Rank based Approach for Extracting Unit Pixel Width Skeleton

N. Neelima, Dr. A. Srikrishna, Dr. K. Gangadhara Rao
Research Scholar, JNTUH, Professor, RVR & JC College of Engineering, Professor, Acharya Nagarjuna University.
E-mail: neelimanalla1979@gmail.com

Abstract: Skeletonization is a transformation of a digital picture component into a subset of the original component. The skeleton is a qualitative tool for matching and analyzing 2D objects. Skeletonization is considered as an important issue because of the close link between an object’s skeleton and its boundary. A rank based skeleton extraction algorithm is presented which iterates itself to remove all the skeleton branches corresponding to the unimportant shape regions depending on the boundary extraction method. The method proposed performance is compared with various methods in the literature such as ZS, LW, and MZS skeletonization algorithms and identified that proposed method out performs well with respect to the performance measures elapsed time, thinning rate, thinning speed, and connectivity.

1. Introduction
Skeletonization, the extract of object skeletons from a given digital image. It is morphological operation that iteratively removes black foreground pixels by layer until 1-point width is achieved. We can redefine the skeleton extraction or reduce a digital image to a minimum size or to reduce the image to such a degree that an image preserves the points required for image transformation. The performance can be assessed using the following parameters [7]: - Elapsed Time, Thinning Speed, Thinning Rate, Connectivity and the image should not contain noise and unnecessary branches.

Altogether, even though more than 300 algorithms were proposed for skeletonization, improvement is required because the current approximate skeletonization Algorithms frequently present one or more of the following drawbacks:
- A high-resolution picture can take a long time to skeletonize.
- Skeletons may not be based inside the form below.
- The obtained skeletons are susceptible to changes in the noise and structure, such as rotation or scaling.
- There may be a different number of components in a shape and its skeleton.
- Objects such as noisy spurts and false short branch between the break can be contained in skeleton
- Points of intersection.
- The branches of the skeleton may be weakened greatly.
Moreover, most techniques are acceptable not for grey images but only for binary images.

Many approach methods for the measurement of skeletons in the discrete world were proposed which can be divided in two groups: the pixel-based and the pixel-based process. Thinning and distance transformation are techniques used in pixel-based approach [11]. There are two types of non-pixel approaches, based either on cross-section and diagrams of Voronoi. [15].

Thinning is a major preprocessing technique important for applications such as signature checks, pattern recognition and compression, etc. Thinning algorithm is a morphological procedure that extracts from binary images selected pre-figure pixels. It retains the topology (scope and connectivity) of the
original region while removing most of the original pixels. Thinning makes it easy and convenient to remove and identify functionality by reducing a certain pattern to a unit thickness. The diluted process converts the figure 1 into a digital pattern with lower thicknesses from one type to another.

![Figure 1. Thinning Process for transforming digital patterns](image)

The rest of the paper is structured as: presentation of the motivation with the existing methods in section 2. The proposed method of image retrieval is modeled in section 3, which insists the significance of the method for skeletonization. The results of the method and performance analysis is demonstrated in section 4 and finally, section 5 concludes the paper.

2. Related Work

There are three major techniques for skeletonization:

- Distance map of ridges of border points identify,
- calculating the boundary point diagram of Voronoi, and
- Layer erosion known as thinning

The lower point of a binary image is called black in Distance Transform [16] with a pixel value of 0; the object value is white and the pixels are 1. A binary image is to be converted to another image, which offers a value that corresponds to a minimum distance of the background for each object pixel. Similar distance metrics lead to various transformations in space. Point p is a pixel target and q is the nearest pixel background. The coordinates of p and q are \((x_p, y_p)\) and \((x_q, y_q)\). The Euclidean distance is defined as:

\[
DT(p) = \sqrt{(x_p - x_q)^2 + (y_p - y_q)^2}
\]

The drawback of distance transformation is that the extracted skeleton does not allow for connectivity and completeness (i.e. the extracted branches can be separated, not all significant visual sections can be represented). Thinning algorithms[1][3] can be split into iterative algorithms and not iterative algorithms. Non-iterative algorithms are fast, but they produce inexact results. Reliable and efficient, iterative algorithms are thinner. The thinning procedure uses templates, where the centre pixel is removed by a match between the template in the image. Iterative [4][4][6] algorithms erode pixel outer layers until layers are no longer available. Nearly all iterative thinning algorithm models, including the Stentiford Thinning process, use Identifying and extracting models [16].

