systemie inżynierii odwrotnej w medycynie do wykonywania modeli czaszek pacjentów, poddanych zabiegowi kraniotomii. Pozwala również przygotowywać protezy kości czaszki do zabiegu kranioplastyki.

Słowa kluczowe: inżynieria odwrotna, detekcja krawędzi

1. Introduction

The reverse engineering technology gives the tools to construct the object basing on the material model – without traditional design [1]. The paper presents the one of the aspects in the reverse engineering – reconstructing the object based on the series of computer tomography (CT) images. The main problem in this reconstruction is initial process in the reverse engineering. The typical solution of edge detection is using the binarization method [2], which requires the value of threshold. In binarization the original grey level image is changed from a continuum of colours or grey level into black-and-white image by assigning to each pixels a value of black or white. The threshold value defines the borderline. All points with illumination less then a certain threshold are

Address: Krzysztof KARBOWSKI, D.Sc. Eng., Cracow University of Technology, Production Engineering Institute, Al. Jana Pawła II 37, 31-864 Kraków, phone: +48(12)6283247, fax: +48(12)6482010, e-mail: karbowski@mech.pk.edu.pl

changed into black, however 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 [2] (Fig. 1). The binarization is popular, simple and easy to use method of edge detection 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, inter-variance, Otsu [2, 3]). The binarization method is prone to local changes of edge's ilillumination, so potentially it may generates the errors of edge detection.

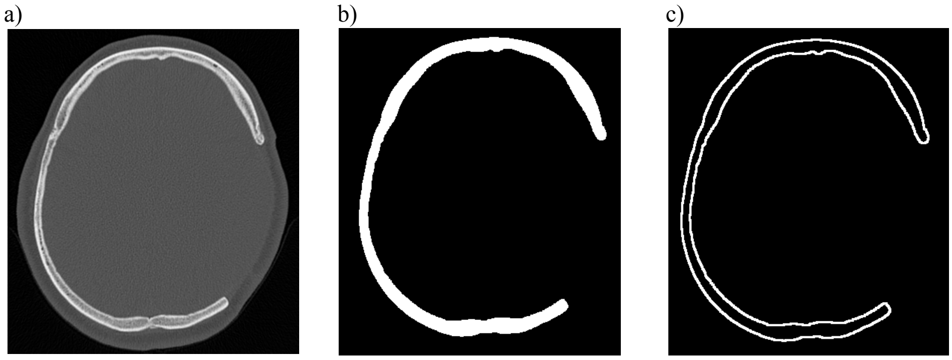

Fig. 1. CT Image of a human skull after: a) binarization, b) and c) thinning process

Another way for edge detection is using the gradient filters [2] (e.g. Sobel or Prewitt). The gradient filters evaluate the changes of points' illumination in the image and change the greyscale image into another greyscale image which shown the illumination gradient (Fig. 2). The main problem with using gradient filters is that they do not create the 1-point edge of object, but they show areas for future edge detection.

The method for edge detection, which creates the 1-point edge based on the illumination gradient analysis, is the Canny edge detector [4]. It means, that it is free from errors of the binarization and the gradient filters. Unfortunately, usually the Canny edge detector creates non-closed edges (Fig. 3).

Shih and Zhang [5] 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.

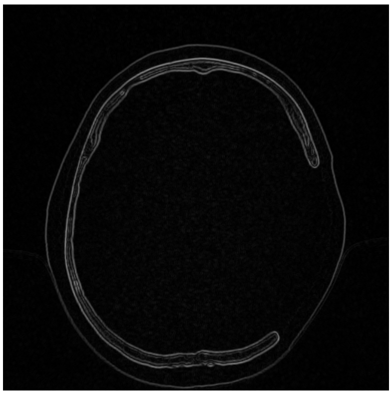

Fig. 2. The Prewitt filter application

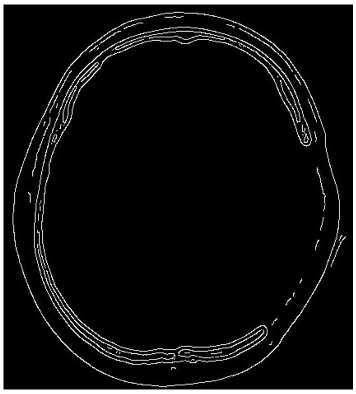

Fig. 3. The Canny edge detector application

Pardo et al. [6] 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 [7] describe a new method for edge detection based on directional space. The principle of method is: 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 [8] 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 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. [9] 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 [10] 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 [11] 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. [12] 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. [13] 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 [4] present an edge detection algorithm, using Haar wavelet transform and signal registration.

