Optica Applicata, Vol. XXIX, No. 4, 1999

Method for extraction of a characteristic feature of a contour image

TADEUSZ NIEDZIELA, ARTUR STANKIEWICZ, RADOSŁAW SZYMCZAK

Institute of Technical Physics, Military University of Technology, ul. Kaliskiego 2, 00–489 Warszawa, Poland.

MIROSŁAW ŚWIĘTOCHOWSKI

Physics Faculty, University of Warsaw, ul. Hoża 64, 02–093 Warszawa, Poland.

A method for extraction of a set of invariant characteristic features is proposed and examples of its application are presented in the paper. The image features are connected with angles between arbitrary line segments — the fragments of the contour. The information of spatial orientation of contour segments is obtained from the behaviour of the image gradient on the contour. The angles between segments are calculated by means of operations on the histogram of contour angles.

1. Introduction

Each process of recognition leading quantitatively to identification must be based on earlier extraction of parameters characteristic of the effect being recognized, the so-called characteristic features. The problem of extraction of characteristic features in images is a wide field of image processing and its solutions have numerous applications.

Characteristic features are a set of parameters on the basis of which unambiguous identification is possible. In many cases, however, unambiguous identification is impossible and recognition of images resolves itself to identification with a parameter determining the probability of identification accuracy. These cases include identifications based on small amount of data. Recognition of an object in a two-dimensional image is an example of such a situation. A 2D image contains significantly less information about the object than its 3D image. Thus, it is necessary to introduce the identification with an inaccuracy of the result obtained.

The method proposed in this paper allows extraction of characteristic features of 2D images of objects. The initial point is detection of the object's shape in the image, *i.e.*, determination of its borders or contour [1]–[9]. The contour should be thin (one-pixel wide) to determine unambiguously the border of the object's shape. The method for extraction of characteristic features (histograms of mutual angles of objects as an autocorrelation of histograms of absolute angles of contour line segments) is based on the use of the contour image and is presented in detail in the further part of this paper.

The shape of an object is related to angles between its contour segments as well as proportions of lengths of these segments. The operation of translation or scale variation does not lead to variation in the inclination of the contour line in relation to an arbitrarily chosen system of coordinates. Also, the relative angles of the contour line do not vary since their elements are invariant. In the case of rotations, the variation in inclination of each line of the object being rotated is the same and the relative angles are invariant. This means that these parameters are invariant in relation to rotation operations in the image plane, a change of scale and translation. Therefore they fit ideally as sets of characteristic features for identification of flat images of objects.

The method presented here is based on extraction of mutual angles between contour segments. The remaining problem is how to extract these parameters. One method consists in using the image gradient at the points of contour occurrence. When an adequate method for contour extraction is selected, the image gradient will be perpendicular to the contour line. An example of such a method is contour extraction in the gradient points of inflexion [10]. With simultaneous smoothing of the image, the contour obtained is almost perpendicular to the gradient. A minute error of not-keeping the perpendicularity between the contour and the gradient is negligible taking into account that recognition of the most interesting objects (disguised) is performed most often on noised and disturbed images introducing much bigger error.

2. Idea of the method for extraction of invariant characteristic features

The set of invariant characteristic features of objects assumed in the method is a set of histograms of mutual angles of contour segments. The mutual angle is understood as inclination between two elements of the contour. After the mutual angles have been determined for the entire image, its quantization is possible.

The mutual angle is calculated as a difference of inclinations of two segments of the contour. The inclination angle of the contour segment is approximated by the inclination of the image gradient vector at a given point which is almost perpendicular to the contour, especially in the methods smoothing the image and searching for the contour on the basis of gradient behaviour.

The contour segment inclination is calculated at each point of contour occurrence. The calculation of the inclination angle is performed using the arc tangent function of the quotient of component values of the gradient. The angle calculated in such a way is included between $-\pi/2$ and $\pi/2$ due to the central symmetry of the tangent function. However, the information about the direction of the gradient is lost, which is a desired effect since we are interested only in the inclination angle but not in the gradient orientation.

It is more comfortable to quantize, first of all, the values of absolute angles of inclination of the contour by building a histogram of absolute angles and next creating the histogram of mutual angles. In such a situation, the creation of mutual angle histogram is a result of autocorrelation of the absolute angles histogram.

