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Application of the Curvature Scale Space Descriptor to the Problem of General Shape Analysis

***Abstract**. In the paper the problem of General Shape Analysis (GSA) is investigated. It is similar to the recognition and retrieval of shapes. However, the analysed shape does not have to belong to any of the template classes. It is only similar to some of them. It may be said that the most general information about a shape is here concluded, namely how round, triangular, elliptical, etc. it is. This approach can be useful when an application uses only few general base classes. In the paper the Curvature Scale Space (CSS) shape description algorithm is applied to the problem.*

***Streszczenie.** W artykule rozpatrywany jest problem Ogólnej Analizy Kształtu (OAK). Jest on zbliżony do rozpoznawania, a także indeksowania kształtów. Jednakże badany kształt nie musi należeć do żadnej z wzorcowych klas. Jest on jedynie podobny do niektórych z nich. Można powiedzieć, że w ten sposób wnioskujemy bardzo ogólną informację o kształcie – w jakim stopniu jest on okrągły, trójkątny, eliptyczny, itd. Omawiane podejście jest przydatne w zastosowaniach, w których stosuje się kilka podstawowych klas. W badaniach zastosowano deskryptor CSS. (**Zastosowanie deskryptora CSS w problemie Ogólnej Analizy Kształtu**)*

Keywords: General Shape Analysis, Curvature Scale Space, Shape Description, Coarse Shape Classification.
Słowa kluczowe: Ogólna Analiza Kształtu, deskryptor Curvature Scale Space, Opis Kształtu, Wstępna Klasyfikacja Kształtu.

Introduction

In the experiments described in the paper a popular shape descriptor, namely Curvature Scale Space, is applied to the General Shape Analysis (GSA). From one point of view, this problem is very similar to the typical retrieval of shapes. However, it is also similar to the shape recognition. It applies the template matching approach for the selection of the appropriate templates from the database – the most similar to the analysed shape. However, in the General Shape Analysis a class stored in the template base is represented usually only by one object. The number of template classes is also strongly reduced (usually this number is equal to ten) and the shapes selected to perform the role of templates are very general, e.g. square, triangle, star, rectangle. Hence, the main goal of the General Shape Analysis is not the precise identification of a tested object, but the conclusion about a general information about it instead [1]. Let us consider the example mentioned few sentences earlier. If we store in the template base the square, triangle, star, rectangle (and so on) then we can conclude in what degree a shape under processing is square, triangular, star-like, rectangular, etc. The described idea is graphically presented in figure 1.

The General Shape Analysis is useful in some specific applications, in which the shape analysis can be formulated on a higher level of abstraction. An example, investigated so far, is the identification of type of a stamp (e.g. official, institutional, public) when searching for probable false digital documents stored on a hard drive. Some experiments on this specific problem were already performed and described e.g. in [2]. Another application is the usage of the General Shape Analysis in large shape databases, where this approach allows for the initial coarse classification. In result we can significantly increase the speed of the classification. Firstly the shape under processing is matched with small number of general classes, and later, after selecting one of them, the closest to the test object, it is only compared with shapes within this smallest class that covers the shapes similar to the previously established general class. This process can be performed several times and the classes can be more detailed at each iteration. The General Shape Analysis can be also applied in linguistic shape retrieval. Once more, it can serve as a method for speeding up the retrieval of a large multimedial database. One can for example use a voice command, e.g. “find images with triangular blue objects” and the system will provide those images as an output. Obviously, the GSA will help in finding the appropriate images.

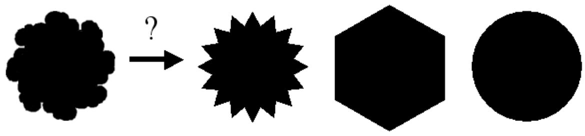

Fig. 1. Illustration of the general shape analysis problem – which general shape is the most similar to the one being processed?

The analysis of some basic properties of a shape is not a very difficult task, however it is not popular. The most comprehensive, theoretical work was done by Paul L. Rosin. He analysed for example the rectangularity [3], ellipticity and triangularity [4], sigmoidality [5], convexity [6], rectilinearity [7], and circularity [8] of a shape. The approach presented in this paper can be considered as the opposite to the above, since here the similarity of a shape to several general templates is investigated. For this purpose any shape description technique can be applied. In this paper the General Shape Analysis is performed using the Curvature Scale Space (CSS) shape descriptor [9], an algorithm very popular in object recognition. It can be easily found in many practical applications. It was used for example in: automatic fitting of digitised contours at multiple scales [10], shape-based image retrieval [11], [12] and recognition [13], recognition of occluded shapes [14], gesture recognition [15], corner detection [16], three-dimensional object representation and recognition [17], image registration [18], motion trajectory-based activity classification [19], measuring of the lesion border irregularity [20], automatic diatom identification [21], smoothing in active contour modelling [22], content based video retrieval [23], classification of chrysanthemum leaves [24], estimation of the fractal dimension from shape contour [25], player gesture recognition in sports video [26], historic document image indexing and retrieval [27], and above all, it was applied in the MPEG-7 standard [28].