Sun et al. [15] 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. [16] 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.

2. Edge detection by directional ilillumination 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 approved in manufacturing processes during the measuring of the objects. This edge detector is implemented in Vision module of LabView system [3].

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. 4). 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.

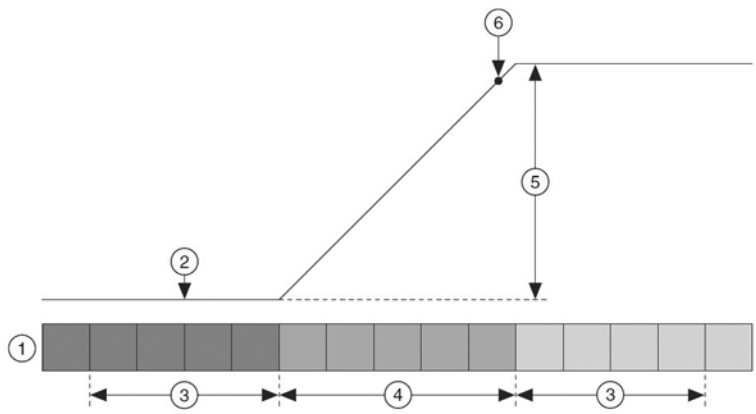

Fig. 4. The schema of edge detection [3]: 1 – pixels, 2 – grayscale values, 3 – width, 4 – steepness, 5 – contrast, 6 – edge location

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 5 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.

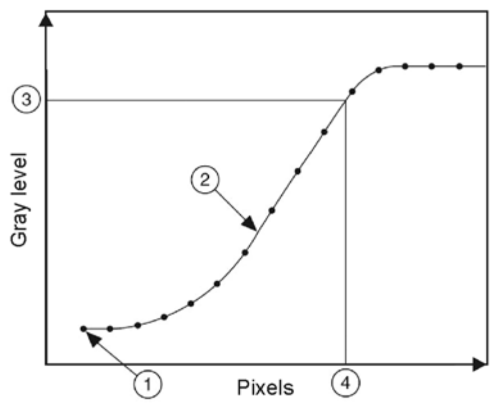

Fig. 5. Obtaining subpixel information using interpolation [3]: 1 – known pixel value, 2 – interpolating function, 3 – interpolated value, 4 – subpixel location

The described algorithm is used in industry but it has the one serious inconvenience, which keeps using it for edge detection of irregular object, like skull's bones – this algorithm requires the direction of vector for illumination analysis [17]. This fact entails necessity of preparing an algorithm for automatically computing of lines, which will be used for directional illumination analysis and edge detection. This algorithm has been worked out by author and it is described below (Fig. 6).

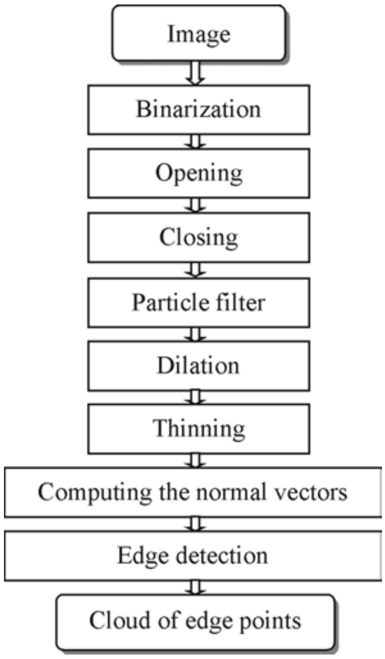

Fig. 6. Algorithm of edge detection

The binarization computes the first choice of object, which edges will be detected (Fig. 7). The next three steps ("open" and "close" and particle filter [3] which removes groups of points with small area) are the operations of image