One should keep in mind that the domain of a histogram is an angle. Thus, calculation of autocorrelation is performed with an introduction of the angle of rotation of the histogram in relation to itself.

To illustrate the idea of the method, a simple example (a low-noised object) is provided. Figure 1 presents two images which, during contour extraction, give two arms, each located at the same angle. The images are rotated with respect to each other and have different lengths of the arms as well as different locations of vertices of angles.

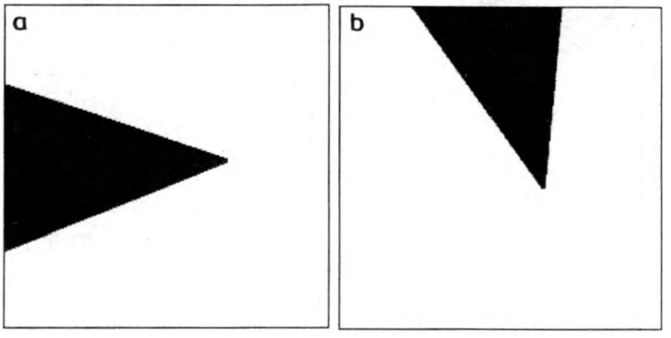

Fig. 1. Images of object of equals angles.

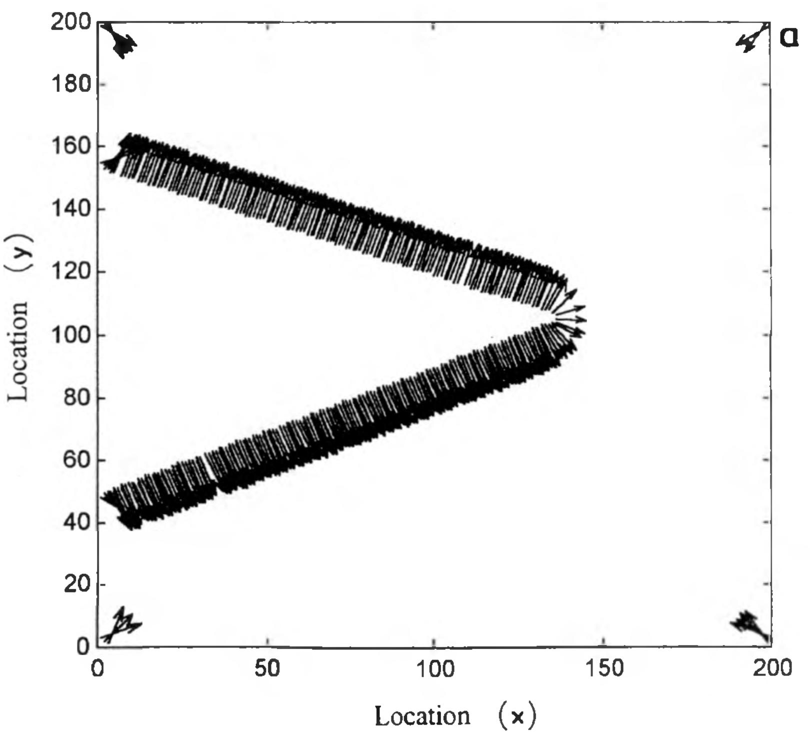

Fig. 2a

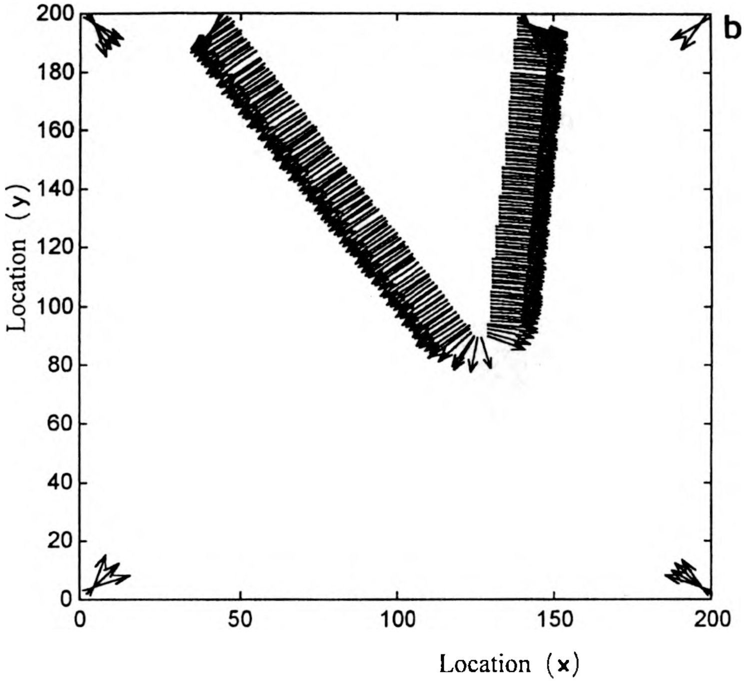

Fig. 2b

