

Corner Detection Using Morphological Skeleton: An Efficient and Nonparametric Approach

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Abstract. In this paper we propose an effective and robust approach for detecting corner points on a given binary image. Unlike other corner detection methods the proposed method is non-parametric in nature, that is, it does not require any input parameter. The proposed method is based on mathematical morphology. It makes use of morphological skeleton for detecting corner points. Convex corner points are obtained by intersecting the morphological boundary and the corresponding skeleton, where as the concave corner points are obtained by intersecting the boundary and the skeleton of the complement image. Experimental results show that the proposed method is more robust and efficient in detecting corner points.

Keywords: Corner points, Morphological skeleton, Non-parametric.

1 Introduction

Corner points on shape curves are effective primitives for shape representation and analysis. Corner points on a digital boundary are found at locations where the nature of the boundary changes abruptly and significantly. They provide critical information of a shape which is useful in pattern analysis and recognition problems. Therefore corner detection in images is an important aspect of computer vision applications.

Many algorithms have been developed for detecting corner points on the boundary curve of an object. The existing corner detection schemes can be broadly classified into two classes, (i) boundary based methods and (ii) Morphology based methods. The former methods involve computation of curvature at every point over a small segment of curve called region of support within the vicinity of the point of interest. The main problems of the boundary based methods are that they are computationally less efficient as they involve determination of region of support and then computation of curvature over the determined region of support involving lots of floating point operations. On the other hand the methods based on mathematical morphology are computationally efficient as they involve only integer operations. In view of this many methods based on mathematical morphology have been proposed in the literature.

[5] have proposed a method for corner detection using mathematical morphology, which makes use of morphological residue for detecting corner points. In their method convex and concave corner points are detected separately. Convex corner clusters are obtained by performing $(A - (A \circ B))$ operation. Subsequently boundary

of the corner cluster is obtained by intersecting the obtained corner clusters with the original boundary. A convex corner point is obtained for each corner cluster. Corner point corresponding to a corner cluster is defined to be the point of intersection of the boundary of the cluster and the normal line passing through the center of the corresponding corner cluster. To detect concave corner points, the procedure is repeated on the complement image. Though the approach is fast, the boundary point detected as corner point is not necessarily a true corner point and some time they are shifted from the actual location. To overcome this problem [2] have suggested a modification by redefining the process of shrinking a corner cluster into a single point. In their approach a corner point in a cluster is defined to be the point with maximal N-hit number. Though the result of the method proposed by [2] is superior to that of [5], it fails to detect all corner points, as the method assumes the existence of only one corner point on each cluster, but in reality there may be more than one corner points in each corner cluster. In addition their method is sensitive to the boundary noise as the N-hit number is susceptible to noise.

[1] proposed a method for corner detection using the asymmetrical closing which is defined as a dilating of an image by a structuring element followed by eroding the result with another structuring element. The idea is to make the dilation and erosion complementary and correspond to variant types of corners. The disadvantage of this method is that sometimes it misses obtuse-angled corners and sharp-angled corners. [4] have proposed a corner detection algorithm based on the morphological skeleton. In this method the corner points are obtained by detecting the zero radius of the maximum plate on the morphological skeleton. The result of the corner detection is achieved by using logical hetero-OR operation between two corner sets of the source image and its complement set. But the drawback of this method is that it detects more spurious corner points. [3] have proposed an improvement to [1]. They have also proposed a method for corner detection using modified regulated morphological operators with adjustable strictness parameters. However, the method is sensitive to the value of strictness parameter, which is difficult to select.

In view of this, in this paper we propose a novel technique for detecting corner points which is as effective as any boundary based technique in detecting corner points and as efficient as any morphology based techniques. The proposed method detects convex and concave corner points separately. At first, morphological skeleton is obtained for a given image. Convex corner points are obtained by intersecting the obtained morphological skeleton of the image with its boundary. Similarly, concave corner points are obtained by performing the same set of operations on the complement image. Further, corner points of the complete image are obtained by performing the union of convex and concave corner points. Even though the method is based on mathematical morphology, the results of the proposed method is independent of size and shape of the structuring element and hence the method does not require any input parameter to decide the size and shape of the structuring element, thus the method is non-parametric in nature.

Rest of the paper is organized as follows: the proposed method is explained in section 2. Experimental results are presented in section 3 followed by the discussions in section 4. Finally paper concludes in section 5.

2 Proposed Method

In this section, we describe the proposed method for detecting corner points present on a given binary image. The proposed method has two stages, skeletonization of the given image followed by localization of corner points.