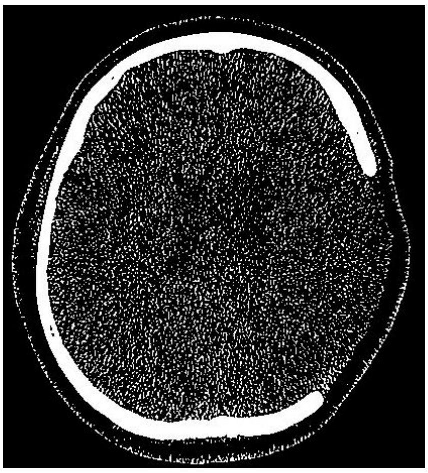

Fig. 7. The CT image after binarization

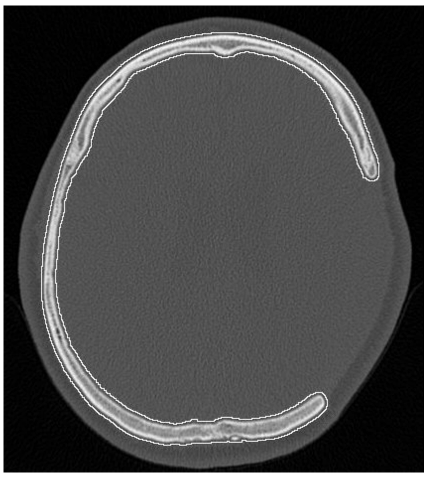

Fig. 8. The CT image with the shape's edge

analysis methods and they transform the binary image which has undesirable points or the holes in binary shape. Transformation, which is named "Dilation" [3], enlarges the binary shape. It assures, that the analyzed object is inside the binary shape. The thinning operation computes the edge of the binary shape (Fig. 8).

The shape's edge is used for computing the normal vectors, which are the lines for illumination analysis – along this lines, the algorithm described earlier detects the edge and creates the cloud of edge's points. This cloud is used in the computer aided design system (CATIA) for preparing the virtual model of the skull.

3. Accuracy of edge detection

The accuracy of edge detection has been estimated by using the special fantom, which was made with the polyvinyl chloride (Fig. 9). The fantom was scanned by the multislice computer tomography Siemens Sensation 10. The CT images has been transformed by the special software, which implements the algorithm described in the previous chapter. The maximum deviation between the nominal diameter and detected edge's points was 0.67 mm.

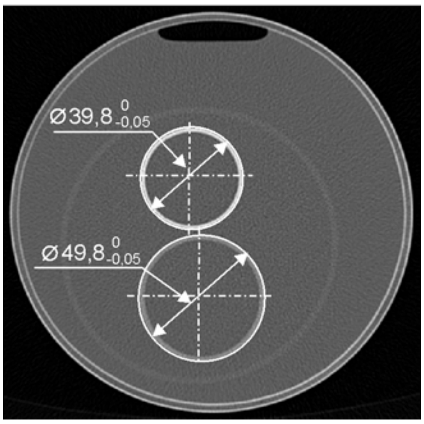

Fig. 9. The CT image of fantom

Fig. 10. The model of the hole in skull

The second test of edge detector has been done, too. The model of the real hole in the skull has been made (the 3-axis milling center has been used), basing on the computer tomography images (Fig. 10). This model was scanned by CT apparatus and the CT images of model have been transformed by edge detector. The result of transformation has been used for preparing the virtual model. In the next step the filling of the hole has been designed and made. The filling has been placed into the hole in model and the maximum gap between model and filling has been measured – this distance was 0.7 mm, but the filling has been designed with the clearance 0.2 mm between hole and filling.

5. Conclusions

The described edge detector has been positive verified in medical applications and it is used for preparing the prosthesis for surgical operation, which require the filling of the skull's holes (Fig. 11, 12).

Fig. 11. The model of skull's hole with the prepared prosthesis

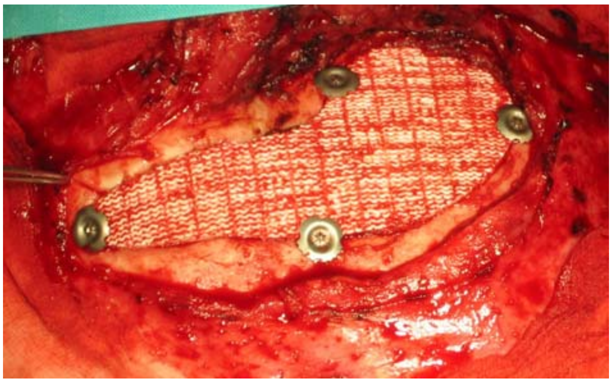

Fig. 12. The cranioplasty surgical operation

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