Fig. 2. Gradient on a contour of smoothed images from Fig. 1 in the points of contour detection. **a** — gradient from Fig. 1**a**, **b** — gradient from Fig. 1**b**.

Figures 2 **a** and **b** illustrate the gradient on the contour from smoothed images together with its directions marked in the image contour points. The gradient vectors have been obtained by the convolution of the image with derivative of a Gaussian function, due to which the gradient vectors seen belong to the gradient field of the image smoothed in a Gaussian way (convolution with a Gaussian function).

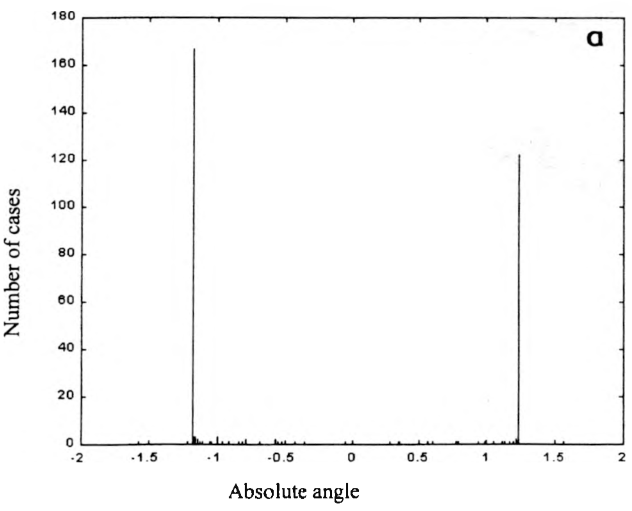

Fig. 3**a**

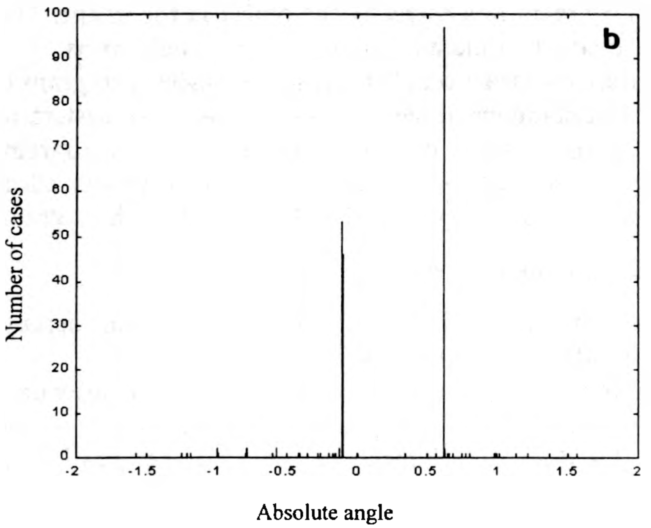

Fig. 3b

Fig. 3. Histograms of absolute angles. **a** — histogram from Fig. 2**a**, b — histogram from Fig. 2**b**.

Figures 3 **a** and **b** present histograms of absolute angles and Fig. 4 shows histograms of mutual angles.

