A novel recursive algorithm for area location using isothetic polygons

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Abstract

In this paper, a novel recursive algorithm is presented for binary image area location. The result of an image segmentation task is usually a set of connected components that belong to certain categories, such as texts, images, lines etc. A challenging task is to restrict all connected components inside simple geometric shapes. For this purpose, isothetic polygons with minimum number of vertices are used in order to achieve simplicity of description and efficiency of storage. These polygons are defined by a recursive formula, where the resulting areas are calculated from successive additions and subtractions of simple rectangular blocks. The proposed area location method can be applied to the majority of image segmentation tasks. The effectiveness of the proposed method has been tested for tracing all page components at a newspaper page decomposition module as well as for tracing objects in the field of a view of a digital camera.

1. Introduction

Image segmentation is a basic procedure for all image understanding and recognition tasks. In this paper we deal with binary image segmentation, a procedure that is necessary for the majority of vision or document processing applications. Many approaches for binary image segmentation have been proposed in the literature mainly based on smearing and labelling [1-3], on image profiling on various directions [4] and on texture information [5]. After applying a segmentation scheme, we usually result to a set of labelled connected components that is difficult to represent or store. A convenient representation of the results of binary image segmentation is to store the surrounding rectangular box of every distinct component. This approach is in some cases inadequate because of possible overlaps between the rectangular boxes. Considering this, we propose a new technique for binary image area location based on isothetic polygons, that is polygons having only horizontal and vertical edges.

The main concept of our approach is to restrict all segmentation results inside simple geometric shapes. We use isothetic polygons because they can be simply handled, sparely stored and easily represented. Additionally, isothetic polygons define specific and definite areas that can be used for evaluation [6] or other post processing purposes. In our polygon estimation approach, we try to preserve simplicity by decreasing the number of polygon vertices to the minimum possible. We state a recursive formula that defines isothetic polygons by successive additions and subtractions of simple rectangular blocks. In most cases, where the surrounding box of a segmented object does not contain any other object, the isothetic polygons are reduced to rectangular blocks.

The proposed algorithm for binary image area location has already been embodied to our automatic newspaper analysis module [1,2]. This includes main newspaper components (text, titles, over and sub-titles, images etc.) extraction, as well as automatic article tracking by an appropriate segment grouping technique. By using isothetic polygons, we handle special cases of texts and inset segments as well as cases of slightly skewed text columns that have a very small gap among them. In order to test the efficiency of our method for an image vision task, we used our approach for tracing distinct objects in the field of a view of a digital camera.

In the sections to follow, we present a recursive formula for isothetic polygons computation, an approach for polygon optimization, as well as experimental results.

2. Isothetic polygon computation

In this section, we will describe how an isothetic polygon is defined in order to locate the segmentation results of a binary image. For convenience, we will employ a simple RLSA process [3] as a segmentation algorithm. However, every segmentation algorithm that yields discrete components can work well with our approach for area location.

Consider a binary image I. Using RLSA we extract smoothed image I_s which consists of connected components A_i. An example of an image I that has a smoothed image I_s consisting of connected components A_1

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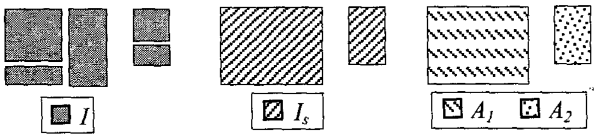
and A_2 is depicted in Figure 1. We can state the following property:

$$I \subseteq I_s = \bigcup_i A_i \qquad (1)$$



(a) (b) (c)

Figure 1. (a) Original image I. (b) Smoothed image I_s. (c) Connected components A_1, A_2 of image I_s.

We define as $S(A_i)$ the surrounding rectangular block of A_i (see Figure 2). From this definition, derives:

$$A_i \subseteq S(A_i) \qquad (2)$$

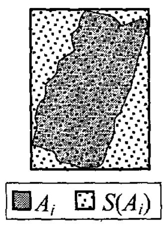


Figure 2. Connected component A_i and its surrounding rectangular block $S(A_i)$.

We define as $N_j(A_i)$ all the connected component areas that belong to $S(A_i)$ and not to A_i, where $j = 1 \ldots F(A_i)$ and $F(A_i)$ is the number of connected components that belong to $S(A_i)$ and not to A_i. Figure 3 illustrates connected component A_i and its corresponding $N_1(A_i)$, $N_2(A_i)$ areas. The following properties can be stated:

$$\bigcup_{j=1}^{F(A_i)} N_j(A_i) \subseteq S(A_i) \qquad (3)$$

$$\bigcup_{j=1}^{F(A_i)} N_j(A_i) \cap A_i = \varnothing \qquad (4)$$

$$S(A_i) - A_i - \bigcup_{j=1}^{F(A_i)} N_j(A_i) \not\in I_s \qquad (5)$$

An isothetic polygon $P(A_i)$ that contains only area A_i and not any part of other connected components, in other words:

$$A_i \subseteq P(A_i) \text{ AND } P(A_i) \cap \bigcup_{j \neq i} A_j = \varnothing \qquad (6)$$

