Morphology Based Spatial Relationships between Local Primitives in Line Drawings

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Abstract. Local primitives and their spatial relationships are useful in the analysis, recognition and retrieval of document and patent binary images. In this paper, a morphology based approach is proposed to establish the connections between the local primitives found at the optimally detected junction points and end points. The grayscale geodesic dilation is employed as the basic technique by taking a marker image with gray values at the local primitives and the skeleton of the original image as the mask image. The geodesic paths along the skeleton between the local primitives are traversed and their points of contact are protected by updating the mask image after each geodesic dilation iteration. By scanning the final marker image for the contact points of the traversed geodesic paths, connections between the local primitives are established. The proposed approach is robust and scale invariant.

Keywords: local primitives, spatial relationships, grayscale geodesic dilation.

1 Introduction

Binary images such as technical drawings, diagrams, flowcharts etc. are found in patents and scientific documents. They are composed of lines intersecting each other in different directions. The local pattern formed by the composition of intersecting or crossing lines at a junction point and end point of lines is called a local primitive. Local primitives and their spatial arrangement are useful in the analysis, recognition and retrieval of binary images. To capture the content of binary images found in patents, different geometric shapes and their spatial relationships have been the target information to be explored in the literature.

In an attempt to capture the topological information in drawings, the spatial relationships between shape primitives have been modeled at inclusion, adjacency and disjoint levels in [8] and at inclusion and adjacency levels in [14].

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Targeting the retrieval of hand drawn sketches, Leung et al. [12] and Parker et al. [15] estimate shape types from each stroke using heuristics and exploit spatial relationship at only inclusion level with the geometrical relationship between multiple strokes. Fonseca et al. [7] capture the topological information of the drawing by isolating polygons and modeling the spatial relationships of polygons in the form of a topology graph. Liu et al. [13] detect the lines and curves in a line drawing and capture the local neighborhood structure of a local patch in the drawing by considering a primitive as a reference and using four geometric cues such as relative minimum distance (the minimum distance between the neighbor and the reference primitives divided by the length of the reference), relative distance, relative length and relative angle to describe the spatial relationships between the reference and neighboring primitives. Huet et al. [11] extract line patterns in skeleton images obtained by Voronoi Skeletonization of patent images and create line segments from the extracted line patterns by a polygonization technique. The relational features of a line segment in relation to another line segment such as relational angle and relational position are used to capture the geometric structure of the image. In an attempt to generate an approximate formal ground truth similar to the ground truth binary map (silhouette) created by a human from the input map of an image, Bergevin et al. [2] use six criteria for grouping the constant-curvature contour primitives in a pairwise fashion based on the Gestalt grouping laws [6]. A grouping criterion is decided based upon the distance of the two primitives in pixels. Santosh et al. [16] presented an approach to unify the topological and spatial relations between two objects by finding a unique reference point set based on their minimum bounding rectangle topology. Forstner [9] emphasizes that the neighborhood relations derived from a Voronoi diagram exhibit uncertainty when the common sides of two Voronoi cells are comparably short. The author proposed the concept of fuzzy Delaunay triangulation which takes into account the uncertainty in neighborhood relations between point fields based on a Voronoi diagram or planar Delaunay triangulation [18].

For the natural images, the local features lying at an arbitrary distance (Euclidean) to a specific local feature inside its circular neighborhood of arbitrary radius are assumed to be spatially related to each other [1], [3]. In binary line drawing images, the technique of an arbitrary circular neighborhood around a local primitive establishes the spatial relationship between two local primitives which may not be geodesically related to each other. In a line drawing image, two local primitives with a geodesic path (skeletal line connection) between them that does not pass through any other primitives are said to have a *geodesic spatial neighborhood relationship*.

To establish the geodesic spatial relationships between the local primitives, a novel mathematical morphology based approach is proposed in this paper. The main contributions are: (1) establishment of connections between local primitives based on the geodesic paths (skeletal line connections between them), (2) adaptation of the mask image after each geodesic dilation iteration to protect the points of contact of the traversed geodesic paths between the local primitives, (3) extraction of adjacency relations (connections) between local primitives based on the image generated by infinite geodesic dilations by the proposed algorithm. The proposed approach is robust in establishing the spatial relationships between all the local primitives found in a line drawing image and is explained in Section 3. The detection and classification of local primitives is explained in Section 2. The results for the proposed approach are presented and discussed in Section 4 and a conclusion is drawn in Section 5.