As has been expected, the histogram of mutual angles in both figures has its peak at the same place. This means that in spite of image rotation, image shift and scale

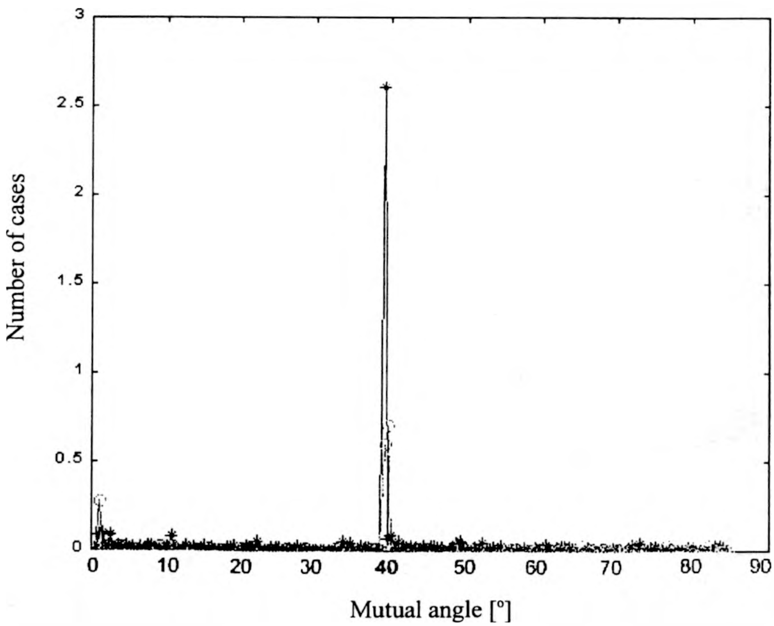

Fig. 4. Histograms of mutual angles. Respective points in the histogram are marked with * and ∘.

change, the histogram obtained characterizes correctly the object in the image. The differences in the peak height relate to different lengths of the angle arms.

Some problem occurring during construction of the absolute angles histogram is the image discretion, which, at simultaneous application of the Cartesian system of coordinates, causes the distinguishing of some contour fragments in the histogram. The consequence is anisotropy of the method's operation. To remove the effect mentioned, one should introduce adequate weights to the absolute angles histogram. The weight $\left(\frac{1+\sin^2(2\alpha)}{2}\right)^{1/2}$ is used in the paper.

The type of weight depends on the method for contour extraction and, thereby, on the way of determining the adjacent contour points.

The application of the method proposed in a more complex example is presented in Figs. 5–7. One can see a weakening of object characteristic peaks due to the presence of clutter. However, this does not change the fact that the location of characteristic peaks is invariant.

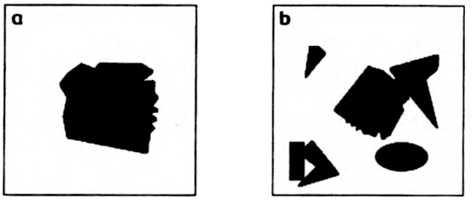

Fig. 5. Presentation of a sample object as well as an identical object reduced and rotated. a – sample object, b – identical object reduced and rotated.