Considering the wide usage and high efficiency of the CSS, the goal of the research presented in this paper was the evaluation of the method applied to the problem of General Shape Analysis. Since the shape as a whole is analysed, we can conclude the global character of this analysis.

The rest of the paper is organised as follows. The second section describes the CSS shape description and matching technique. The third section provides the experimental results and their discussion. Finally, the last section concludes the paper.

Description of the Curvature Scale Space Shape Representation

The description of the Curvature Scale Space algorithm, presented in this section, was based on [26]. The method is invariant to rotation, scaling and the location of an object within the image. It is also very robust to noise, what results from the method of obtaining the shape description. In general, the CSS representation is derived using the convolution of a path-based parametric representation of a curve extracted from the boundary of processed shape with a Gaussian function of increasing variance σ^2. The zeros of curvatures of the convoluted curves are extracted and combined in a scale space representation. Those values are derived during the evolution of the planar curve changed by the expanding Gaussian function.

The closed planar curve r is represented parametrically for axes x and y using the normalized arc length parameter u:

(1) $$r(u) = \{x(u), y(u) \mid u \in [0,1]\}.$$

The evolved curve is represented as Γ_σ:

(2) $$\Gamma_\sigma(u) = \{\chi(u,\sigma), \psi(u,\sigma),$$

where:

(3) $$\chi(u,\sigma) = x(u) \otimes g(u,\sigma),$$

(4) $$\psi(u,\sigma) = y(u) \otimes g(u,\sigma),$$

and:

$\otimes$ - the convolution operator,

g - Gaussian function of width σ, calculated using the formula:

(5) $$g(u,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-u^2/2\sigma^2}.$$

The curvature κ of Γ can be formulated as:

(6) $$\kappa(u,\sigma) = \frac{\chi_u(u,\sigma) - \psi_{uu}(u,\sigma) - \chi_{uu}(u,\sigma) - \psi_u(u,\sigma)}{(\chi_u(u,\sigma)^2 + \psi_u(u,\sigma)^2)^{3/2}},$$

where:

(7) $$\chi_u(u,\sigma) = \frac{\partial}{\partial u}(x(u) \otimes g(u,\sigma)) = x(u) \otimes g_u(u,\sigma),$$

(8) $$\chi_{uu}(u,\sigma) = \frac{\partial^2}{\partial^2 u}(x(u) \otimes g(u,\sigma)) = x(u) \otimes g_{uu}(u,\sigma),$$

(9) $$\psi_u(u,\sigma) = y(u) \otimes g_u(u,\sigma),$$

(10) $$\psi_{uu}(u,\sigma) = y(u) \otimes g_{uu}(u,\sigma).$$

Finally, the CSS image I_c gives in result a multi-scale representation of zero crossing points:

(11) $$I_c = \{(u,\sigma) \mid \kappa(u,\sigma) = 0, u \in [0,1], \sigma \geq 0\}.$$

The last stage of the descriptor construction is the selection of contour maxima locations in CSS image I_c. They are used as a representation of a shape.

The similarity between two represented objects is calculated through matching between two sets of maxima, representing them. The method firstly finds any possible changes in orientation in one of the two shapes, and then a circular shift is applied in order to compensate their influence. Later the Euclidean distance is calculated between the two sets, indicating the dissimilarity measure.

Results of the Performed Experiment and their Discussion

The experiment on the application of the Curvature Scale Space to the General Shape Analysis problem was performed using fifty shapes. They were divided into two groups. The first one consisted of ten the most general shapes that were the templates. The second group was composed of forty test objects. All shapes were stored in bitmaps, 200 × 200 pixel size. Both, the templates and test shapes, are presented in Fig.2. The templates can be seen in the first row, while the shapes from the second to the last row were used as the test objects.

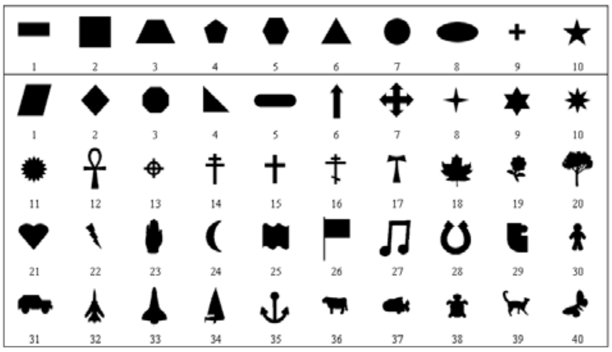

Fig. 2. The division of shapes into 10 templates (first row) and 40 test objects (rest).

