in the following point, corners less than $\pi/2$ prevail, or vice versa. This depends on distinction of brightness of image's points. Thus there is a double allocation of edges, which allow estimating this brightness differentiation. Furthermore due to application proposed method we can enhance the fine details which not visible on originals (Figs.5d). A little gap may occur in saddle points vicinities during processing fine objects. To overcome this drawback we can directly refer these points to the segmented objects.

Another example of proposed image transformation application is analysis of the cracking degree at the interior surface and outside of the input water economizer collector into the steam-boiler (Fig. 5e, 5f). In this case the important role belong to the quality of cracks allocation, because theirs position is crucial for state analysis [11]. For that purpose we use thresholding for previously segmented image. The application of well-known techniques as method of k-means, maximum of histogram variation, maximum of histogram entropy don't permits to gain suitable results. That's why we employed heuristic method, which compare transformed pixel intensity, mean intensity and standard deviation of image intensities. Also it includes parameter, which can be modified by user. As shown in Fig. 5f such approach can specify practically all cracks` situated on the image.

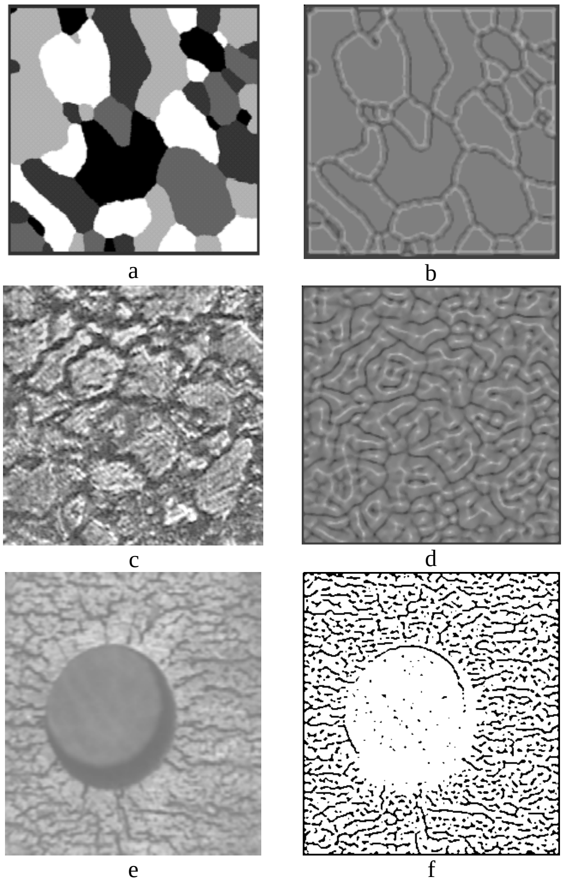


Fig. 5. Simulation of proposed method on real images. (a) processed image of aluminum microstructure, (c), (e) steel microstructure, (b), (d),(f) – application results

## 4. Conclusions

In this paper a novel method for image segmentation using local classification of surfaces on the basis of normal vectors arrangement in image point vicinity is outlined. In contrast to traditional approaches, which based on establishing curvature in point, proposed one express the local surface shape as some integral estimate of relative position of normal vectors.

The application of proposed technicks for some syntetic and real images is shown. Also it is necessary to note that the proposed method is the most suitable for segmentation of thin objects, for instance: roads on landscape images, blood vessels on medical images, etc.

## 5. Acknowledgment

This research has been partially funded by grant of NASU for youth scientist research.

## 6. References

[1] J. Bigun, G. Granlund, and J. Wiklund, "Multidimensional orientation estimation with application to texture analysis and optical flow", **IEEE Trans. on PAMI**, Vol. 13, No. 8, 1991, pp. 775-790.

[2] D. Eberly, R. Gardner, B. Morse, S. Pizer, and C. Scharlach, "Ridges for image analysis", **Journal of Mathematical Imaging and Vision,** No. 4, 1994, pp. 353-373.