A very successful and proven fine algorithm, Zhang and Suen[1] is the ZSA algorithm[17] that has been proposed by both Zhang and Suen. The algorithm runs concurrently on three neighborhoods. It is thinning. The ZS algorithm has two subphrases and is a directional algorithm. The first subitem tries to delete pixels in the southwestern frontier and pixels in the northwestern corner, while the other is intended to remove pixels in the northwest borders and in the southeast corner (i.e. opposite lines). Connectivity failure due to the absolute absence of 2X2 quadrant patterns is the downside of this algorithm. This does not cover the topology. The results are not a pixel-thick skeleton that breaks up the first property of a successful thinning algorithm. The redundant pixels are responsible.
3. Rank based Skeleton

The following are the steps to extract the skeleton from original image.

3.1 Generate initial skeleton

Input: original image        output: S(A)

A skeleton S(A) is simple. If z is a point of S(A) and (D)z is the largest disk centered in z and contained in A - this disk is called “maximum disk”. The disk (D)z touches A’s boundary at two or more different locations.

The skeleton of A is defined by terms of erosions and openings

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

with \( S_k(A) = (A \ominus kB) \ominus (A \ominus kB)^2B \)

Where B is the structuring element and \((A \ominus kB)\) indicates k successive erosions of A:

\[
(A \ominus kB) = (\ldots ( ((A \ominus B) \ominus B) \ominus \ldots ) \ominus B
\]

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

\[
K = \max \{ k \mid (A \ominus kB) \neq \emptyset \}
\]

In conclusion S(A) can be obtained as the union of skeleton subsets \( S_k(A) \).

The skeleton can be obtained using the operations of mathematical morphology.

3.2 Generate initial polygon

Input: A        output: P_i initial polygon

The boundary of an image is regarded as the initial polygon \( P^i \).

A convex hull is used for identifying the boundary of an image. Using morphological algorithms Convex hull is generated. The convex hull of set A is generated with the use of structuring element sequences. Let Bi, i=1 2, 3, 4 stand for 4 structuring elements as shown in figure 2.

![Figure 2: Structuring of Elements](image)

The procedure for implementing the convex hull is given in the equation.

\[
X_i^k = (X_{i-1} \ominus B^i) \cup A \quad i = 1,2,3,\ldots
\]

With \( X_0 = A \). Now let \( D^i = X_{conv}^i \), where the subscript “conv” indicates convergence in the sense that \( X_i^k = X_{k+1} \).

Then the convex hull of A is

\[
C(A) = D^1 \cup D^2 \cup D^3 \cup D^4
\]

The method involves applying the hit-or - miss transform iteratively to A with B1, but if further adjustments do not occur the union takes place with A and the outcome is called D1. The method is repeated with B2 until there are no additional changes. The union of four resulting Ds is the convex hull of A.

3.3 Generate simple polygon

Input: \( P^i \)        output: \( P^k \)

A consecutive segment of the convex hull is called i.e. S1, S2 is substituted with an individual line section, which links the S1 U S2 endpoints. DCE generates a basic polygons series \( P = P_n, P_{n-1}, \ldots \).
P3 so that Pn-k is obtained by removing the least contribution of the shape based on the following measure k.

\[ K(s_1, s_2) = \beta(s_1, s_2) l(s_1) l(s_2) / (l(s_1) + l(s_2)) \]

Where the angle of the corner considering S1 and S2 is \( \beta(s_1, s_2) \), and l is the length function.

3.4 Skeleton Pruning

Input: \( P^k, S^k(D) \) output: Pruned Skeleton

\( S^n(D) \) is chopped with \( P^k \) by removing all \( S^n(D) \) skeleton items so that the s generated points are contained within a single segment of the contour. A section of the contour is identified as part of the shape boundary approx. the straight line of two adjacent \( P^k \) vertices. -- cut point s is a polygon partition contour segment and can therefore be considered an insignificant, removable skeleton. On the other side, the skeletal matching is done using the distance measure. The original image and its skeleton is shown in figure 3.