2.1 Skeletonization

Skeletonization is a process of reducing foreground regions in a binary image to a skeletal residue that largely preserves the extent and connectivity of the original region while throwing away most of the original foreground pixels. To realize this, imagine that the foreground regions in the input binary image are made of some uniform slow-burning material. Ignite simultaneously at all points along the boundary of this region and watch the fire move towards the centre of the image. At the points where the fire traveling from two different boundaries meet, the fire will extinguish itself. Such points put together form the so called 'quench line' and this line is taken as the skeleton of the image. From the above definition it is clear that thinning of an image produces a sort of skeleton.

Skeletonization of an image is also defined as the loci of centers of bi-tangent circles that fit entirely within the foreground region of the image and Fig-1 illustrates this for a rectangular shape.

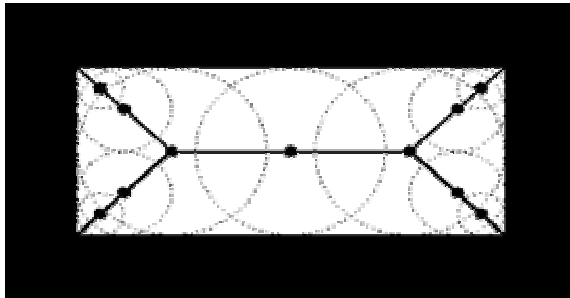


Fig. 1. Skeleton of a rectangle defined in terms of bi-tangent circles

Though, the terms medial axis transform (MAT) and skeletonization are often used interchangeably, in a strict sense, skeletonization is defined for a binary image and MAT is defined for a graylevel image, where each point on the skeleton has an intensity which represents its distance to a boundary in the original object.

The skeleton/MAT can be produced in two ways. The first is to use some kind of morphological thinning that successively erodes away pixels from the boundary (while preserving the end points of line segments) until no more thinning is possible, at which point what is left approximates the skeleton. The alternative method is to first calculate the distance transform of the image. The skeleton then lies along the *singularities* (i.e. creases or curvature discontinuities) in the distance transform. This

latter approach is more suited for calculating the MAT since the MAT is same as the distance transform but with all points off the skeleton suppressed to zero.

The skeleton of a given image A can be expressed in terms of erosions and openings. That is, skeleton S of A denoted by $S(A)$, is given by

$$S(A) = \bigcup_{k=0}^K S_k(A)$$

with

$$S_k(A) = \bigcup_{k=0}^K \{(A \ominus kB) - [(A \ominus kB) \circ B]\}$$

where B is a structuring element, $(A \ominus kB)$ indicates k successive erosions of A; that is

$$(A \ominus kB) = ((\dots (A \ominus B) \ominus B \ominus \dots) \ominus B$$

k times, and K is the last iterative step before A erodes to an empty set. In other words,

$$K = \max\{k \mid (A \ominus kB) \neq \emptyset\}.$$

It can be noticed that A can be reconstructed from these subsets by using the equation

$$A = \bigcup_{k=0}^K (S_k(A) \oplus kB).$$

2.2 Corner Localization

The proposed corner localization scheme detects convex and concave corner points separately. In order to obtain the convex corner points, the proposed method first extracts the morphological skeleton of the given image, and then the obtained morphological skeleton is intersected with the boundary of the image. Since morphological skeleton always touches the convex corner points, the intersection of morphological skeleton with the boundary helps us in detecting all convex corner points. Therefore, convex corner points are obtained as follows:

Let C be the boundary curve of the image A, which is obtained by

$$C = [A - (A \ominus B)]$$

where, B is 3×3 square structuring element.

Convex corner points are obtained by

$$\text{Convex_Corner}(A) = C \cap S(A)$$

Similarly, the concave corner points are obtained by

$$\text{Concave_Corner}(A) = C \cap S(A^1 \oplus E)$$

where, A^1 is the complement image of A, and C is the boundary of A^1 and E is a rhombus structuring element. In case of detecting concave corner points, before ob-

taining the skeleton, A^1 is dilated with a rhombus structuring element E , because $S(A^1)$ does not have any point common with the C .

Overall corner points are obtained by performing union of convex corner set and concave corner set, that is,

$$Corner\ Points(A) = Convex_Corner(A) \cup Concave_Corner(A)$$

The proposed method is explained in detail with the help of the following illustration, Fig-2(a) shows the original image. Fig-2(b) shows the boundary of the original image and its morphological skeleton. It can be observed that morphological skeleton intersects the boundary of the image at convex corner points and hence the convex corner points are the points where the skeleton of the image intersects with the boundary of the image (Fig-2(c)). Fig-2(d) shows the boundary of the original image and the morphological skeleton for the complement of the original image. It can be observed that the skeleton of the complement image intersect the boundary at concave corner point. The detected concave corner points are given in Fig-2(e), and the corner points on the image, which is the union of convex and concave corner points is shown in Fig-2(f).