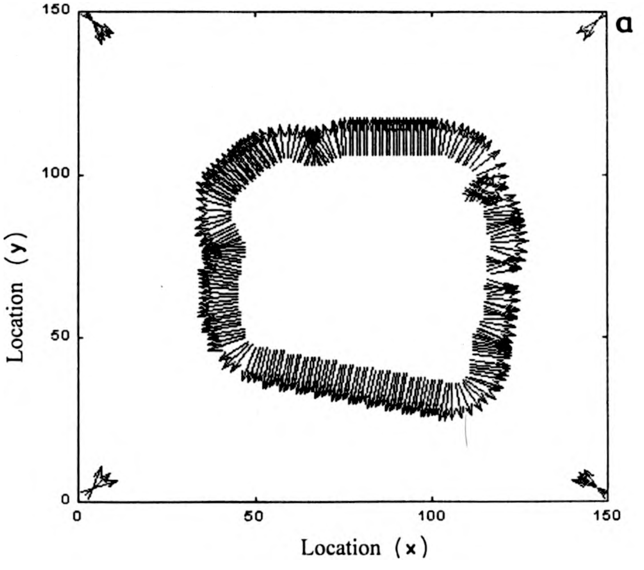

Fig. 6a

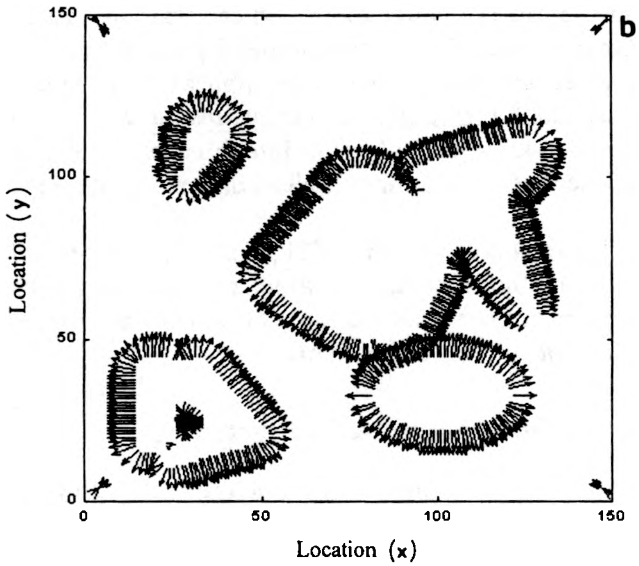

Fig. 6b

Fig. 6. Gradient image in the places where contour of objects from Fig. 5 occurs. **a** — gradient from Fig. 5**a**, **b** — gradient from Fig. 5**b**.

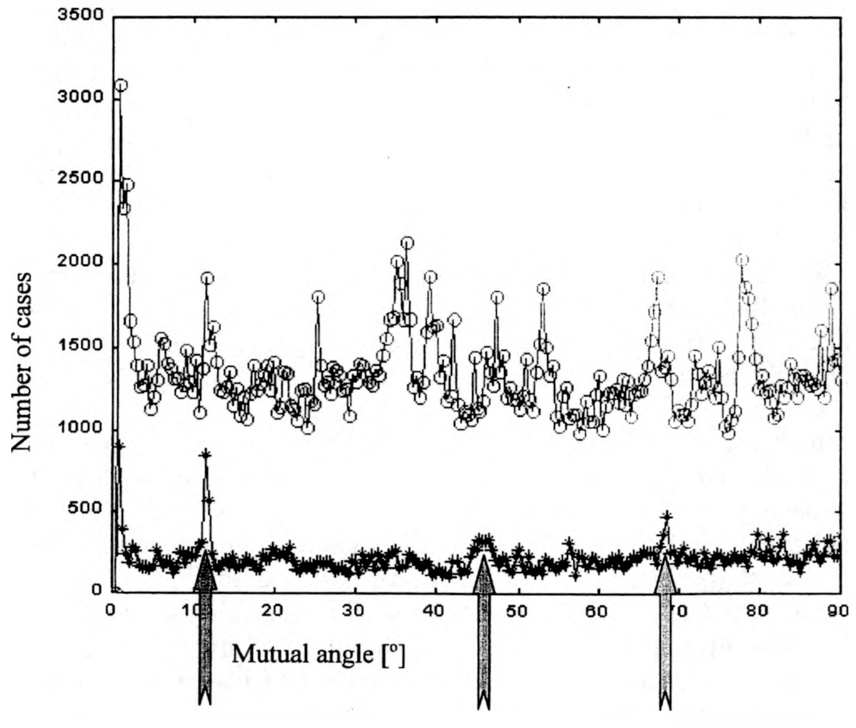

Fig. 7. Histograms of mutual angles for objects from Fig. 6.

The height of peaks in the histogram is related to the object scale (a square dependence). An object of small dimensions could be totally noised by the occurrence of clutter. It seems necessary to make an analysis with the application of image division into smaller parts and searching for an object at various resolutions of the method. The resolution of the method relates to the level of interference, dimension of characteristic peaks of the object being searched for as well as dimension of image fragments being analyzed.

The dynamic technology of cellular neural networks [11], [12] in the form of electronic chips augurs well for the methods of local character of computations performed. The application of hardware implementations of a cellular neural network would make fast identification of objects possible.