[3] J. M.Gauch, S. Pizer, "Multiresolution analysis of ridges and valleys in gray-scale images", **IEEE Trans. on PAMI.,** Vol. 15, No.6, 1993, pp. 635-646.

[4] R.M. Haralick, L.T. Watson, T.J. Laffey, "The topographic primal sketch ", **Int. J. Robot Res**, No 2, 1983, pp. 195-217.

[5] J. J. Koederink, A.J. Doorn, "Surface shape and curvature scales ", **Image Vis. Comput.** , Vol.10, No. 8, 1992, pp. 557-562.

[6] D. Lloret, J. Serrat, A. M. López, J. J. Villanueva. "Ultrasound to Magnetic Resonance Volume Registration for Brain Sinking Measurement", in Proc. **IbPRIA 2003**, Mallorca, Spain, 2003, pp. 420-427

[7] A.M. Lopez, F. Lumbreras, J. Serrat, J. Villanueva, "Evaluation of methods for ridge and valley detection ", **IEEE Trans. on PAMI,** Vol. 20, No.4, 1999, pp. 327-335.

[8] L. Silva, O. Bellon, P. Gotardo, "Edge-based image segmentation using curvature sign maps from reflectance and range images", in Proc **IEEE Int. Conf. on Image Processing**, Thessaloniki, Greece, 2001, pp. 730-733.

[9] P. Sukanya, R. Takamatsu, Sato Makoto, "Multiscale image analysis through the surface-shape operator", **Journal of Electronic Imaging,** No 3, 2000, pp. 305-316.

[10] J. A.Torpe, **Elementary topics in differential geometry**, New York: Heidelberg - Berlin: Springer - Verlag, 1979.

[11] Kosarevych R. J., Student O. Z., Onyschak J.D., Markov A.D., Ripej I.V., Rusyn B.P., Nykyforchyn H.M."The estimation of thermofatigue cracks damage of the water economizer collector", Physicochemical Mechanics of Materials, No.1, 2004, pp.109-114.

vectors in point vicinity. This correspondence must be expressed as some integral estimate of relative position of normal vectors. On the contrast of shape operator, which calculates the change of normal vectors in the direction of tangent vector, we take into account positioning of normal vectors in point vicinity.

Consider the point vicinity in image plane and vectors directed from bottom of the vicinity to it center (Fig.2).

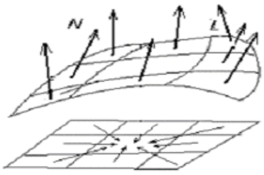


Fig. 2: Normal vectors *N* and vectors directed to vicinity center.

Further make the parallel shift of normal vectors along vertical axe to this vicinity. Now we can take into account the values of the angels between normal vectors and those one from the plane.

The sum of angels among vectors is chosen as a feature for surface shape. In other words, the following transformations are applied to input image *F*: $f(x,y) \rightarrow g(x,y) = \sum_{j=1}^{k} Arc\cos\psi_j$ , where *f(x, y), g (x, y)* - brightness of the initial and transformed images respectively, $\psi$ - a corner between the vector of a normal in the point and the vector directed to the vicinity center. On the basis of such transformation it is possible to offer the following local classification of surfaces: we will interpret the neighborhood of points as part of a plane, if $\left|\sum_j \psi_j - 4\pi k\right| < thr, \psi_j \in O(f(x,y))$, *thr* - some threshold, *k*- depends on vicinity size. The surface in points vicinity is convex if $\forall j \in O(f(x,y)) \quad \psi_j > \frac{\pi}{2}$ on the contrary - concave if $\forall j \in O(f(x,y)) \; \psi_j < \frac{\pi}{2}$ , where *O (f (x, y))* - vicinity of point *f (x, y).*

It is possible to explain applications of such transformation by the following reasons. Let us consider a point of an image which brightness is maximal in some local area, which means that it is on the top of convex part of surface. It is easy to see that normal vectors will be located under corners greater than π/2 to vectors from the plane at this point vicinity. In case when the point has the minimal value of brightness, these normal vectors will be located under corners lesser then π/2. The point of surface can be characterized as saddle in case when normal vectors form angles simultaneously grater and lesser then π/2 in opposite directions in point vicinity. Therefore, the sum of such corners can characterize the form of a local part of a surface.