2 Detection and Classification of Local Primitives

At first, a homotopic skeleton of the original image is obtained by performing a series of sequential morphological thinning operations [17]. Template based matching [17] is used to detect junction points and end points in the homotopic skeleton which gives rise to false detections due to the false skeletal lines introduced during the thinning process of the image as can be seen in Figure 1(a). A morphological spurring operation [17] removes the parasitic skeletal lines in the skeleton image by the number of iterations it is performed. An intersection of the skeleton image containing detections with an iteratively morphological spurred image eradicates the false detections. To determine an optimum number of iterations for the morphological spurring operation, the proposed approach takes into account the average thickness of lines L_{th} obtained by taking a weighted average of the pattern spectrum [17] $PS_k(I)$ obtained from the granulometry of the original image, given as:

$$L_{th} = \frac{\sum_k PS_k(I) * k}{\sum_k PS_k(I)} \quad (1)$$

where $PS_k(I)$ is the value of bin k of the $PS_k(I)$ and is obtained by taking the discrete derivative of the granulometric curve of the original image. To remove the noisy detections, an optimum number of spurring iterations for EPs are computed as $GI_{EP} = \lceil L_{th}/2 \rceil$ and for JPs as $GI_{JP} = \lfloor L_{th} \rfloor$ (the values for L_{th} obtained are floating point) [5]. An optimum detection for JPs and EPs is shown in the Figures 1(b) and 1(c) respectively. The combined optimum detection of EPs and JPs is shown in Figure 2(l) superimposed as green plus marks on the ground truth marked as red.

The local primitives (EPPs and JPPs) are classified into primitive classes by taking into account their composition in an 8-directional space using a distance based approach [4]. Lines in regions around junction and end points are quantized into 8 directions, which are represented in a binary vector similar to the approach used in the Local Binary Pattern (LBP) [10]. There are 8 end point primitive classes and 244 junction point primitive classes (not 248 because the junction point primitives composed of lines having an angular difference of exactly 180^o with each other do not fulfill the definition of a junction point primitive and would be 4 in number in 8-directional space). As a result of this process, each EPP and JPP has a class number associated with it. It is also possible to quantize into 4 directions instead of 8, resulting in only 14 classes (4 for EPPs and 10 for JPPs).

(a) (b) (c)

Fig. 1. (a) Noisy thinned image with JPs and EPs detected (b) The GI_{JP} times spurred skeletal image with JPs detection.(c) EPs detection in GI_{EP} times spurred skeletal image.

3 Geodesic Spatial Relationships between Local Primitives

To establish the geodesic spatial neighborhood relationship between such local primitives, the proposed approach intends to traverse the existing geodesic path between them. By establishing the geodesic spatial relationships between the local primitives found in a line drawing, the pair-wise co-occurrence of local primitives can be captured. To traverse the geodesic paths between all the local primitives, the proposed approach constructs a gray scale image G by placing unique gray value pixels at the positions of the local primitives and a gray scale skeleton image S by assigning a gray value $G_m = \max(G) + 1$ to the non-zero pixels in the binary skeleton image obtained by GI_{EP} spurring iterations in Section 2. To establish the geodesic spatial relationships between the local primitives, a morphology based approach using successive gray scale geodesic dilations is adopted. Considering S as the mask image and G as the marker image, the proposed approach performs successive gray scale geodesic dilations [17]. At the n^{th} grayscale geodesic dilation, a grayscale marker image I_{d_n} and the grayscale mask image I_{m_n} are obtained by:

$$I_{d_n} = \delta\left(I_{d_{n-1}}\right) \wedge I_{m_{n-1}} \tag{2}$$

$$I_{m_n} = I_{m_{n-1}} \wedge f_{0 \to G_m}\left(I_{d_n}\right) \tag{3}$$

where $n = 1, 2, ...$ and $I_{d_0} = G$, $I_{m_0} = S$ are the initial grayscale marker and mask images as shown in Figures 2 (a) and (d) respectively for an example image. The function $f_{0 \to G_m}$ converts all zero-pixels in I_{d_n} to G_m. Successive gray scale geodesic dilations are performed until $I_{d_n} = I_{d_{n-1}}$ where each dilation operation δ is performed by a unit structuring element. When applying the above process, at each successive geodesic dilation operation, geodesic paths emerging from each local primitive towards their spatially connected local primitives are traversed by converting one non-zero pixel of each geodesic path (skeletal line connection) to the corresponding gray value of the local primitive. A geodesic path consisting of n pixels between two local primitives takes $n/2$ successive dilation operations to be traversed from each local primitive. In this way, geodesic