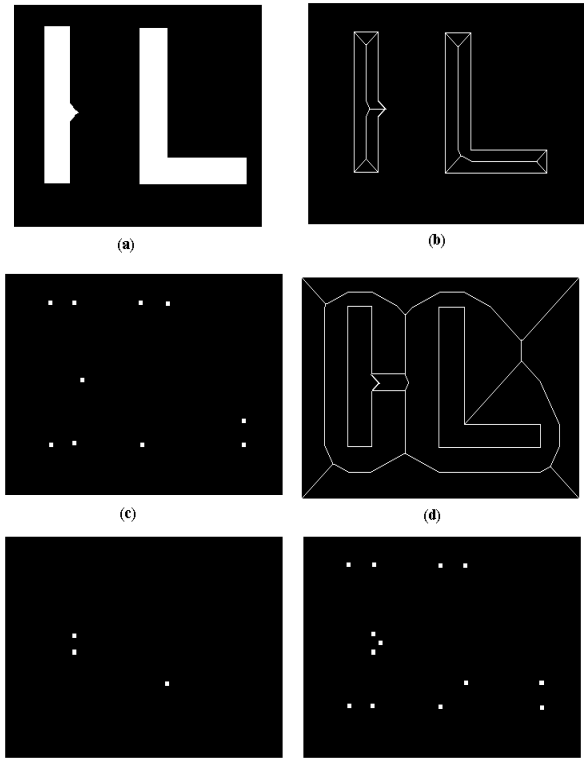


Fig. 2. (a) original image, (b) Boundary and skeleton of (a), (c) Convex Corner points, (d) skeleton of complement image, (e) Concave corner points and (f) All corner points

Thus, the proposed algorithm for detecting corner points on a given binary image is as trivial as follows:

Algorithm: Detect Corner Points

Input: Binary Image (A)

Output: Corner points of the image (A)

Method:

Step 1: Extract the Boundary C as, $C = A - (A \ominus B)$.

Step 2: Extract the Morphological Skeleton $S(A)$.

Step 3: Obtain Convex corner points as $\text{Convex_Corners}(A) = C \cap S(A)$.

Step 4: Extract the Morphological Skeleton $S(A^1 \oplus E)$.

Step 5: Obtain Concave corner points as $\text{Concave_Corners}(A) = C \cap S(A^1 \oplus E)$.

Step 6: Obtain Corner points (A) by performing union of Convex and Concave corner sets.

Algorithm ends.

It can be observed that the proposed method for detecting corner points does not require any input parameters, and hence it is non-parametric. Further, for detecting corner points it is not necessary to obtain the complete skeleton. Thus, it is quite enough if we apply four or five iteration of skeletonization process. In addition, efficiency of the proposed method further be improved by implementing the proposed method on parallel computers with SIMD architecture, where the process of convex corner and concave corner can be run parallelly. Therefore the proposed method is both effective and efficient.

3 Experimental Results

In order to reveal the robustness of the proposed method in real pragmatic situation we have conducted several experiments on several shapes (including the shapes

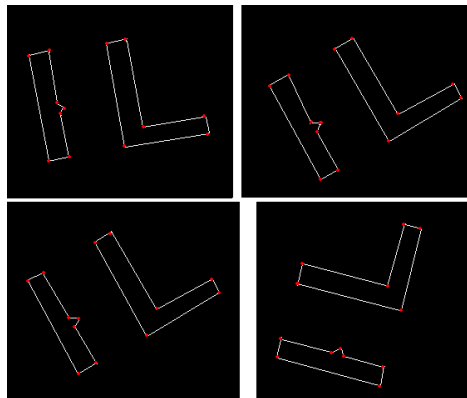


Fig. 3. Results of the proposed method for shape shown in Fig-2(a), in different orientations

