MODIFIED DISTANCE SIGNATURE AS AN ENHANCIVE DESCRIPTOR OF COMPLEX PLANAR SHAPES

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Abstract: In this paper, a simple and efficient approach to classify planar shapes is proposed. This approach is based on comparison of areas of dynamicly sampled classic signatures. Presented approach is dedicated to the recognition of convex and concave planar shapes, containing openings in the area enclosed by boundary. A way to calculate the discrete representation of classic distance-versus-angle signatures, a reduction of memory requirements and a number of calculations are presented. Analysis carried out from classification experiments applied to images of real objects (car-engine collector seals) indicates good properties of dissimilarity coefficients, based on modified signature, taken as an object descriptor.

1 INRODUCTION

The way of representing visual information concerning the objects found in the scene plays a fundamental role in the process of recognition and classification. One of the most essential characteristics enabling the recognition of an object is a shape. That is why the analysis of the scene often leads to the patterns comparison and to the recognition of object shapes. The shape analysis is linked with the problem of appropriate representation of the shape and the methods of its description (Demant, 1999), (Gonzales, 1992). The methods of the shape describing are fundamentally based on information concerning its contour or information about its area as a whole. The object description should be invariant with regard to translation, rotation and scale change. Apart from clarity, selectivity and precision, a good shape descriptor should have low computation complexity and universal application (Gonzales, 1992), (Zhang, 2004). The above-mentioned features of a good descriptor are often contradictory.

In the following, the global approach towards the shape description based on boundary by using centroid distance signature is presented. The modified principle of calcutating shape signature and comparison with a standard approach is also discussed. The algorithm efficiency of examining the similarity both of convex and concave objects and objects with openings is given. Application of the modified signature in the process of recognition is illustrated by classifying the images of car-engine collector seals.

2 CENTROID DISTANCE SIGNATURE AND ITS AREA

The classic shape signature is a 1D function representing a 2D shape bordered by a contour. The subject of discussion is the shape signature using the distance of contour pixels from the defined reference point. The standard example is the distance between contour pixels and the center of gravity of the contour (or whole figure) as the function of the angle (Gonzales, 1992). This definition of the descriptor is suitable for representing convex shapes. In many concave or disconnected shapes (e.g. for objects having holes), we obtain more than single distance value for the same angle ϕ. In a general case, the signature is a mapping of the angle into a distance set and the shape signature is represented by ordered series of pairs $\mathbf{S}=\{(\phi_i, R_i)\}$. To obtain R_i values, a continuous signature must be sampled. In a classic approach, sampling is done at a constant step $\Delta\phi = 2\pi/N$, where N is an assumed angular resolution. As a result, sampled signature representation $\mathbf{S}=\{(i\Delta\phi, R_i),\ i=1, ..., N\}$ is obtained.

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In a general case, more R_{ik} for a given $i\Delta\phi$ be obtained (Parker, 1998).

The approach proposed here consists of tracking the contour pixel by pixel and building a signature taking into account the local dynamics of the contour. With this approach sampling is performed at a variable step. The algorithm of shape signature determination consists of the following steps:

1. Extracting all object contours.
2. Calculating coordinates of a chosen reference point $P_R\,(x_R, y_R)$.
3. Tracking an external contour ***C***.
4. For each pixel $C_j\,(x_j, y_j)$, calculating a distance R_j from the point P_R and an angle ϕ_j as $arctan((y_j - y_R)/(x_j - x_R))$ and storing them in a signature mapping table $\mathbf{S}[\phi_j, R_j]$.
5. Determining a maximal distance R_{MAX}.
6. Rewriting **chosen** normalized values R_j/R_{MAX} to a modified signature table.
7. Repeating the whole procedure for all internal contours of openings in the analyzed object (steps 4-6).

The choice of consecutive points from the signature mapping table $\mathbf{S}[\phi_j, R_j]$, to rewrite them into the modified signature table, is determined by three parameters, which describe sampling process:

- $\Delta R/R$ – the relative pixel distance change parameter between consecutive signature points (the fundamental sampling condition meaning that for consecutive point $|R_{j+1} - R_j| / R_{MAX} \geq \Delta R/R$);
- ϕ_{MIN} – the minimal angle change between signature samples (a condition guaranteeing that between consecutive modified signature points the angle increment will not be less then a predefined value $|\phi_{j+1} - \phi_j| \geq \phi_{MIN}$);
- ϕ_{MAX} – the maximal angle change (the angle increment will not be greater then a predefined value $|\phi_{i+1} - \phi_i| \leq \phi_{MAX}$).