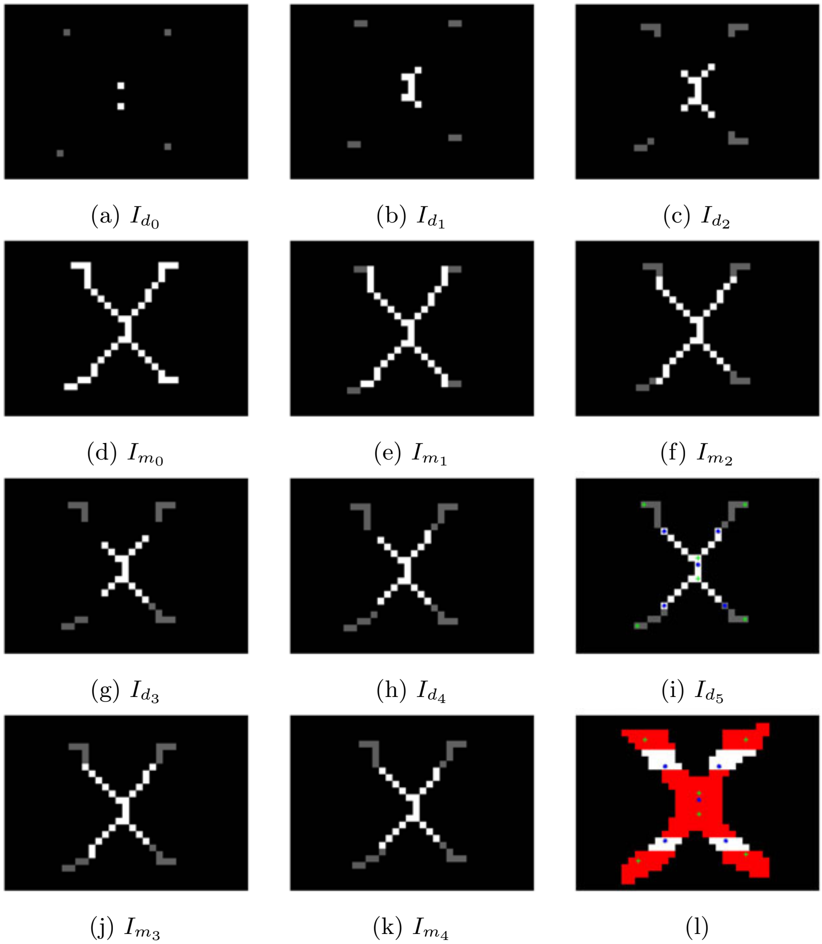

Fig. 2. (a)-(c) and (g)-(i) show the successive grayscale marker images at each successive grayscale geodesic dilation. $I_{d_0} = G$ is the initial gray scale marker image and I_{d_5} is the final grayscale image for the example image containing points of contact shown with blue asterisk marks and locations of local primitives with green plus marks. (d)-(f) and (j), (k) show the corresponding grayscale mask images at successive geodesic dilation. $I_{m_0} = S$ is the initial mask image obtained by assigning gray value G_m to non-zero pixels to the skeleton image $SSI_{GI_{EP}}$. The original example image with red ground truth for JPs and EPs, superimposed detection of JPs and EPs in green plus marks and their contact points for geodesic spatial relationships in blue asterisk marks determined by the proposed method is shown in (l).

paths of short length are traversed before than the long ones. Continuing the path traversing procedure overruns the contact points of already traversed paths of short lengths. To protect the contact points, the mask image I_{m_n} is updated after each successive dilation operation as given by Equation 3. The successive