The substantial role in proposed method belongs to the size of point's vicinity. On the basis of conducted study the most suitable result was obtained in case when the sizes of vicinity and object are commensurable quantities. Also investigated that preferable size of Gaussian window must twice exceed the object's size.

The mentioned above vectors from plane vicinity have dimension of $R^2$. The researches carried on the use of vectors with dimension of $R^3$ yielded less satisfactory results. It is possible to explain this by the fact that in this case values of corners between of normal vectors and vicinity vectors will be close to π/2 which will not allow to characterize the form of a surface.

## 3. Application

The application of proposed transformation on synthetic images is shown in Fig 3. On image 3a is shown homogeneous background and darken spots randomly placed on it. Conversely on image 3b spots are brighter then background. On figs. 3c and 3d the transformed images are shown. As we see proposed transform could enhance the image.

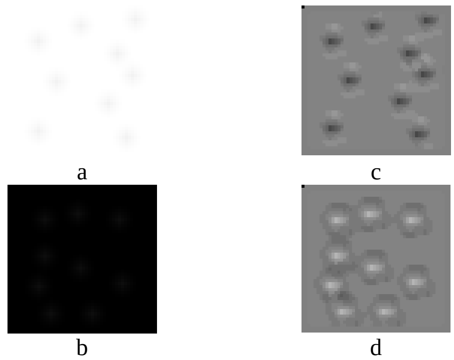


Fig 3. Simulation of proposed method on synthetic images. (a) homogeneous background with darker spots, (c) homogeneous background with lighter spots, (b), (d) – application results.

With purpose to compare proposed method with one known [6] we apply it for MR image. Figure 4 compare obtained results. The elapsed CPU time for result shown on Fig. 4b in a 200 MHz PC Pentium Pro with 64 MB of RAM under Linux OS is about 10s [6]. For our result (Fig. 4c) elapsed CPU time in a 233 MHz PC Pentium Pro with 40 MB of RAM under Windows-98 OS is about 5s.

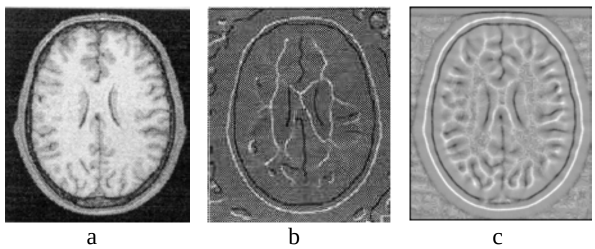


Fig. 4. (a) 256×256 MR slice, (b) result obtained in [6], (c) result gained via proposed method.

On figure 5 are shown result of adaptation of proposed method on some real images. The segmentations' results shown on Fig. 5b illustrate that by the proposed method is possible to achieve as edges allocation, and in addition to estimate the level of brightness of segmented areas. Because of rapid change of brightness on borders of flat regions in the points vicinity initially corners greater than π/2 prevail, than,

# Image Segmentation Using Local Classification Of Surfaces On The Basis Of Normal Vectors Arrangement In Point's Vicinity

*Rostyslav Kosarevych*•, *Bohdan Rusyn*•, *Andrij Markov*♦, *Oleksandra Student*♦

•Department of Methods and Systems of Images Processing, Analysis And Identification
♦Department Of Corrosion And Hydrogen Degradation And Protection Of Materials
Karpenko Physics-Mechanics Institute of NAS of Ukraine
kosarevych@ipm.lviv.ua

## Abstract

In this paper a novel approach to characterize of surface shape in local area is presented. In contrast of well-known curvature settle features our classification based on analysis of arrangement of normal vectors in point vicinity. We establish that the sum of corners wich form by normal vectors and another one from image plane could characterize the shape of surface.

