Enhanced Morphological Contour Representation and Reconstruction using Line Segments

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Abstract

The paper proposes an enhanced morphological contour/edge representation algorithm for the representation of 2D binary shapes of digital images. The concise representation algorithm uses representative lines of different sizes and types to cover all the significant features of the binary contour/edge image. These well characterized representative line segments, which may overlap among different types, take minimum representative points than that of most other prominent shape representation algorithms including MST and MSD. The new algorithm is computationally efficient than most other algorithms in the literature and is also capable of approximating edge images. The approximated outputs produced by the proposed algorithm by using minimal number of representative points are more natural to the original shapes than that of MST and MSD.

Keywords: closing, dilation, erosion, opening, representation

1. INTRODUCTION

Humans recognize objects mainly on the basis of their shapes and so its representation is an important issue of concern in image processing and computer vision to provide the foundation for image coding [4], shape matching and object recognition [1], content-based video processing [12], [13], image data retrieval [14], character recognition [2], automatic visual inspection and medical diagnostics [3]. A good shape representation algorithm should be precise, well defined, accurate, complete, easily reconstruct able and computationally efficient.

Targeting these requirements, through these years a number of representation algorithms have evolved focusing the shape characteristics [4]-[5], [7], [9], [15]-[16]. Charif and Schonfeld [17] made a thinning based shape representation algorithm. Multiple structuring elements and minimal enclosing structure elements are proposed in the scheme of Pitas et. al [7]. Algorithms including parity check [8] and chain code [18] are also proposed for representing shape images. But the conventional parity check is not reversible unless the shapes are very simple. Maragos attempted to represent an image as a minimal union of translated and scaled patterns from a finite basic pattern class. Y. M. Y. Hasan and L. J. Karam [10] proposed a reversible contour representation algorithm in which shape images is decomposed into residual and ambiguous contours but the algorithm is too complex in its representation and reconstruction phases.

Many basic morphological shape representations have also been employed [5], [11], [16] on binary shape images. The morphological skeleton transform (MST) [4] represents shape as a union of all maximal disks but the disks tend to be larger in size and highly overlapping. As a variation to the morphological skeleton transform a decomposition scheme is proposed in [16]. The morphological shape decomposition (MSD) [5] decomposes the binary shape into non-overlapping components of overlapping disks each, which tend to be smaller affecting the reconstruction efficiency. Though these algorithms could meet some of the basic requirements of a typical representation algorithm, they lose their focus in parallely meeting other vital aspects like computational efficiency, lesser bit-rate, minimal representative points and so on.

In this paper, we propose a new representation algorithm where a given shape is represented as a union of a number of overlapping lines contained in the given shape. The paper is organized in 6 sections. Section 2 gives an overview of the fundamental morphological operations involved in the shape representation scheme and explains the features of MSD and MST. Section 3 explains the features and improved characteristics of the proposed shape representation and reconstruction algorithms. The simulation results are provided in Section 4. Further Scope is explored in section 5 and Conclusions are finally made in Section 6.

2. MORPHOLOGICAL REPRESENTATION OPERATORS

The binary shapes extracted from images are represented before being stored in the knowledge base. The shape so represented is reconstructed and filled to be matched or recognized later on with a suitable input as shall be the requirement. The shape representation scheme passes the image to be represented through a morphological pre-processing set-up. It is then subjected to the reversible shape representation algorithms. The general morphological operations involved in these steps, the features of the top-ranking internal shape representation algorithms, MST and MSD are highlighted in this section

2.1 Basic Morphological Operations

In the morphological analysis of binary images, a *2D* image is defined as a subset of *2D* Euclidean space $R \times R$ or its digital equivalent $Z \times Z$ .For a digital image $A \in Z \times Z$ and a point, $b \in Z \times Z$,the translation of A by b is defined as

$$(A)_b = \{a+b \mid a \in A\} \quad (1)$$

The morphological dilation of the image A by the structuring element (SE), B expands the image while morphological erosion of A by B shrinks the image. They are defined respectively in (2) and (3).