This process determines a modified signature taking into account the dynamics of the shape. For $\Delta R/R = 0$ classic shape signature is obtained for step $\Delta\phi = \phi_{MIN}$. The choice of the reference point P_R should not be accidental to ensure the invariance with regard to the object translation in the frame. The less subject to disruption the location of P_R, the more precise the descriptor. The normalization with respect to R_{MAX} lets the descriptor to be invariant regards to the scale change.

In the presented approach, the essential element for signature comparison is the signature area. In the case of some convex shapes, the signature area corresponds to the area delimited by a curve built of signature points. In the case of some concave objects and objects with openings, in order to determine the signature area, there is a need for interpolation of the modified signature. This is a consequence of the variable sampling rate and the independent external and internal contours tracking. After extending the modified signature to each spike, the appropriate region filling is made (Fig. 1). At this stage, the information from contour tracking algorithm is used.

3 SIMILARITY OF PLANAR OBJECTS

Object similarity analysis, while signatures represent shapes, refers to the comparison of signature areas (Parker, 1998). For comparison the XOR operation between the spikes of two signatures is used. Comparison is made with respect to the corresponding values of scanned angles. The calculated difference between areas is related to the reference area and this relative symmetric area difference is taken as a coefficient of non-similarity of compared shapes (*DISS* coefficient). As the reference area, an area of the box bounding signature or an area of one of the compared signatures is taken. To suppress nonlinear effects, due to the transformation from the *Cartesian* coordinate system to the polar coordinate system, R_j^2/R^2_{MAX} values in XOR operation are used, while calculating signature area. In this way, weight coefficient of an area pixel is proportional to the pixel distance from the reference point, as every area pixel represents the arc length of circle section determined by ϕ_{MIN} and R_j. Such a coefficient is denoted as *DISSW*.

Rotational invariance is obtained by repeated calculations of signature area differences, each time cyclically translating one signature with respect to the other. The minimum of calculated XOR values (i.e. XOR value for the best matching of shape signatures) determines the *DISSW* coefficient value (3). With the classic approach, both signatures have N spikes, for the same angle values. In the proposed approach, modified signatures consist respectively of $N_1 \leq N$ and $N_2 \leq N$ spikes. In the case of classic signatures, N^2 comparisons are required (for N area spikes and N shifts). In the proposed modification case, only N_1N_2 comparisons are performed, because the second signature is shifted only N_2 times and compared for N_1 angle values. Spikes are not available for all angle values, thus to calculate XOR area difference an interpolation has to be performed.

4 EXPERIMENT DESCRIPTION

In order to validate the proposed approach to the objects classification an experiment consisting of examining a set of car-engine seals was undertaken. In the experiment twelve seals (twelve classes of objects) were used, for which twenty shots in several varied positions were made (for various orientations and projection scales). The scene was lit by two lamps from above obliquely from two opposites sides thus object edges cast slight shadows. After preprocessing, tresholding and filtration with a median filter 3×3, a set of 240 binary images of objects was created (resolution 2 pixels/mm). The first shot in each population for each class, maintaining the same stable acquisition conditions, produced image of class prototype. These prototypes for twelve classes are shown in Fig. 2.

Comparison of classification methods using classic and modified signatures was based on *DISSW* value histograms comparison. Changes of class discrimination measure, based on *DISSW* mean and standard deviation values were analyzed.

4.1 Parameters of Analysis

For analyzed images, classic signature was calculated for $\Delta\phi = 0.5°$. For calculating modified signature values $\Delta R/R \leq 2.5\%$ and $\phi_{MAX} = 5°$ have been chosen. These parameters enable still appropriate reconstruction of object contours. Values of *DISSW* errors were calculated for all prototypes of classes by using classic signature comparison method. After analyzing these results, two seal pairs with the smallest dissimilarity errors were chosen. Comparison of classifiers based on classic and modified signatures was executed for pairs (***H2***, ***H4***) and (***D3***, ***N2***). Dissimilarity errors were calculated for each image compared to the others. If for ordered pair of classes (***C1***, C***2***) the sets of their signatures are denoted as:

$$\mathbf{SC1} = \{sc1_1, sc1_2, ..., sc1_{20}\}, \qquad (1)$$

$$\mathbf{SC2} = \{sc2_1, sc2_2, ..., sc2_{20}\} \qquad (2)$$

where sck_i is the signature for i^{ih} image of the object from ***Ck***, then the dissimilarity errors for a pair (***C1***, C***2***) are calculated for all $i, j \in \{1, 2, ..., 20\}$ as:

$$DISSW = min\,[(sc1_i)\ \mathrm{XOR}\ (sc2_j)]\,/\,sc1_i\,. \qquad (3)$$

First, errors in the standard case for $\Delta\phi = 0.5°$ ($N = 720$) were calculated. Then, resolution was decreased to $\Delta\phi = 1.5°$ ($N = 240$). These results are compared to the errors obtained with the modified signature, at $\bar{N}_{MOD} \approx N$. Modified signatures were calculated for: $\phi_{MIN} = 0.5°$, $\phi_{MAX} = 5°$, $\Delta R/R = 2\%$. Experiment was performed for two reference points (center of shape and center of boundary).

The calculated *DISSW* values are distorted by: a transformation to the polar coordinate system, a discretization, a tresholding (all being a method error) as well as by optical deformations of camera and shadows on the scene. The method error was checked for standard case at $\Delta\phi = 0.5°$ with the center of shape as the reference point. *DISSW* values were calculated for prototype images analytically transformed to positions corresponding to object positions in the set of images for a given class. These errors did not exceed 5%. The remaining errors are regarded as a noise.

4.2 Analysis of Results

Analysis of experimental results is based on comparison of mean and standard deviation values *(m, σ)* for within-class and between-class errors. In Fig. 3, *DISSW* coefficient values histograms for pair (***H4***, ***H2***) are presented. In the standard case for shape center and for $\Delta\phi = 0.5°$ (named as an accurate case), calculated values of statistical parameters *(m, σ)* of *DISSW* values are as follows:

- (6.0, 2.3) for (***H2***, ***H2***);
- (28.0, 1.4) for (***H2***, ***H4***);
- (6.1, 2.4) for (***H4***, ***H4***);
- (26.9, 1.5) for (***H4***, ***H2***).

To compare both classic and modified methods, a dispersion measure of classes (***C1***, ***C2***) is defined as:

$$D\,(\mathbf{C1},\mathbf{C2}) = |m_{C11} - m_{C12}|(\sigma_{C11}^2 + \sigma_{C12}^2)^{-0.5}, \qquad (4)$$

where m_{C11}, σ_{C11}^2 are the mean and the variance of (***C1, C1***) within-class *DISSW* values and m_{C12}, σ_{C12}^2 are the mean and the variance of (***C1***, ***C2***) between-class *DISSW* values, respectively.

Calculated values of *D* are presented in Tab. 1. In the standard case ($\Delta\phi = 1.5°$), for pairs (***H2***, ***H4***) and (***H4***, ***H2***), value of the measure *D* decreases, nearly twice. In the modified signatures case, at the same number of signature spikes, value of the dispersion measure *D* increases with respect to standard case ($\Delta\phi = 1.5°$) and is even bigger then in the accurate case ($\Delta\phi = 0.5°$). The results for the pair (***D3***, ***N2***) change in a similar manner.

Table 1: Values of dispersion D for center of shape.

Method	H2 H4	H4 H2	D3 N2	N2 D3
Classic $\Delta\phi = 0.5°$	8.1	7.4	9.0	9.8
Classic $\Delta\phi = 1.5°$	4.5	3.8	7.3	7.8
Modified	8.5	8.0	9.0	9.9

Table 2: Values of dispersion D for center of boundary.

Method	H2 H4	H4 H2
Classic $\Delta\phi = 1.5°$	2.1	2.4
Modified	2.9	4.2

Greater values of D and their smaller changes are due to other type of shape and reduced radial resolution. Applied radial resolution was always equal to 1/500 R_{MAX}, but objects from ***D3*** and ***N2*** classes have bigger absolute values R_{MAX} then the other ones.