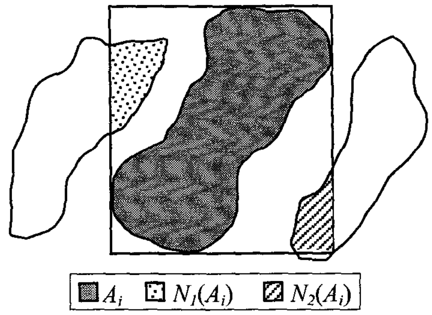


Figure 3. Connected component A_i and its corresponding $N_1(A_1)$, $N_2(A_1)$ areas that belong to $S(A_i)$ and not to A_i.

can be defined by the following recursive definition:

$$P(A_i) = S(A_i) - \bigcup_{j=1}^{F(A_i)} P(N_j(A_i)) \qquad (7)$$

Area $P(A_i)$ is an isothetic polygon because it is a result of successive additions or subtractions of rectangular blocks. At the case that area $S(A_i)$ contains only A_i and not any other connected component, that is $F(A_i) = 0$, equation (7) becomes:

$$P(A_i) = S(A_i) \qquad (8)$$

For the calculation of the isothetic polygon $P(A_i)$ of a connected component A_i, we use the recursive definition (7) until all related $P()$ are reduced to rectangular blocks (equation 8). An example of $P(A_i)$ calculation is demonstrated on Figure 4. In this case, since $F(A_i) = 2$, equation (7) becomes:

$$P(A_i) = S(A_i) - P(N_1(A_i)) - P(N_2(A_i)) \qquad (9)$$

Since $F(N_1(A_i)) = 1$ and $F(N_2(A_i)) = 0$, isothetic polygons $P(N_1(A_i))$, $P(N_2(A_i))$ are calculated as follows:

$$P(N_1(A_i)) = S(N_1(A_i)) - P(N_1(N_1(A_i))) \qquad (10)$$

$$P(N_2(A_i)) = S(N_2(A_i)) \qquad (11)$$

$$P(N_1(N_1(A_i))) = S(N_1(N_1(A_i))) \qquad (12)$$

(9),(10),(11),(12)

$$P(A_i) = S(A_i) - S(N_1(A_i)) + S(N_1(N_1(A_i))) - S(N_2(A_i)) \qquad (13)$$

An efficient computation of isothetic polygons that is more suitable for implementation can be derived as follows. Assume that B_v, $v = 0 \ldots N$, are all the rectangular blocks that need to be calculated in order to compute the isothetic polygon $P(A_i)$. In addition, let R_v be the number of times that $P(A_i)$ has to call itself in order to calculate a

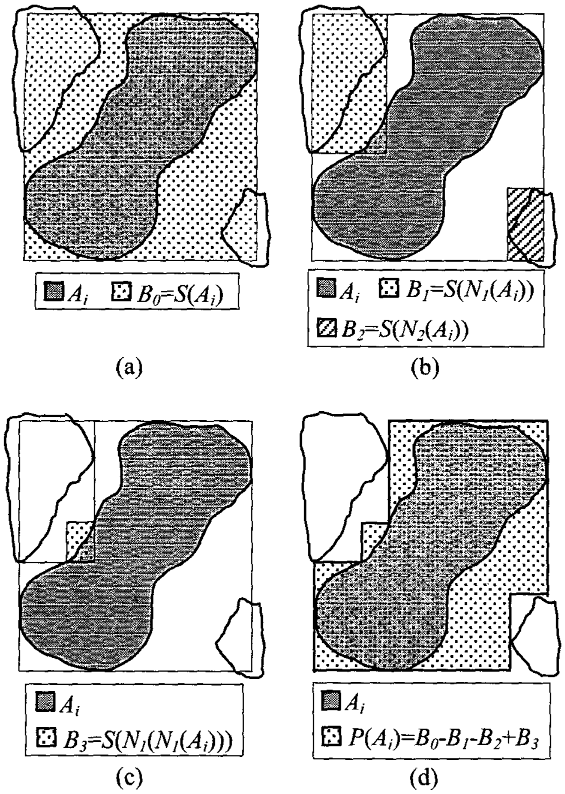


Figure 4. Calculation of the isothetic polygon $P(A_i)$ of the connected component A_i.

rectangular block B_v. We can state that an isothetic polygon $P(A_i)$ is defined from the following equation:

$$P(A_i) = \sum_{v=0}^{N} (4\left\lfloor \frac{R_v}{2} \right\rfloor - 2R_v + 1)B_v \qquad (14)$$

where $\lfloor x \rfloor$ is the integer part of x. Parameter $(4\left\lfloor \frac{R_v}{2} \right\rfloor - 2R_v + 1)$ is equal to 1 if R_v is even and to -1 if R_v is odd. For the example of Figure 4, we have:

$$B_0 = S(A_i),\ R_0 = 0 \qquad (15)$$

$$B_1 = S(N_1(A_i)),\ R_1 = 1 \qquad (16)$$

$$B_2 = S(N_2(A_i)),\ R_2 = 1 \qquad (17)$$

$$B_3 = S(N_1(N_1(A_i))),\ R_3 = 2 \qquad (18)$$

(14),(15),(16),(17),(18)

