Identification of Curvature Features with Use of Boundary-Skeleton Model of Image

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Abstract: - A method of identification of curvature features for shape description and recognition is suggested. The method is based on the relation between local boundary features and the skeleton structure of a plain domain. It uses a continuous boundary-skeleton model of an image. The model consists of a boundary of a polygonal figure approximating a raster image, and a skeleton of the figure. To reveal curvature features the skeleton base representing fundamental structure of the image is used. A procedure of profile line segmentation from a face image based on the suggested method is presented.

Key–Words: Boundary-skeleton model, skeleton base, curvature features, face profile segmentation

1 Introduction

Curvature analysis of an object's boundary is an important tool for image shape recognition. Curvature features such as zero-crossings or extrema and their combinations are used to obtain shape description and identify structural parts of an outline [1, 2, 3, 4, 5, 6, 7]. To estimate curvature of a boundary represented in the raster form a number of techniques can be applied: curvature models for raster or polygonal boundary [8, 9]; approximation with splines [10, 11]; and scale-space analysis [6, 7, 12].

In this paper we consider a method of identification of curvature features, allowing one to work with polygonal representation of a contour. The method is based on use of continuous boundary-skeleton model of an image. This model consists of a boundary of a polygonal figure approximating a raster image, and a skeleton of the figure.

The skeleton (or medial axes) presented in [13] is an effective tool to describe the structure of a plane domain. From the first works of Blum many papers is devoted to investigation of the skeleton of a domain with a piecewise smooth boundary (see, for example, [14]). In particular, the skeleton shape is known to be sensitive to local features of the domain boundary: each point of a local maximum of curvature (or a break) on the boundary generates a separate terminal branch of the skeleton. The suggested method of detection and analysis of curvature extrema is based on this feature. To reveal curvature features the skeleton base representing fundamental structure of the image is used.

2 Boundary-Skeleton Model of Image

To construct the boundary model, we approximate the discrete binary image with a polygonal figure, which separates the points of the object from those of the background (Fig. 1). In the approach considered, we use the approximation by a polygon with the minimal perimeter [15]. It should be noted that this solution is not unique and any algorithm of polygonal approximation may be used.

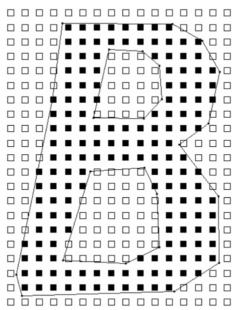

Fig. 1. Discrete binary image and its approximation with a polygonal figure

On the basis of the obtained polygonal figure the skeleton model of the image is constructed. To obtain skeletal representation of a polygonal figure the algorithm described in [15, 16] is used. This algorithm is based on construction of so-called generalized Delaunay triangulation for collection of vertices and edges of the polygon.

The form of a skeleton of a figure is extremely sensitive to local features of its boundary. Small change in boundary curvatures results in essential changes of topological features of a skeleton (Fig. 2). At the same time, there is a part of a skeleton reflecting fundamental structural features of an image.

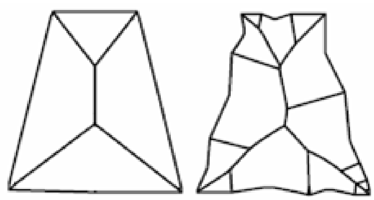

Fig. 2. Sensitivity of skeleton to insignificant boundary changes

Therefore, we suggest to use the so-called skeleton base (Fig. 3) described in [17] as the approximation of this fundamental part. The base skeleton is a subset of the skeleton of the polygonal figure, which has the following important property: each edge of the base skeleton approximates a part of the skeleton of any region, whose Hausdorff deviation from the figure does not exceed ε, with the accuracy $\delta = \frac{\varepsilon}{\cos^2 \alpha/2}$.

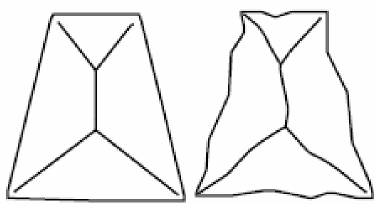

Fig. 3. Skeleton bases of slightly different images

3 Curvature Features

For each point p of the skeleton base there is a so-called base circle. It is the circle with the center at p and radius $r + \varepsilon$, where r is the radius of the maximal inscribed circle with the center at p, and ε is the accuracy of approximation (Fig. 4).