Finally, results for modified and standard case ($\Delta\phi = 1.5°$) are compared while the reference point was changed. Results for pair (***H2***, ***H4***), calculated for center of external contour as the reference point, are presented in Fig. 4 and Tab. 2. Increase of error values and their standard deviation values can be observed. For standard case, (m, σ) values of *DISSW* coefficient are as follows:

- (12.6, 5.7) for (***H2***, ***H2***);
- (27.0, 3.8) for (***H2***, ***H4***);
- (11.7, 4.7) for (***H4***, ***H4***);
- (25.9, 3.7) for (***H4***, ***H2***).

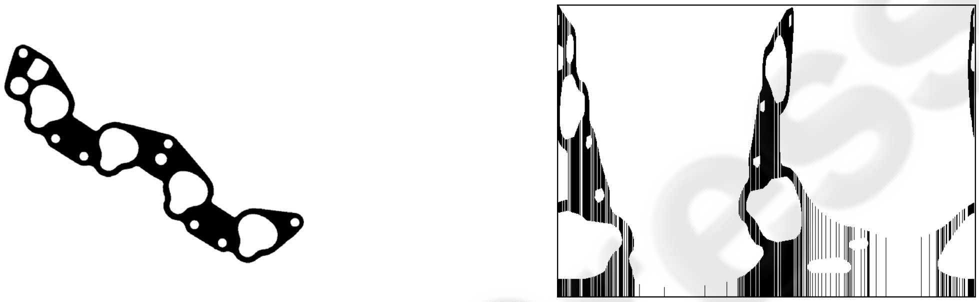
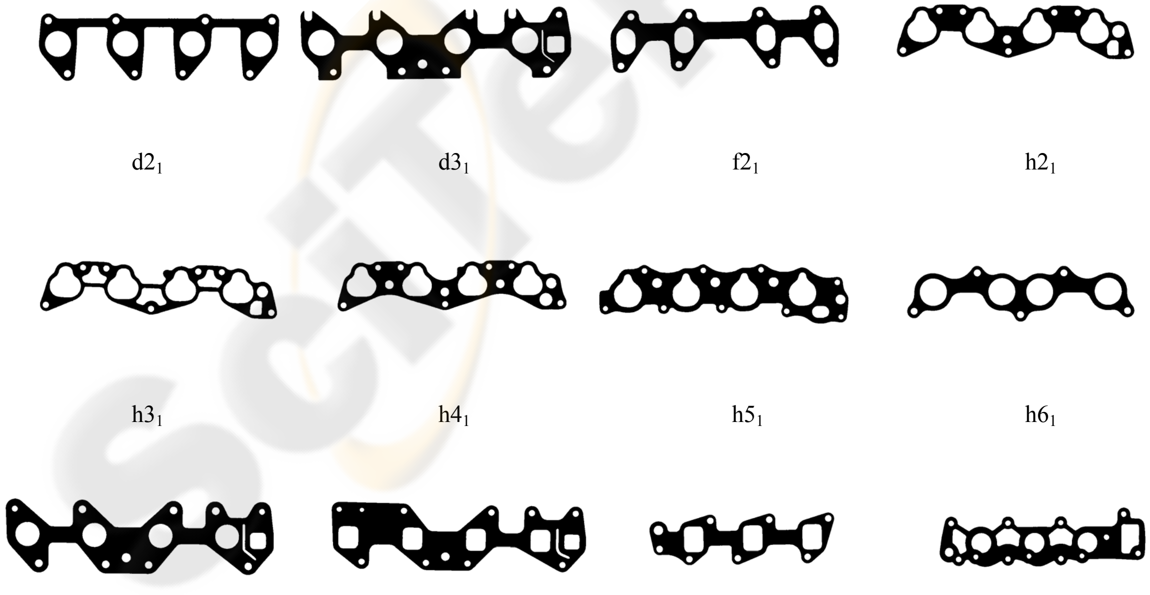


Figure 1: Shape of a car-engine collector seal (left) and its modified signature (right).



d2_1 d3_1 f2_1 h2_1

h3_1 h4_1 h5_1 h6_1

n2_1 o2_1 s2_1 t2_1

Figure 2: Images of car engine collector seal class prototypes.

This is due to the greater sensitivity of contour center to the noise. For considered objects, the number of contour pixels was 30 - 40 times smaller that the number of pixels belonging to the object shape. Decrease of angular resolution and increase of noise level lead to overlapping between within-class and between-class errors (in Fig. 4 common area of histograms is marked by light gray color).