$$P(A_i) = B_0 - B_1 - B_2 + B_3 \qquad (19)$$

3. Isothetic polygon optimization

The above-described method locates an isothetic polygon that contains a connected component area. Our intention is to locate polygons with minimum number of vertices in order to achieve simplicity of description and efficiency of storage. In most cases the isothetic polygons are reduced to rectangular blocks. There are still some cases where the located polygons can be simplified. An example is demonstrated in Figure 5a. In order to optimize polygon extraction, we extend rectangular areas $S(N_j(A_i))$ towards vertical or horizontal directions until we reach $S(A_i)$ limit or $S(N_j(A_i)) \cap A_i \neq \varnothing$. As we can see in the example of Figure 5b, the number of polygon vertices is decreased from 8 to 6 after the above mentioned polygon optimization technique.

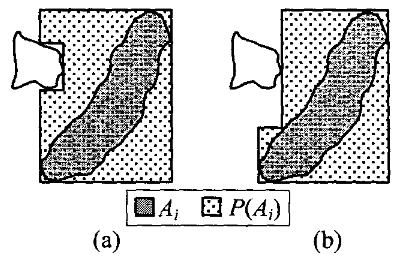


Figure 5. Calculation of the isothetic polygon $P(A_i)$. (a) Without optimization (8 vertices). (b) With optimization (6 vertices)

4. Algorithm for polygon computation

We will present all the necessary steps in order to segment image I to several isothetic polygons after applying RLSA. These steps can easily be revised for any segmentation method that results to discrete connected components.

Step 1: Apply RLSA to image I and extract image I_s ($I_s(x,y) = 1$ for foreground points, 0 for background points).

Step 2: Set i=1.

Step 3: Perform a top-down scan of the image I_s to find the first foreground pixel ($I_s(x,y) = 1$) that belongs to area A_i.

Step 4: Trace the contour of A_i (see [7])

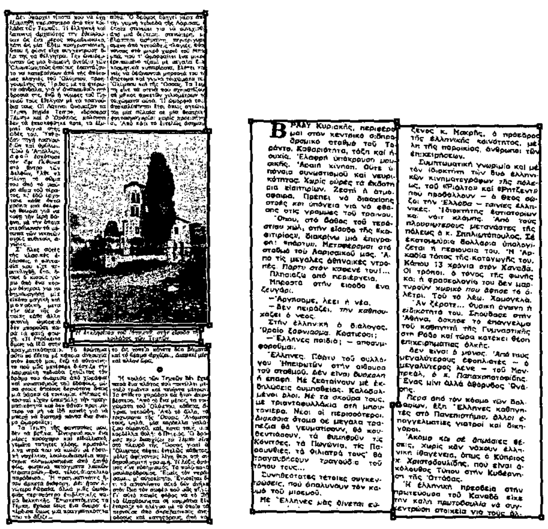
Step 5: Extract $P(A_i)$ using equation (14) and the optimization technique of section 3 considering as foreground points all points with non-zero value.

Step 6: All points of image I_s that are inside isothetic polygon $P(A_i)$ are given value 2.

Step 7: Until there remains no unscanned foreground pixel, continue with the top-down scan of step 3 after setting i=i+1.

5. Experimental results

The proposed method for area location using isothetic polygons was extensively tested in a large binary image collection. Lambrakis Press Archives works on an extensive Greek newspaper digitization project for the creation of a digital library based on archival newspaper material. For this purpose, we have developed integrated algorithms for newspaper page decomposition and article tracking [1-2]. Figure 6 demonstrates the use of isothetic polygons for representing the results of segmenting newspaper pages. We face the problem of text and inset segments (Figure 6a) and the problem of slightly skewed text columns (Figure 6b). A second demonstration of our proposed method concerns the tracing of discrete objects (chess items) which lay in the field of a view of a CCD camera (Figure 7). We first proceed to a thresholding, a smoothing processing using RLSA and then depict two different objects that are located inside the area of two corresponding isothetic polygons.

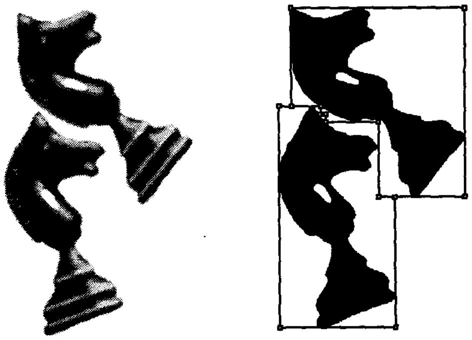


(a) (b)

Figure 6. Document image decomposition. (a) Mixed document. (b) Skewed document

6. Conclusions

A novel method is proposed for locating binary image segmentation results. Isothetic polygons with minimum number of vertices are used in order to restrict all distinct areas in an efficient way for both representation and storage purposes.



(a) (b)

Figure 7. Tracing of chess items. (a) Original image. (b) Discrete objects and their corresponding isothetic polygons.

7. References

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