Contour Tracking

Image Processing Basics: Contour-based Pattern Matching

Pattern Matching is a method to search for a given template or so-called model within an image. The procedure results in a similarity image with a score figure at every pixel. The higher the score, the higher will be the probability for a real match between the template and the image region in the vicinity of this individual pixel. There are some matching methods based upon the contours of objects rather than grey-level templates. These algorithms process edges in images and use quite abstract relations between geometric primitives to check geometric models of objects.

Contours

The contour is the perimeter of a binary object. To use this concept, objects must have been successfully segmented from the background. Figure 1 shows an example with segmentation by simple thresholding. Labeling results in single binary objects, which are white in this example, and usually provides the contour on the fly, as shown in the right part of figure 1. Contour pixels are those object pixels which have neighbors in the object as well as in the background (or to be more precise, which have an object pixel in their 8-connected pixel neighborhood and a background pixel in their 4-connected pixel neighborhood). Based upon this criterion, these special object pixels can be separated and stored as the contour. A well-known and efficient method for coding the contour is the chain code. Beginning with a starting point on the contour the boundary of the object is traced from pixel to pixel and the corresponding direction is stored as an integer between 0 and 7. Figure 2 shows an example according to a common convention, Freeman's chain code. The starting point (x,y), depicted in red, is found by scanning the image from the left and from the top and is thus determined unambiguously. The contour completely determines the binary object, since the pixel pattern may be reconstructed from the boundary by filling, and thus must contain all the information which might be extracted from the 2D-object. As a consequence, there should exist methods to recognize an object based solely upon the characteristics of its contour. Let us have a look at an ideal square with edges parallel to the axes of the coordinate system. The starting point (x,y) will be the upper left corner. The contour is traced counter-clockwise, resulting in the direction 6 for the first edge, 0 for the second edge, 2 for the third and finally 4 for the last edge. Freeman's code for this square will thus consist of, depending upon the edge length, 20 directions with code 6, e.g., followed by 20 directions with code 0 and so on. Four groups of identical directions with equal length, each followed by a counter-clockwise turn by 90°, will thus code a square. A turn by 90° corresponds to adding +2 (modulo 8) to the actual Freeman-direction and can be easily detected with an algorithm. Even an ideal square, however, will not show just four uniform directions after a real image acquisition, especially when the rotational position may be at random, but after smoothing the chain code, straight line segments with corresponding directional changes at their end points may be inferred. This simple example already shows the basic idea of contour-based pattern matching. Processing of the contour results in a geometric model of the object, which is de-

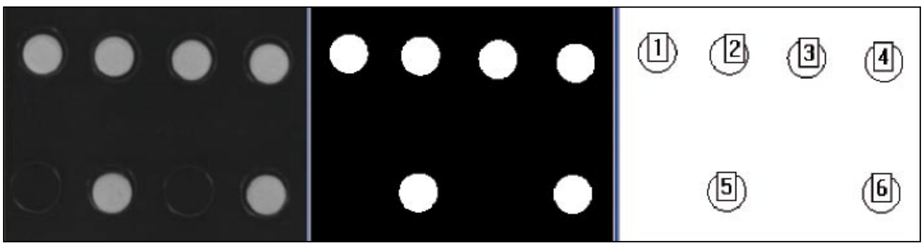

Fig 1: Grey-level image, binary image and label image with contours of binary objects.

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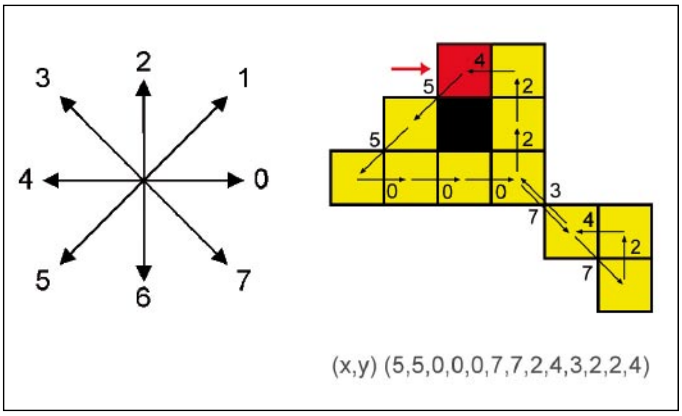

Fig. 2: Freeman's chain-code (left) and an example for chain-coding (right). The contour is traced counter-clockwise, beginning with the red starting point (x,y), and the direction of the subsequent contour step is stored.

scribed in abstract terms rather than as a grey-level template. In this sense, we will look at a square, when the contour is made up of four straight line segments of equal length, which are connected at their ends with a counter-clockwise change of direction by 90°. It is immediately clear that this description will apply to a square whatever its dimensions and angular orientation will be. The model thus will a priori be invariant with respect to scaling and orientation, which is quite a nice feature.