$$A \oplus B = \bigcup_{b \in B} (A)_b \quad (2)$$

$$A \Theta B = \bigcap_{b \in B} (A)_{-b} \quad (3)$$

Opening of the binary image A by structuring element B denoted as $A \circ B$, is defined as

$$A \circ B = (A \Theta B) \oplus B \quad (4)$$

Closing of the binary image A by structure element B denoted as $A \bullet B$, is defined as

$$A \bullet B = (A \oplus B) \Theta B \quad (5)$$

2.2 The MST and MSD

The morphological skeleton transform (MST) [4] is a simple and efficient shape representation scheme where a binary shape X is represented as union of all the maximal disks contained in it. These maximal disks of different sizes may overlap with each other as can be determined directly from the shape.

$$X = \bigcup_{i=0}^{N} S_i \oplus iB \quad (6)$$

Where

$$S_i = (X \Theta iB) \setminus ((X \Theta iB) \circ B) \quad (7)$$

'\ ' is the logical difference operator, N is the largest integer such that $X \Theta NB \neq \phi$ and $iB = B \oplus B \oplus \ldots \oplus B$ *i times* is a disk of size *i.* The skeleton subset S_i contains the centers of all maximal inscribable disks of size *i*. A maximal disk cannot be contained in a representative disk of larger size and the maximal disks of different sizes may overlap. So, in general

$$(S_i \oplus iB) \cap (S_j \oplus jB) \neq \phi, \quad for\ i \neq j \qquad (8)$$

Another interpretation on these skeleton subsets is that *Si* is the set of centers of all disks of size *i* in *X* that are not contained in any representative (maximal) disks of larger sizes, the shape can be reconstructed as

$$X = ((((S_N \oplus B) \cup S_{N-1}) \oplus B) \cup S_{N-2}) \oplus ... \cup S_0 \qquad (9)$$

Therefore, *N* dilations with *B* will be needed to reconstruct *X* from all the skeleton subsets. The MST usually uses comparatively fewer numbers of larger, overlapping disks to represent a given shape. There is no simple and obvious way of combining representative disks into more meaningful shape components due to heavy overlapping.

The morphological shape decomposition (MSD) [5] decomposed a binary shape into a union of certain non overlapping disks contained in the shape with minimum morphological operations. A binary shape *X* is represented by the MSD as a union of certain disks contained in *X* .

$$X = \bigcup_{i=0}^{N} L_i \oplus iB \qquad (10)$$

Where $L_N = X \ominus NB$ and

$$L_i = \left(X \setminus \left(\bigcup_{j=i+1}^{N} L_j \oplus jB \right) \right) \ominus iB, \quad 0 \leq i < N \qquad (11)$$

Again, *N* is the largest integer such that $X \ominus NB \neq \phi$. The sets of centers of representative disks of different sizes $L_N, L_{N-1} .... L_0$ are determined in the order given and then

$$(L_i \oplus iB) \cap (L_j \oplus jB) = \phi, \quad for\ i \neq j \qquad (12)$$

The centers, *Li* of all the disks of size *i* contained in *X* that do not intersect with any representative disks of larger sizes are determined by removing all the representative disks of larger sizes from the given shape and then finding all the centers of representative disks of size *i* in the remaining areas. Overlapping between disks of the same size still exists. Similar to the MST, the original image *X* can be reconstructed using *N* dilations with *B* such that

$$X = ((((L_N \oplus B) \cup L_{N-1}) \oplus B) \cup L_{N-2}) \oplus .... \cup L_0 \qquad (13)$$

Where some of the *Li's* can be empty.

Thus shape can be easily represented by the components generated by MSD using the larger number of smaller, non-overlapping disks. Though the level of redundancy and the reconstruction cost when compared to MST are less, the numbers of disks used by the MSD are higher.