## 1. Introduction

In most computer vision application, image segmentation constitutes a crucial initial step before performing high-level tasks. The image model underling some image segmentation methods considers images as the sampling of a smooth manifold. Objects shown on images are treated as ridge/valley structures (lines in 2D, lines and surfaces in 3D) by this approach [2], [3], [5]. It allows applying the apparatus of differential geometry to construction the points' attributes. The decision on belonging of an image's point to the object is made on the basis of these features. One of the most useful for its invariance properties is that based on the level set curvature.

It is well known [3] that negative minima of the level curve curvature *k*, level-by-level form valley-likes curves and positive maxima ridge-like curves. They are characterized by the following local test: $e = \nabla k \cdot \mathbf{v} = 0$, where $\nabla e \cdot \mathbf{v} < 0$, $k > 0$ means ridge-like, *v*- is the level curve tangent and $\nabla e \cdot \mathbf{v} > 0$, $k < 0$ means valley-like. In [7] it is shown that values of curvature in surfaces point are equal to calculation divergence of normalized gradient vector field in point's neighborhood. In [4] it has been discussed in the context of the Hessian matrix and directional derivatives that the eigenvalues of the Hessian corresponds to the principal curvatures of surface. On the basis of these eigenvalues also the so-called surface shape operators are proposed [8,9] which allow classifying a point of a surface.

Formal definition of the shape operator is based on the analysis of change of normal direction $N$ on oriented $n$ - surfaces $L \subset R^{n+1}$. Linear function $S_p$: $L_p \to L_p$, where $L_p$ - tangent space, measures speed of turn $N$ passing through a point $p$ along any curve belonging to a surface. Tangent space comes back simultaneously with turn of normal $N$ thus it is possible to interpret $S_p(v)$ as a measure of turn tangent space passing through $p$ along a curve. As a result, $S_p$ contains the information about the form of surface $L$ near point $p$ [10].

Above-mentioned approaches for curvature calculation require the analytical description of a surface. Nevertheless, in case of images we have their discrete model, therefore for construction of attributes it is necessary to use numerical methods or other rough calculations. It results in increase in errors and as consequence necessity of application of additional means for improvement of results, which inevitably evoke increases of time expenses for processing. For example in [7] to increase the degree the collapse/repulsion of gradient vectors used the so-called structure tensor, which is well known tool for analyzing oriented textures [1].

Therefore, the investigation of other possible ways to characterize the form of discretely set surface is desirable. In this paper the novel approach for surface shape characterization is proposed. Our suggestions are based on the local analysis of the direction of surfaces' normal vectors in point's neighborhood.

## 2. Method

For this purpose firstly we smooth the image by convolving it with Gaussian. Therefore we can treat the image as approach of smooth surface. The following stage consist in construction of normal vectors at each point of image surface. For this objective we generate two sets in the vicinity of the every image point.

From elements of one we consistently get out three points for construction of the equation of the plane they belong to, and elements of the other are used for establishing an absolute error between image surface and the constructed plane (Fig.1). The plane for which the calculated error is the least is considered as the surface's tangent plane in this point. On the basis of the equation of this plane the normal that is considered as normal to a surface of the image in a point is created. We choose two vectors $v_1$, $v_2$, which belong to this plane and by the expression $N = \frac{v_1 \times v_2}{|v_1 \times v_2|}$ obtain the normal vector.

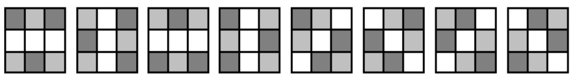

Fig.1. Some possible sets of points for tangent plane construction.

The next stage consists of establishment of conformity between the shape of a surface and arrangement of normal