Correlating the Contour

As suggested above, the smoothed chain code of a binary object may be directly compared to the chain code of the template. In order to be invariant against scaling, which means to find similar objects but with different dimensions, the method must use the chain code normalized to a standard length. When the angular orientation is not controlled, there usually will be different starting points for the chain code of the object and of the template, respectively. Matching will be much more complicated under such circumstances. In some applications, features may be calculated from the chain code such as a histogram of directions, e.g., but information will be lost by such procedures, and the classification will in general be ambiguous. An alternative is to code the contour as the radius function. To obtain this function, the centre of mass of the binary object is determined. Starting from a reference direction, the distance between the centre of mass and the contour is measured in defined angular steps and plotted as function of the polar angle. This radius or polar distance function is like a finger print of the object, sometimes also called the signature. An example is shown in figure 3. The red curve in the right upper part of the figure is the smoothed radius function for the pentagon-shaped object shown on the left side. To match this function with a template, the signature of the object under examination is compared with the radius function of the template by shifting the template step by step through the full range of sampling angles and calculating the correlation for every position. When the correlation is above a certain, empirically pre-determined threshold, we have a match. The object is found, and, as additional useful information, the rotational position can be determined, since the angle of best match is known. This method may be regarded as the application of classic pattern matching with grey-level templates to the contour, represented by the radius function, and thus may well be called contour-based pattern matching. Abstract properties of a geometric model, however, have not been used in this approach.

Geometric Model Finder

Pattern matching applied to the contour function requires binary objects, and successful segmentation and a continuous boundary line without gaps are prerequisites. The description of the template by means of an abstract geometric model, however, opens up the possibility to directly compare features of the model with structures within the grey-level image. For this purpose, the first step is to calculate an edge image from the grey-level file and, in the ideal case, to thin these edges to a width of one pixel. The contours of objects thus show up as edges. There also appear, however, edge structures which do not belong to objects but are due to shadows or stem from the surface texture of objects, and some contours are frayed out. The next step is to look for the geometric primitives in the edge image, which appear in the description of the template in terms of geometric modelling. For the case of the square mentioned above, the edge image will be scanned for straight lines. Well suited for this task is the Hough-transform, which calculates a score for straight lines and also for collinear straight line segments. The score can be used to discriminate random matches against the best candidates for true straight line segments in the image [1]. There also exists a Hough-transform for circles, which has already been treated within this series of articles [2]. Straight lines and circles usually are sufficient for the description of contours of real-world objects as a combination of polygons and circular segments. For the square treated as an example above the geometric model means that four straight line segments of equal length have to appear in the edge image, which are in contact at their ends and show a counter-clockwise directional shift of 90° to each other. When only three line segments of equal length are found and a fourth line segment which is shorter, but the requirements concerning directions are fulfilled and three connecting points appear at the ends of the lines, there is a good chance that there is a square in the image which has been partly occluded by another object or is just shadowed. Such a structure may not be classified as a square immediately, but might be a good candidate for a closer look at the image region. Several Geometric Model Finders use more or less complex versions of the Hough-transform for geometric primitives and utilize the relations between these structural elements in the framework of the geometric model for the template or are based on the generalized Hough-transform [3]. By means of these procedures objects can be found which show severe gaps in their contours or which are partly occluded by other objects. With increasing number of parameters in a geometric model, however, the complexity of the implementation will grow, and the processing time will usually soon break the limit of the available time slice, at least for industrial applications.

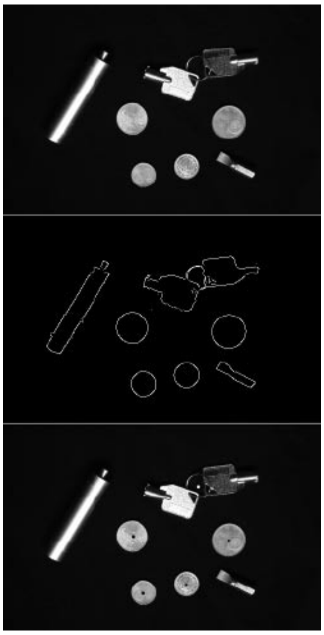

Fig. 4: Grey-level image (top), edge image (centre) and result of the Hough-transform for circles (bottom); points are depicted as overlay with the original image to show the centers of the circles detected. Mind the white point as centre of the partly occluded metal ring.

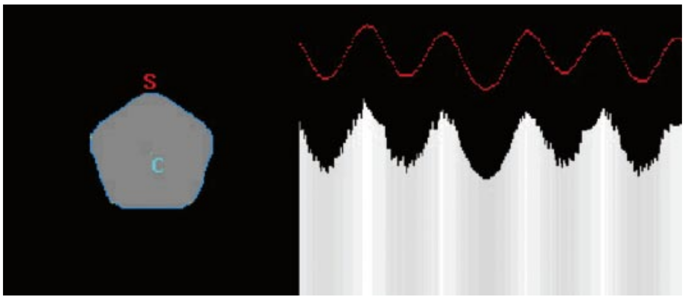

Fig. 3: An object and the corresponding radius function. C is the centre of mass of the object, S is the first contour pixel in the polar distance plot.

Conclusion

Contour-based pattern matching usually refers to search methods in grey-level images based on edge-images and using geometric models of objects. Such Geometric Model Finders may result in good performance even with partly occluded objects and can be invariant with respect to scaling and rotational position. Like the classic grey-level correlation, contour-based methods will only give a (sometimes quite small) probability for a match between the template and a structure in the image. There is a huge range of different approaches for construction and implementation of these procedures [4]. In figure 4, we used the Hough-transform for circles to demonstrate that even simple methods may already be robust with respect to reflections and inhomogeneous lighting, may show good discrimination against further structures and can be quite successful with partly occluded objects. Complex models may soon get out of control concerning processing time and must be carefully optimized [4]. There is no doubt, however, that Geometric Model Finders are a valuable additional tool in the image processing workshop and meanwhile belong to the basics of this field.

References

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