3. PROPOSED REPRESENTATION ALGORITHM

The proposed representation algorithm represents shape as a union of a number of representative lines contained in its boundary extracted image. This algorithm is efficient than many other shape representation algorithms, represents all type of images, even the edge extracted images with less number of representative points. It is featured towards cost effective representation of shapes, reduced representation error and least burden in pattern recognition applications. The operations involved in representation and reconstruction of the shape of the object is schematically shown in Figure 1.

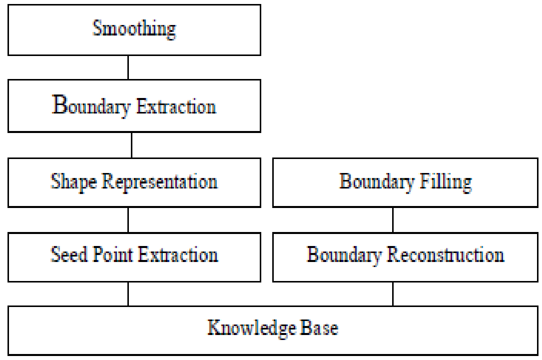

Figure 1. Block diagram of Representation Scheme

3.1. Boundary Extraction and Smoothing

The noise manifestations in the shape of the object is smoothened by performing closing after opening the input binary shape images and is represented as

$$(A \circ B) \bullet B \qquad (14)$$

In the proposed representation scheme, the internal boundary, *K* of the shape, *A* or the set of object pixels that have at least one non-object neighbor is extracted from the morphological erosion gradient (EG). $K = EG(A, B) = A \setminus A \Theta B$ (15)

where *B* is a *3*x*3* *4* or *8* connected flat structural element. The boundary extracted image is then represented by proposed representation algorithm.

3.2. Proposed Representation Algorithm

The new approach uses four types of structural elements which are shown in Figure 2. These structural elements represent the boundary extracted binary shape image, *K* as a union of maximal representative lines such that

$$K = \bigcup_{j=1}^{4} \bigcup_{i=0}^{N} C_{ij} \oplus iB_j \qquad (16)$$

where $0 \leq i$ □ N and $j=1....4$.

$$C_{ij} = \left(K \setminus \left(\bigcup_{k=i+1}^{N} C_{kj} \oplus kB_j \right) \right) \Theta iB_j \qquad (17)$$

and

$$C_{Nj} = K \Theta NB_j$$

If there arise any two points x_{ij}, y_{ij} such that $x_{ij}, y_{ij} \in C_{ij}$

and if $(x_{ij} \oplus iB_j) \cap (y_{ij} \oplus iB_j) \neq \phi$

one of them is arbitrarily selected and other is rejected. The sets of centers of representative disks of different sizes $C_{Nj}, C_{N-1j}, \ldots, C_0$ must be determined in the order given, then

$$(C_{ij} \oplus iB_j) \cap (C_{kl} \oplus kB_l) = \phi, \quad for\ j = l \qquad (18)$$ and

$$(C_{ij} \oplus iB_j) \cap (C_{kl} \oplus kB_l) \neq \phi, \quad for\ j \neq l \qquad (19)$$

This means that overlapping of representative lines is allowed only between lines of different types.

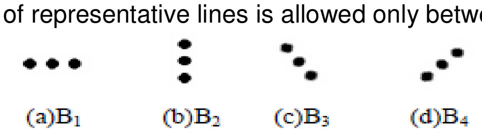

Figure 2. Four basic structural elements

Here, in this new approach the representative points used to represent a shape are very less when compared with MSD and MST. The four basic structural elements when dilated twice with themselves can be written as $3B_1$, $3B_2$, $3B_3$, $3B_4$ and are shown in Figure 3.