The base circle with the center at the terminal vertex of the internal skeleton base has an arch that approximates the corresponding fragment of the polygonal figure's boundary (and the boundary of any figure approximating the object) with known accuracy (Fig. 5). Thus, the fragment can be considered as a

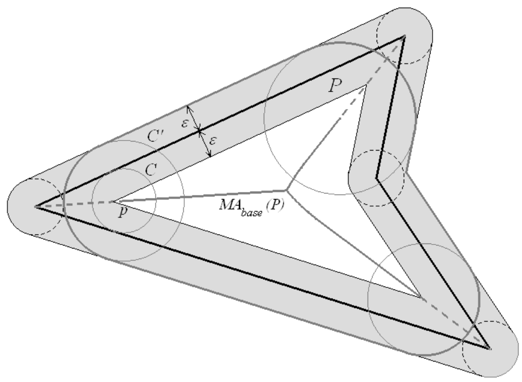

Fig. 4. Skeleton base and base circles. $MA_{base}(P)$ is the skeleton base of the polygon P (pruned parts of the polygon's skeleton are shown with dotted lines); C is the maximal inscribed circle with the center at p; C' is the base circle with the center at p

local maximum of contour curvature within the limits of the accuracy of approximation.

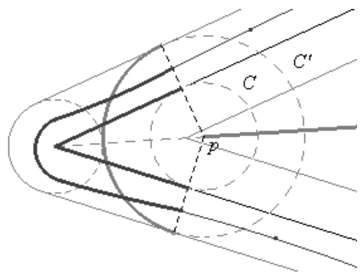

Fig. 5. The arch of the base circle C' approximates the corresponding fragment of the approximating figure's boundary

Likewise, if we consider the external skeleton base of the polygonal figure the arches of base circles with the centers at terminal vertices indicate the local minima of contour curvature within the limits of approximation accuracy.

Thus, to identify the curvature features of the object contour on a discrete image, the continuous model of the image based on polygonal approximation can be used. The model includes the boundary of the polygonal figure dividing the image plane into figure component (containing all object points) and background components (containing all background points); and skeleton bases of both components (Fig. 6).

4 Segmentation of Face Profile

The described approach was applied to the problem of face profile segmentation. The shape of the facial profile is an important distinctive feature of a

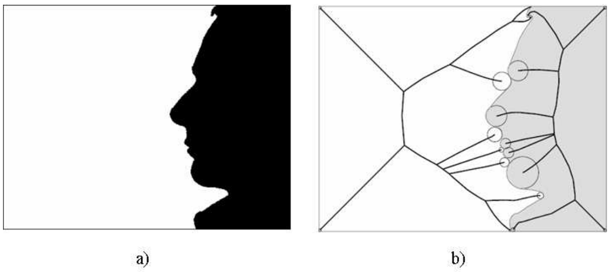

Fig. 6. Binarized image of a head (a) and its boundary-skeleton model (b)

face. It is used in machine vision systems solving various recognition problems, from person identification [18, 19, 20, 21, 22, 23, 24, 25] to recognition of emotions and facial gestures [26, 27].

An important preprocessing stage of face recognition is the extraction of the profile line from the face image. To identify the profile part in the head contour, fiducial points (nose tip, nose bridge, eyebrow arcade, lips, chin etc.) are usually searched. It is convenient to consider fiducial points as curvature extrema of the head contour.

The suggested algorithm of profile line segmentation with use of the described boundary-skeleton model looks as follows.

Let us assume that the head on the image is turned to the left. Then the profile line is searched within the left part of the head contour (from the most left point with the maximal ordinate to the most left point with the minimal ordinate).

To identify the fiducial points, the set of terminal vertices of internal and external skeleton bases, which maximal inscribed circles touch the specified boundary fragment, and the set of corresponding base circles are considered.

The combination of base circles associated with the nose is searched within the middle part of the boundary fragment. This combination should consist of three circles situated in sequence along the boundary: the first one is external (nose bridge), the second is internal (nose tip), and the third is external again (nose basis) (Fig. 7). The specified area can contain a number of such triplets. Therefore an additional check of a found triplet is made.