The modified signature improves the discernability of classes. Tests performed on modified signatures of real images reveal good properties of the dissimilarity coefficient as an object discriminator.

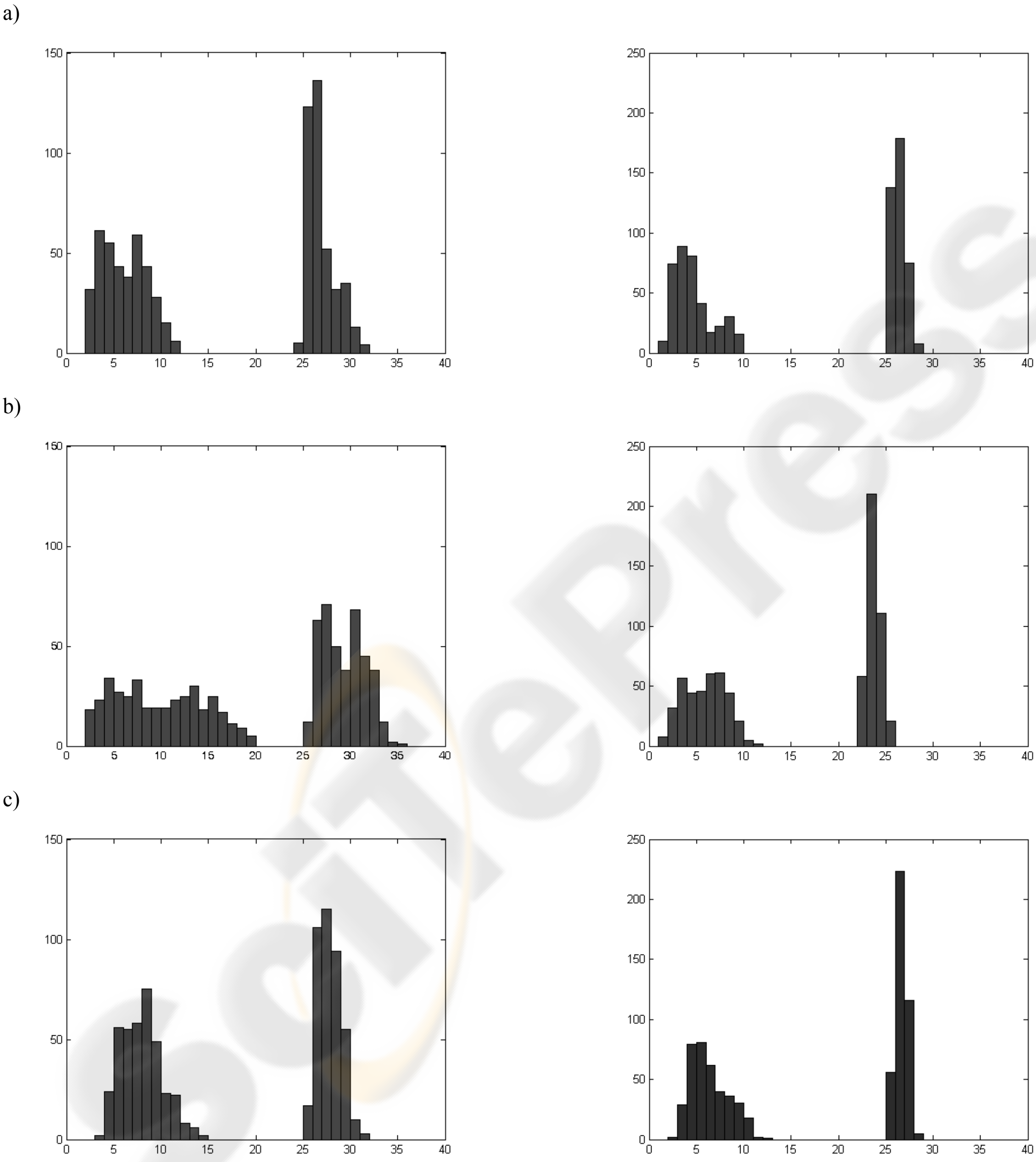


Figure 3: Histograms of within-class and between-class dissimilarity errors for (H4, H2) – left and (N2, D3) – right, for shape center as the reference point: a) classic Δϕ = 0.5°, b) classic Δϕ = 1.5°, c) modified ΔR/R = 2%, $\bar{N}_{H4} = 250$, $\bar{N}_{N2} = 237$.