![Figure 3. Original Image and Skeleton](image)

4. Simulation Results and Discussions

In this section, the performance of the proposed method is evaluated by utilization of MPEG7 dataset test set as shown in Figure 4 consists of 70 classes of shapes each having 20 members.

![Figure 4. Training dataset used to obtain skeleton image](image)

4.1 Performance Analysis Measures

Performance assessment is an important criterion for the implementation of any algorithm in a given application. Many smaller algorithms and techniques available require trade-offs between one or more topological and geometrical demands. Thinning algorithms can be estimated according to the following parameters:
a) Connectivity  
b) Unit Pixel width (Thinning Rate and Thinning Speed)  
c) Elapsed Time

The parameters are described as given below:

**a) Connectivity:** The connectivity of pixels on the output skeleton is studied. If the skeleton has a linked number of components 1 this means that the thin image comprises all of the pixels.

**b) Unit Pixel Width:** Two parameters are taken into account on a triangle count for measuring the skeleton width or thinness:

i) **Thinning Rate:** This calculation counts the number of triangles in the image and provides an indication of the sizes of the pixels. The Thinning rate TTR is calculated as shown below:

\[ TTR = (1 - \frac{TTCT}{TTCO}) \]

Where \( TTCT \) = Total count of triangles in thin image

Where \( TTCO \) = Total count of triangles in original image.

If the TTR value is 1 the skeleton is perfectly thin and if the TTR value is 0, the image is not at all thin.

ii) **Thinning Speed (TS):** measures the number of pixels thinned per time unit (second) given by:

\[ TS = \frac{DP}{ET} \]

\[ DP = OP - SP \]

Where DP or points are removed, the number of black points which are removed during thinning, surgery or the number of object points are black points of an image before dilution, SP or (skeletal points), is the number black points left after thinning.

**c) Elapsed Time:** Elapsed Time is the duration from the start of the process until the end of the process. The following Figures 5, 6, and 7 represent original images and skeleton images of apple, beetle, and butterfly after the implementation of Lu Wang algorithm, Zhang-Suen algorithm, Modified Zhang-Suen algorithm, and Rank based algorithm. By comparison, unnecessary branches are present in skeleton images for LW, ZS and MZS algorithms. Skeletons are good for rank based algorithm when compared with other thinning algorithms.

The experimental results are shown and compared in Figure 5, in order to test the efficacy of the rank dependent algorithm. Figures show: (b) an image diluted with the LW algorithm, (c) an image thinner with the ZS algorithm, (d) an image diluted with a MZS algorithm and (e) the image diluted with an algorithm dependent on the Level.

![Figure 5. a) Input Image  b) LW  c) ZS  d) MZS  e) Rank based](image)
Figure 6. a) Input Image  b) LW  c) ZS  d) MZS  e) Rank based

Figure 7. a) Input Image  b) LW  c) ZS  d) MZS  e) Rank based

For each algorithm applied in the thinning process, elapsed time, thinning rate, thinning speed, and connectivity are measured. Table 1 shows obtained performance metrics by applying existing methods ZS, LW, MZS and proposed Rank based algorithm. Here we obtained elapsed time, thinning rate, thinning speed and connectivity to measure the performance of proposed method in comparison with existing methods.