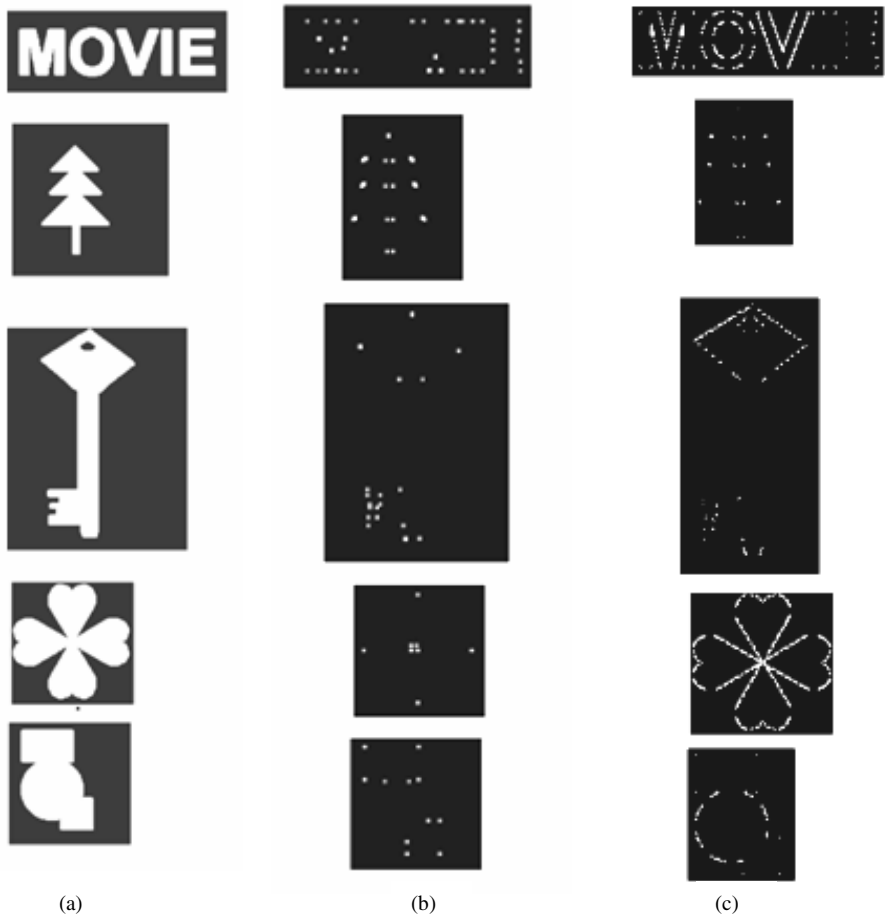


Fig. 4. (a) Input Objects, (b) Corner points detected by proposed method and (c) Corner points detected by Yu et. al., (2001)

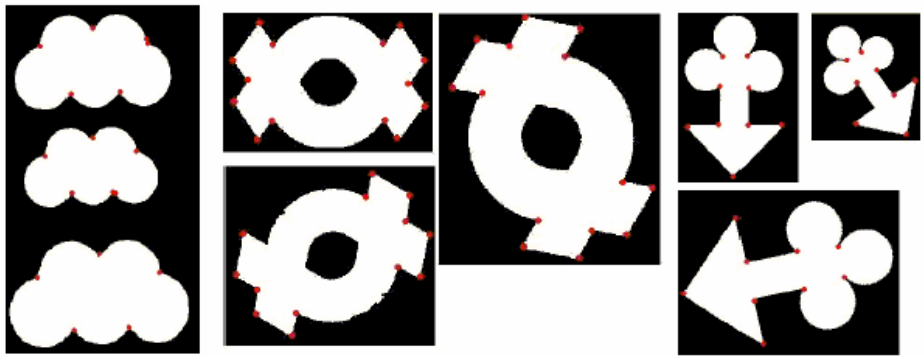


Fig. 5. Results of the proposed method for shapes in different orientations and scaling factors

considered by many researchers) with different scaling factors and in different orientations. The set of shapes considered for experimentation includes shapes with smooth curve segments of different radii or curvature, curvilinear segments, straight line segments. Fig-4 (b) shows the results of the proposed method for various shapes. For the purpose of establishing the superiority of the proposed method over existing morphology based methods, the results of the proposed method are compared with that of the method proposed by [4], this method is purposefully chosen, as it is claimed to be the best method in the literature. The results of the [4] method is given in Fig-4 (c) for the input images shown in Fig-4 (a). It can be observed from the Fig-4, that the method proposed by [4] has detected many spurious corner points. On the other hand the proposed method has not detected even a single spurious corner point. Fig-3 and Fig-5 show the results of the proposed method for the shapes in different orientations and scaling factors, which reveals the invariance property of the proposed method in detecting corner points. The objects shown in Fig-5 contains moderate amount of noise, the results of the proposed method on these objects demonstrates the noise withstanding property of the proposed method.

4 Discussion

The major problem with the existing boundary based corner detection schemes is that they are less efficient since at every boundary point, it is required to compute the region of support and as well the curvature at that point to decide if the point is a corner point. In addition they are parametric in nature. The advantage of these methods is that all true corner points are detected. On the other hand, the morphological operation based approaches appear to be more efficient since they selectively decide the parts of the boundary which have corner points to locate the true corner points. But they are less effective as they failed to detect all true corner points. Unlike these, the proposed method being simple approach is both efficient and effective. In addition, the proposed method is nonparametric, as it does not require any input parameter either to decide the size or shape of the structuring element. The existing morphology based methods ([5], [2], [1]) demand input parameters to decide the size and shape of the structuring element and the performance of these methods are heavily driven by the chosen input parameters.

5 Conclusion

A simple method for corner detection using mathematical morphology is presented in this paper. The method is based on morphological skeleton. Corner points are the points where the morphological skeleton intersects the boundary of the image. The proposed method unlike the other morphology based methods detects all corner points present in the extracted corner clusters. In addition the proposed method is non-parametric. The experimental results reveal that the proposed method outperforms the existing morphology based corner detection schemes.

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