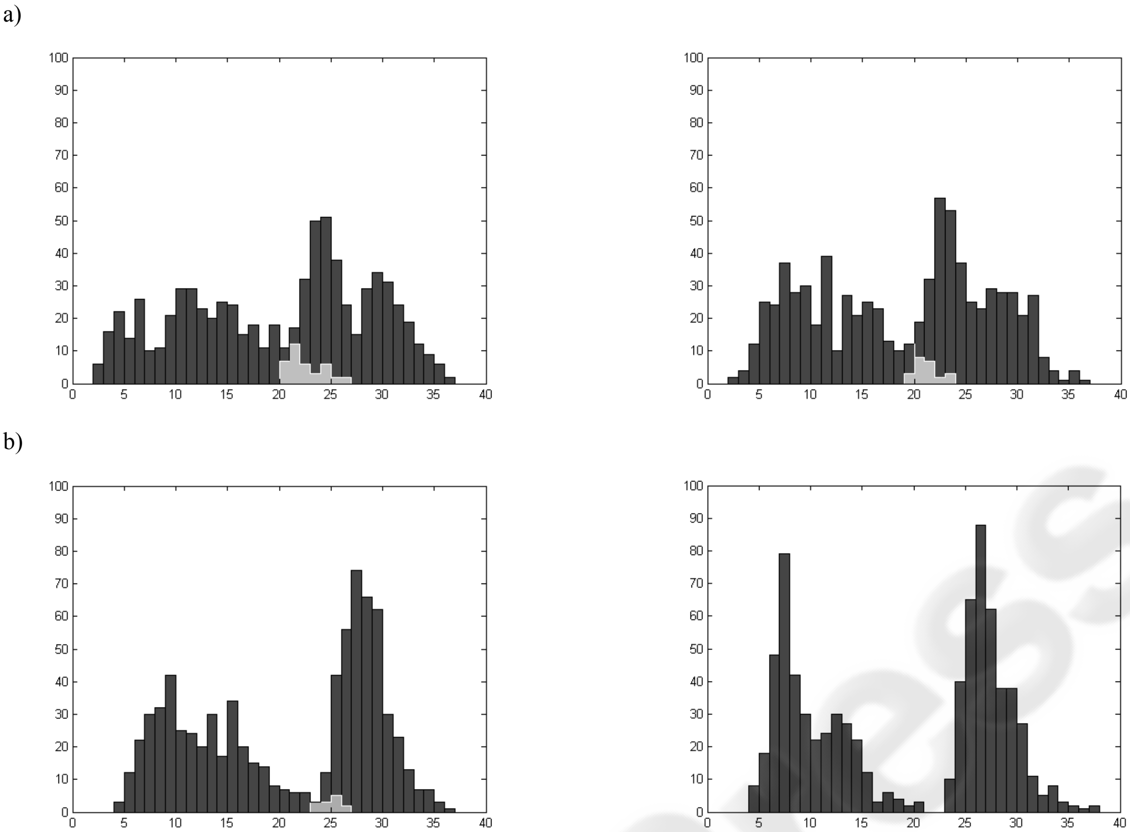


Figure 5: Histograms of within-class and between-class dissimilarity errors for (H2, H4) – left and (H4, H2) – right, for boundary pixels center as the reference point: a) classic $\Delta\phi = 1.5°$, b) modified $\Delta R/R_{MAX} = 2\%$, $\overline{N}_{H2} = 242$, $\overline{N}_{H4} = 253$.

5 SUMMARY

Application of the signatures of planar objects to recognition and classification is simple, fast and computationally effective. The presented method of describing complex objects can be used in the case of convex, concave and disconnected shapes with openings. The modified shape descriptor is invariant to translation and scale change, and the mode of comparison assures its invariance with regard to rotation. The proposed modified approach takes into account the variability of object contours leading to automatic changes in the frequency of sampling of classic signatures. The descriptor is directly connected with the shape of the object. Parameter values taken to calculation of the modified signature are simple to choose and the validation of shape comparison results is natural. The use of modified signatures reduces the memory requirements and the number of calculations without deteriorating recognition results. Test undertaken on the real objects images, indicates a good performance of the dissimilarity coefficient determined with the modified signature method. This coefficient enables good discrimination of objects indicating the suitability of this method for robotic inspection and visual control systems.

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