| Image  | ZS   | LW   | MZS  | Rank based |
|--------|------|------|------|------------|
| Elapsed Time (seconds) | Bird | 3.6075 | 3.4601 | 8.3857 | 3.477 |
| Thinning | 1    | 1    | 1    | 1          |
| Rate | Thinning Speed | Connectivity | Elapsed Time (seconds) | Thinning Rate | Connectivity | Elapsed Time (seconds) | Thinning Rate | Connectivity |
|------|----------------|--------------|------------------------|---------------|--------------|------------------------|---------------|--------------|
|      | 0.5200         | 2.2951       | 5.0081                 | 0.7793        | 4            | 5                      | 5             | 6            |
| Carriage | 2.301-2         | 2.2166       | 6.8361                 | 1.7214        | 1            | 1                      | 1             | 1            |
|        | 1.5020         | 2.1162       | 0.3193                 | 0.0430        | 7            | 9                      | 5             | 5            |
| Butterfly | 33.638         | 33.276       | 84.652                 | 3.2541        | 1            | 1                      | 1             | 1            |
|        | 18.650         | 19.380       | 19.784                 | 1.1005        | 318          | 486                    | 842           | 5            |
| Camel  | 8.8341         | 8.1899       | 20.506                 | 4.2424        | 1            | 1                      | 1             | 1            |
|        | 7.5948         | 7.5916       | 19.744                 | 1.6032        | 8            | 9                      | 9             | 6            |
| Beetle | 23.869         | 22.101       | 60.748                 | 5.0333        | 0.3070       | 7.4740                 | 8.2640        | 3.7505       |
|        | 302            | 308          | 495                    | 8             | 1            | 1                      | 1             | 1            |
| Bottle | 1.966          | 1.846        | 5.891                  | 1.223         | 1            | 1                      | 1             | 1            |
|        | 0.7480         | 0.4900       | 4.2910                 | 0.6080        | 2            | 2                      | 2             | 6            |
The performance metrics are calculated by applying ZS, LW, MZS, proposed Rank based on around 1400 images containing 70 classes of shapes by taking 20 image members from each class. In Table I, obtained measures are shown only for 10 image classes like bird, carriage, butterfly, camel, beetle, bottle, brick, children, face, and hammer. It is observed that the proposed method exhibits better performance with elapsed time with most of the cases. Thinning rate is remained same with proposed method in comparison with existing methods. The proposed method exhibits improved thinning speed with image classes belonging to bird, carriage, butterfly, camel, beetle, bottle, brick, children, but only average thinning speed is obtained with image classes face, hammer in comparison with existing methods. Even though, thinning speed is good with face and hammer image classes in existing methods but those methods are leaded to higher value in elapsed time.

Improved connectivity measure is achieved through proposed rank based skeleton algorithm with image classes butterfly, camel, beetle containing complex shape structures, for these images, the

|                | Elapsed Time(seconds) | Brick 3.6900 | 3.666 | 10.389 | 2.152 |
|----------------|-----------------------|-------------|-------|--------|-------|
| Thinning Rate  |                       | 1           | 1     | 1      | 1     |
| Thinning Speed |                       | 1.7300      | 0.2780| **0.9140** | **0.424** |
| Connectivity   |                       | 4           | 5     | 5      | 7     |
| Elapsed Time(seconds) | Children 1.896 | 1.838 | 1.949 | 1.990 |
| Thinning Rate  |                       | 1           | 1     | 1      | 1     |
| Thinning Speed |                       | 0.9360      | 1.0940| **0.5290** | **0.4600** |
| Connectivity   |                       | 2           | 2     | 2      | 7     |
| Elapsed Time(seconds) | Face 8.407 | 8.475 | 19.214 | 4.900 |
| Thinning Rate  |                       | 1           | 1     | 1      | 1     |
| Thinning Speed |                       | 3.922       | 1.1500| 1.4320 | 4.800 |
| Connectivity   |                       | 3           | 4     | 4      | 8     |
| Elapsed Time(seconds) | Hammer 1.607 | 1.5471 | 4.087 | 1.5641 |
| Thinning Rate  |                       | 1           | 1     | 1      | 1     |
| Thinning Speed |                       | 1.4310      | 1.4840| **2.636** | **0.9222** |
| Connectivity   |                       | 4           | 4     | 4      | 6     |
existing methods yielded connectivity value in terms of hundreds but proposed method has exhibited a value not more than 10 even with complex classes.

Comparing with all 70 classes of images with complex structures, we have observed the proposed method exhibits better performance measures in comparison with ZS, LW, and MZS thinning algorithms.

5. Conclusion

In this paper, rank based skeletonization technique is presented. The skeletons are obtained using the boundary based on polygon simplification method. The experiments are conducted on MPEG7 datasets which shows that proposed rank based skeletonization method is significantly superior to skeletonization methods listed in the literature. The performance is measured using both subjective and objective analysis. The Subjective analysis shows that skeleton has singleton potential. The objective analysis has been done against Thinning rate, Thinning speed, Connectivity and Elapsed time. It was observed that Rank Based Skeletonization technique gives good results for all parameters above other algorithms.

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