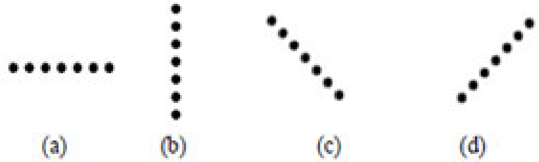

Figure 3. Structural elements (a)$3B_1$ (b)$3B_2$ (c)$3B_3$ (d) $3B_4$

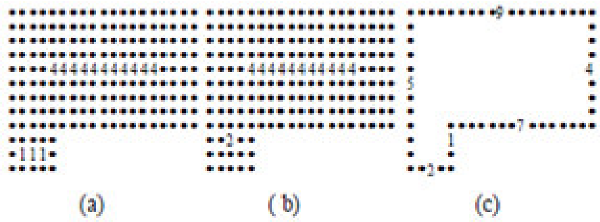

Figure 4. Representation example: (a) MSD, (b) MST, and (c) Proposed algorithm

In this implementation, the unit line B_1 is defined as B_1 the size two line $2B_1$ is defined as $B_1 \oplus B_1$ and the size three line $3B_1$ is defined as $(B_1 \oplus B_1) \oplus B_1$. In general, a line of size *i* and type *j* is defined

$$iB_j = (i-1)B_j \oplus B_j, where\ 1 \le j \le 4 \qquad (20)$$

In this proposed representation algorithm, overlapping is allowed only between representative line segments of different types. A line is selected if it matches with some parts of the given boundary image. Compared to MST and MSD, the overlapping level is much lower since the overlapping between two lines segments is always reduced to a single point. Therefore the redundancy level is much lower when compared to MST and MSD; the moderate overlapping reduces the number of representative points needed. Consider the image in Figure 4. The MST uses twelve representative points, the MSD uses a maximum number of fourteen points and the proposed method uses the fewest number of six points to represent it. For an image X , the proposed representation algorithm produces a sequence of center point sets: $C_{Nj}, C_{N-1j}, .., C_0$.

3.3. Representation Seed Point Extraction

If N_{ijk} is the four/eight neighbors of C_{ij} then

$$Seed_{ij} = \{k \,/\, for\ any\ N_{ijk} \subset X \Theta SB\} \qquad (21)$$

where *SB* is a 4 or 8 connected structural element which depends upon the seed filling algorithm. The cardinality $(CARD(Seed_{ij}))$ on being greater than one, any one of them is arbitrarily selected as the seed point, $Seed_{i,j}$. The final representative set, *RP* for the proposed algorithm is a combination of C_{ij} and $Seed_{ij}$. i.e.,

$$RP_{ij} = \{ (RC_{ij}, R_k) \,/\, RC_{ij} = C_{ij}\ and\ R_k = Seed_{ij} \} \qquad (22)$$

The seed point $Seed_{ij}$ is stored to refer it as one of the constraints in the representative table which ranges between zero to seven and further the region filling in the reconstruction phase of the algorithm uses these seed point indices to reconstruct the original shape.

3.4. The Reconstruction Algorithm

The representative point set, *RP* of the boundary extracted binary shape generated by the representation algorithm is used by the proposed lossless reconstruction algorithm. Similar to the MST and MSD, the boundary image *K* can be reconstructed using *N* dilations of *RCij* with *Bj*

$$K = \bigcup_{j=1}^{4} (((C_{N,j} \oplus B_j) \cup C_{N-1,j}) \oplus B_j) \oplus ... \cup C_0 \quad . \qquad (23)$$

for all *j=1…4*

$N \times 4$ dilations are needed to reconstruct the contour/ boundary of the given shape. This reconstruction algorithm is much faster than most other algorithms in the literature since the overlapping level is reduced to some points of the lines. Looking into the R_k field of the representative point set, *RP* the initial seed point for region filling is identified and is fed to the appropriate seed-filling algorithm for reconstructing the original shape. In this scheme the traditional area filling algorithm is used.