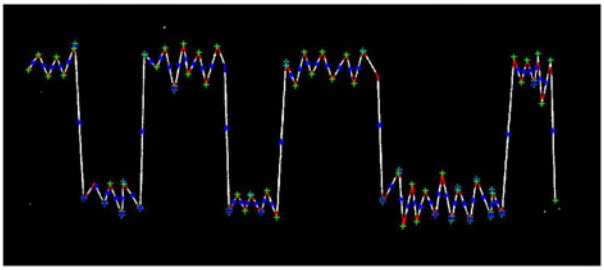

Fig. 3. One of the ten images with ground truth points (red) and superimposed detected EPs and JPs (green) with contact points of traversed geodesic paths (blue)

steps involved in the establishment of geodesic spatial relationships between local primitives by the proposed approach are shown visually for an example image in the Figure 2. Figures 2 (b), (c), (g), (h) and (i) show the images obtained by the successive gray scale geodesic dilation operations given by Equation 2. The corresponding I_{m_n} mask images for the I_{d_n} marker images are shown in Figures 2 (d), (e), (f), (j) and (k).

The final gray scale image I_{d_n} contains all the traversed geodesic paths with their contact points which consist of two neighboring pixels with different gray values indicating the spatially connected local primitives. Local primitives which have geodesic spatial relationships between them are found by scanning I_{d_n} for the neighboring different gray value pixels and their neighborhood relations are established by locating their corresponding locations in the original image using the initial grayscale image e.g. the neighboring pixels at a contact point of the traversed geodesic path between a JP with gray value 3 and an EP with gray value 20 indicates that JP 3 is spatially connected to EP 20 and the geodesic

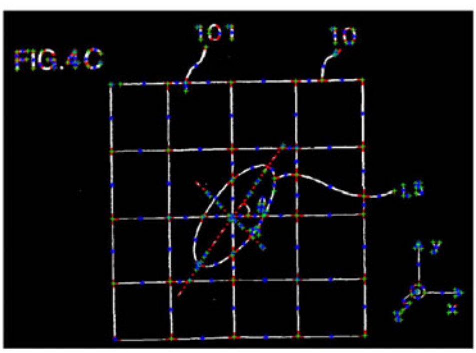

Fig. 4. One of the ten images with ground truth points (red) and superimposed detected EPs and JPs (green) with contact points of traversed geodesic paths (blue)

spatial relationship between the corresponding local primitives of these gray values is established in the original image. The established geodesic spatial relationships between the local primitives (EPPs and JPPs) by the proposed approach are shown superimposed on the final I_{d_n} (which is I_{d_5} for this image) and original example image with ground truth of junction and end points (marked as red) in Figures 2 (i) and (l). The green points mark the JPs and EPs and the blue points mark the contact points of the geodesic paths traversed from each point towards other neighboring points.

4 Results and Discussion

To evaluate the performance of the proposed approach ten images are selected from a publically available patent image database[1]. The visual results for two out of the ten selected images are shown in Figures 3 and 4. It can be seen that the proposed approach successfully establishes the geodesic spatial relationships between all the local primitives found at the detected junction and end points. Having established the geodesic neighborhood relations of the local primitives by the developed method, the pairwise co-occurrences of the local primitives in addition to their independent occurrences can be captured. In an occurrence histogram each bin represents the occurrence frequency of a local primitive, whereas each bin of co-occurrence histogram represents the occurrence frequency of a pair of local primitives. The representation of line drawing images in terms of the occurrence and co-occurrence histograms of local primitives are useful in the recognition, analysis and retrieval of these images. It is noted that the establishment of geodesic spatial relationships is highly dependent on the detection of EPs and JPs which is a first step in the proposed approach. Due to the false EPs and JPs detections, geodesic spatial relationships can be established between a true and a false local primitive, which can be overcome by eradicating the false detections. The proposed approach takes $n/2$ iterations to establish the spatial relationships between two primitives which are n pixels apart. So, the computational complexity of the approach depends upon the longest distance (in terms of pixels) of any two primitives in an image and scale of the image as well.

5 Conclusion

A novel mathematical morphology based approach employing the grayscale geodesic dilation is proposed to establish the spatial relationships between the local primitives found at the junction and end points in binary line drawing images. The proposed approach is robust and successfully established the geodesic spatial relationships between all the local primitives. As the detection and classification of local primitives found at the junction points and end points is the first step, the establishment of geodesic spatial relationships depends upon the detection of these points. By establishing the geodesic spatial relationships between

[1] http://mklab.iti.gr/content/patent-database

local primitives, their pairwise co-occurrences in addition to the independent occurrences can be captured in the form of histograms which are useful in the recognition, retrieval and classification of drawing images.

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