The idea of the test was simple. Each of the forty test objects was represented using CSS, and so were the ten templates (general shapes). In figure 3 some examples of shapes and CSS descriptions obtained for them are provided. A very interesting effect can be observed for the circle from figure 3. In theory, for the circle the straight line should be obtained as a result of the CSS transform. As one can clearly see it is not. The description is close to the line, influenced by noise. This can be easily explained by the discrete character of the shapes within the investigated images, and hence - the discretization errors. In order to reduce the influence of the scale change between matched objects, the descriptions were normalised to the constant size (520 x 400). Hence, in figure 3, the CSS curves do not have units. Additionally, this operation reduced the problem of small local perturbations, as in the discussed case of the circle.

Basing on the template matching approach, the description of a test shape was matched with all the descriptions of the templates. The three smallest dissimilarity values indicated the general shapes closest to a test shape for the algorithm under analysis. Pictorial representations of the results as well as the obtained dissimilarity values are provided in table 1.

Table 1. The results of the experiment and dissimilarity values obtained for particular test shapes according to three the closest template general shapes.

1	1625	1636	1743
2	1073	1087	1122
3	589	628	701
4	520	605	633
5	726	740	764
6	1193	1221	1256
7	2420	2452	2453
8	2605	2611	2773
9	1283	1308	1329
10	2282	2308	2335
11	1901	1902	2014
12	2702	2739	2779
13	1945	1970	2199
14	2031	2126	2268
15	1845	1875	1967
16	2289	2400	2453
17	2068	2075	2178
18	1851	1907	1918
19	1269	1345	1430
20	1868	1915	1931
21	2459	2562	2620
22	1750	1794	1898
23	1862	1932	2094
24	2613	2646	2832
25	2058	2097	2200
26	2211	2231	2269
27	1001	1015	1233
28	1193	1312	1316
29	1444	1508	1627
30	1012	1133	1265
31	1203	1208	1217
32	1737	1779	1794
33	2580	2611	2635
34	1622	1716	1939
35	1087	1168	1182
36	1660	1664	1729
37	2364	2372	2564
38	1974	1987	2155
39	2208	2277	2334
40	2540	2597	2746

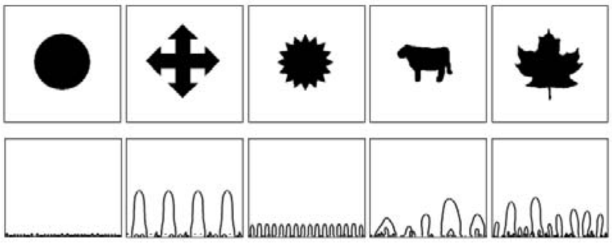

Fig. 3. Examples of shapes used in the experiment (first row) and CSS descriptors obtained for them (second row).

Some of the results provided by CSS descriptor applied to the problem of General Shape Analysis seem to be correct. For example, the turtle (object no. 38) in general is round, and the circle was indicated at the first place. Its shape has however some additional parts – limbs and a head. Hence, we can assume that the second indicated template – a star – is proper as well. Another interesting example is the flag with the flagpole (object no. 26). The algorithm pointed out the square at the first place. Indeed, the most important part of the object – the flag – is similar to it. Two other objects – the jet (object no. 32) and the space shuttle (object no. 33), if rotated, are similar to the indicated ellipse. In case of the arrow (object no. 6) selected template – the rectangle – definitely seems to be the most similar amongst the used general shapes. In some cases (object no. 5 – the rectangle with rounded corners, object no.15 – the cross, object no. 29 – the trademark, object no. 31 – the car, and object no. 36 – the cow) the rectangle was indicated at the second place and was definitely similar to the tested object. However, the tested shape descriptor did not work entirely properly. The circle was the most popular result at the first place. Although there are some objects similar to this general shape (e.g. object no. 11 – the sun, object no. 13 – the Celtic cross, object no. 21 – the heart), in most cases that was not correct. Therefore, from this point of view, the CSS shape descriptor is not ideal for the GSA problem. Some other solutions clearly have to be investigated.

Conclusions

The investigated in the paper problem of General Shape Analysis can be applied if the precise identification of a shape is not expected, but some general information about it is rather desirable, e.g. how triangular, round or elliptical an object is. This kind of some general conclusions can be useful for example in the coarse classification, performed as an initial step in the retrieval within a large database. Moreover this process can be performed repetitiously, at each step using the more and more precise shapes. However, in that case, only the first, initial stage can be considered as the General Shape Analysis. The another application is the general deduction about a shape. An example was mentioned in this paper – the analysis of stamps' shapes extracted from digital documents.

The General Shape Analysis can be based on the typical template matching approach. In this case the same algorithms as for shape recognition or retrieval can be used. However, the number of the template classes has to be small and they have to contain only the most general shapes.

In this paper the Curvature Scale Space, a very efficient and popular shape description algorithm, was applied to the above-mentioned problem. The results were described in the previous section. Generally speaking, they are correct in many cases, however, the selection of the circle at the first place was in many cases undesirable. Hence, future works on the General Shape Analysis include mainly the application of other shape description algorithms to this problem in order to find a better method for it.

Wydanie publikacji zrealizowano przy udziale środków finansowych otrzymanych z budżetu Województwa Zachodniopomorskiego.

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