For each circle in the triplet the corresponding fragment of the contour is investigated, and the vertex most distant from the center of the circle is searched. Let us label the vertices corresponding to the nose bridge, the nose tip and the nose basis as A, B and C, respectively. The triangle ABC (Fig. 8) must sat-

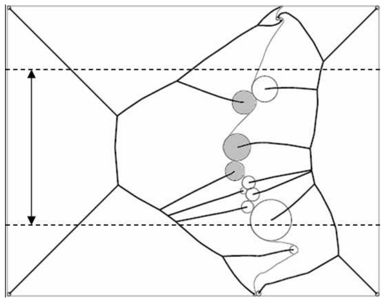

Fig. 7. Base circles determining the nose

isfy the following conditions: (a) the projection D of B to AC divides AC so that the length of CD is less than the length of DA; (b) the length of AC should not be very small in relation to the height of the middle part of the fragment (for experiments we used the following ratios: the height of the fragment makes 3/4 of the head figure height; the length of AC should not be less than 1/5 of the middle fragment's height).

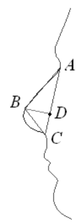

Fig. 8. Nose triangle

If triangle ABC does not satisfy the specified conditions a next triplet of circles is searched.

Once the nose is found, the first internal circle situated above the nose bridge circle is considered as the circle of the eyebrow arcade (Fig. 9).

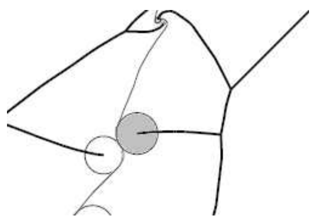

Fig. 9. Base circles of the upper part of the face

Then we search for the first external circle above the eyebrow arcade (it indicates the place where the hair begins). When the circle is found, the height of the obtained forehead is checked to exclude external circles caused by eyelashes and eyebrows. If the forehead's height is less than 1/5 of the height of the nose, the next external circle is investigated.

If no external circle is found, the following rule is used to determine the top vertex of this profile: the height of the forehead part is equal to the height of the nose.

Below the nose basis there is the contour fragment corresponding to the lips and the chin. Ideally, this fragment is described by a sequence of five circles, three internal and two external (Fig. 10), with the internal circle corresponding to the chin being the last circle in this sequence. The absence of one or more lip circles is also possible (there can be nine variants of the sequence). Thus, to find the chin, the sequence of five circles located below the nose base circle is considered. If the sequence is ended with one or more external circles we exclude these circles until the last circle becomes internal. Then a type of the sequence is determined depending on the order of internal and external circles.

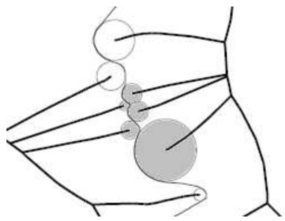

Fig. 10. Base circles of the lower part of the face

To test the segmentation procedure two image bases were used: the face database of the University of Bern [28] consisting of 150 grayscale images of 30 persons and the image base prepared by authors which contains 152 color images of 17 persons.

Each image was transformed to a binary image of a head with use of brightness or color segmentation. Then the boundary-skeleton model of a raster image was constructed, and profile line segmentation according to the described scheme was made.

Correct profile lines were obtained for 293 images from the data set. The chin part was incorrectly extracted from 6 images due to presence of a beard. In 3 cases the forehead part was wrongly identified as the nose. An example of the profile segmentation is presented in the Fig. 11.

The segmentation scheme is based on a rather simplified model of the profile line. It does not take into account possible significant deformations of the shape caused by various details (such as beard and glasses) and facial muscle activity. Nevertheless, the scheme provides the basis for further development and modification.

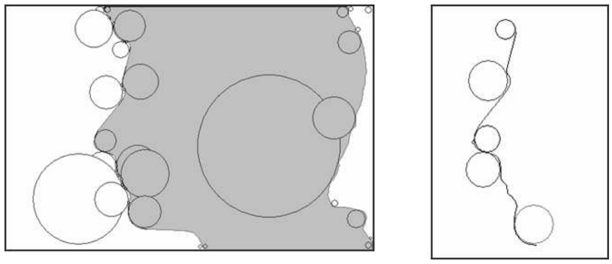

Fig. 11. Profile segmentation on the image from the face database of the University of Bern

5 Conclusion

The concerned continuous model of the image which includes the boundary of the approximating polygonal figure and skeleton bases of both figure and background components, makes it possible to identify the contour fragments containing the required combination of curvature features without the approximation by piecewise smooth curves or contour smoothing. To investigate curvature features at different levels of detail, base skeletons with various values of approximation accuracy can be used.

Acknowledgements: The research was supported by the Russian Foundation for Basic Research (projects 05-01-00542 and 05-07-90395).

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