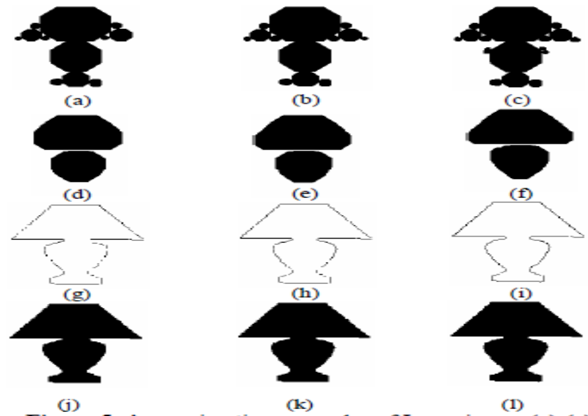

Figure 5. Approximation examples of Lamp image (a)-(c) MSD, (d)-(f) MST, (g)-(i) New algorithm before edge linking and filling. (j)-(l) New algorithm after edge linking and filling. 1st, 2nd and 3rd columns respectively use 80, 100 and 120 RPs.

4. Experimental Results and Simulation Analysis

The proposed representation algorithm is tested on a variety of binary shape images of varied sizes and complexity of which Teapot, Lamp, Telephone, Temple, Puzzle, Letters, Digits, Lena, House, Tree, Building are used here for subjective and objective comparisons. The approximation examples of Lamp image shown in Figure 5. confirm the improved subjectiveness and efficiency of the proposed representation algorithm over the MSD and MST. The reconstructed images generated by the proposed algorithm are shown through Figure.6 (g) to Figure.6 (i). These outputs are edge liked by using the effective edge linking algorithm proposed in [6] and are then filled by the traditional flood filling algorithm as are shown in (j) to (l) of Figure 5. The reconstructed shapes from the new algorithms are more equivalent to the original binary shapes though different number of RPs are used by the three representation schemes; 80, 100 and 120 respectively as are shown in the first three columns of Figure 5.

Table 1. Representative Points (RP) and Computation time (CT) in Seconds of MST, MSD, J. Xu Approach and Proposed Algorithms.

Images	MST		MSD		J. Xu Approach		Proposed Algorithm	
	RP	CT	RP	CT	RP	CT	RP	CT
Teapot	188	49.31	349	41.62	217	45.83	141	26.7
Lamp	238	51.74	439	46.37	248	47.62	140	28.3
Telephone	300	62.98	587	54.89	305	59.37	189	32.4
Temple	1715	85.23	1837	70.42	1879	78.91	697	37.1
Puzzle	286	57.70	450	43.25	281	48.48	281	27.1
Letters	567	65.49	585	55.27	460	60.62	460	29.6
Digits	731	75.25	717	65.85	613	71.47	613	32.2
Lenna	1501	84.32	1600	71.36	1347	78.27	712	35.8
House	1005	70.88	1101	60.85	963	67.68	963	30.1
Tree	1919	97.73	1956	75.38	1658	84.94	952	36.1
Building	2346	98.16	2876	85.32	2149	91.82	1476	46.1

(a) (b) (c)

Figure 6. Approximation example (a) Canny edge detected Image of cameraman. (b) Image reconstructed by new algorithm using 800 RP (c) Image reconstructed by new algorithm using 1000 RP

The proposed representation algorithm is also capable of approximating edge images. This can be observed from Figure.6 where the edge detected cameraman image is approximated by the proposed algorithm with fewer representative points. Figure.6 (b) and (c) respectively are the images reconstructed by the proposed algorithm using800RP and 1000RP. Table.1 shows the number of Representative Points (RP) and the Computation time(CT) in Seconds of MST, MSD and the Proposed Algorithms. The representative points used by the proposed algorithm for representing the binary shape is far less when compared to the conventional MST, MSD, J. Xu Approach [11] as recorded in the Table 1 which also shows the improved computational efficiency of the proposed representation algorithm over the MST and the MSD.

5. CONSLUSION & FUTURE WORK

In this paper, a new morphological shape and edge representation and reconstruction algorithm is proposed which represents a boundary extracted binary shape as a union of a number of maximal lines contained in the shape. The experimental results have shown that this algorithm performs better than the more prevalent morphological boundary representation algorithms, the MST and the MSD in terms of representative points and computational efficiency. In case of multi-contour images, multi-component images, there will be many seed points to be stored in the representation. In case of round or circular shapes, the number of line segments will be many to give a compact representation of the contour. Attempts to refine the algorithm to address the above issues can be made.

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