3. Recognition with the use of mutual angles histogram

The mutual angles histogram is a vector the components of which are related to the shape of objects appearing in the image. Each object can have an adequate vector attributed. The length of this vector relates to the object scale, whereas the direction corresponding with the shape is invariant.

In the case of objects that do not overlap, the vector determined for the whole image is a linear combination of the vectors of individual objects. The objects overlapping partially create a more complicated situation. An object usually has a complex shape and its individual fragments can be treated as those independently introducing information about the object, having their own vectors – histograms of angles. The whole shape of the object is an adequate linear superposition of its fragments in the meaning of histograms of angles.

The searching for an object in the case where it is not overlapped by other objects is a simple problem not requiring the application of neural networks. It is sufficient to check how far the direction of the total image histogram vector differs from the direction of the vector for the object.

The case of objects overlapping requires the application of methods resistant to fragmentation of the object image. Such methods include computations with the use of neural networks. Various cases of object fragmentation gathered in the form of a teaching set allow the neural network for learning to recognize the object partially covered.

The histogram vector, before being delivered to the input of a neural network, should be prepared adequately. In the case of a vector of a large number of elements, it could be advisable to make a projection on a subspace (*i.e.*, to select only a portion of coordinates of the vector). However, the coordinates selected should include those which take high values (peaks) for the object being searched for.

The hidden and output layers of the neural network recognizing an image can have small dimensions, adequately to the network capacity and number of objects stored. The input layer dimension depends on the number of histogram elements being considered in the recognition.

4. Summary

The method proposed for extraction of invariant characteristic features enables us to obtain the result in a simple and fast way. It is based, however, on the assumption that contour lines are approximately perpendicular to the image gradient. The application of various resolutions of the searching for an object and corresponding various degrees of image smoothing would allow effective detection and identification of objects in images. The problem is selection of a method for comparison of histogram peaks. At least two methods can be applied: correlative and neural ones. To teach and search for a specific object with the neural method, one can select the values of mutual angles histogram peaks and a few values besides the peaks, as input data for the first layer of neurons.

Acknowledgements – The work was performed within the research project No. 0T00A 031 12 sponsored by the State Committee for Scientific Research (KBN) in the years 1997–1998.

References

[1] NIEDZIELA T., STANKIEWICZ A., JAROSZEWICZ L.R., MERTA I., Opt. Appl. **28** (1998), 81.
[2] OSTROWSKI M., *Image Information* (in Polish), WNT, Warsaw 1992.
[3] CANNY J., IEEE Trans. Pattern Anal. Machine Intel. **8** (1986), 679.
[4] STANKIEWICZ A., MERTA I., JAROSZEWICZ L.R., *The edge regularization of noised image method*, Int. Workshop on Cellular Neural Networks and Their Applications, CNNA'96, Sevilla, Spain, June 24–26, 1996, p. 207.
[5] STANKIEWICZ A., MERTA I., JAROSZEWICZ L.R., *Extraction of contours from highly noised images with the method for regularization with discontinuities*, XI School on Optoelectronics, Photonics in Information Processing, Ustroń, May 6–10, 1996, Part II, p. 125 (in Polish).
[6] GEE A., DORIA D., Proc. SPIE, **1709** (1992), 304.
[7] NIEDZIELA T., STANKIEWICZ A., JAROSZEWICZ L.R., Proc. SPIE **3730** (1998), 32.
[8] TADEUSIEWICZ R., *Visual Systems of Industrial Robots* (in Polish), WNT, Warsaw 1992.
[9] NIEDZIELA T., STANKIEWICZ A., MERTA I., J. Tech. Phys. **40** (1999), 181.
[10] STNKIEWICZ A., NIEDZIELA T., *Inflexion points as a method for contour detection in noised images*, Research Works of the Institute of Air Force Technology, Warsaw, No. 1 (1997), 57.
[11] KACPRZAK T., ŚLOT K., *Cellular Neural Networks* (in Polish), PWN–Sci. Publ., Warsaw–Łódź, 1995.
[12] CHUA L.O., YANG L., IFE Trans. Circuit Synt. **35** (1988), 1273.

Received March 30, 1999
in revised form August 20, 1999