A New Approach to Morphological Method by Anytime Algorithm for Real-time Image Processing

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Abstract

Real-time system requires not only the perfect result but also the partial usable result which produces in time under time restriction. Morphological method is a tool for extracting image components that are useful in the representation and description of region shape, such as boundaries, and skeletons, which are especially applied in image preprocessing. This paper proposes a new approach to morphological method using anytime algorithm for boundary extraction. First, multi-structuring elements are constructed by changing the direction. Then,morphology erosionoperation usingmulti-structuring element is performed step by step by using the previous result as input at current stepaccording to the concept of anytime algorithm. We can confirm the effectiveness of proposed method by the experimental resultswith coarse-to-fine results and the quality of results improves when the processing time increases. This gives an idea to solving the time quality trade-off problem in real-time image processing.

1. Introduction

The processing of image/video data involves with the operations in low, intermediate and high levels [1]. The quality of image processing is usually evaluated by high extraction rate or low error rate. Itis easy and clear to evaluate single image processing task, but if the system is composed of many tasks,it would becomes difficult to evaluate the combined processing result due to the processing time overload and the resource constraint such as speed of processor, and memory requirement. Moreover, the results of image processing vary according to the combination of the methods and tasks. Real-time image processing system (RTIP) has the constraints like processing time, and hardware resources. So, the problems of time constraint have been involved in the processing of image processing task for the systems like object tracking and image transmission systems.

In order to solve the time-quality trade-off problem in RTIP, the basic idea is by dividing the task into the sub-tasks, and then the combination of operations are performedby these sub-tasksstep by step. Thus, the overall performancecan be realized under time restriction although the quality of result is not perfect. We already introduced how to schedule the image processing tasks by using anytime algorithm, and how to apply anytime algorithm in some of image processing tasks [3]-[5]. Our main purpose is to construct the image processing library which combines of anytime algorithmic image processing methods in low, mid, and high level processing in order to provide the partial but usable result under time restriction for RTIP and embedded system applications.

Morphological method is a technique for the analysis and processing of geometrical structures and features based onset theory. It is a tool for extracting image components or features that are useful in the representation and description of region shape, such as boundaries, skeletons, convex hull, which are especially appliedin image preprocessing [2]. *H. Hedberg* et al. proposed the binary morphology algorithm with spatially variant structuring elements for the software and hardware implementations of embedded system which requires low power consumption and low memory requirements [7].*S.Ramli* etal.proposed an algorithm that selects appropriate structuring element of the processed image and makesuse morphological operator such as erosion operation to extract useful features for classification [8].

In order to differentiate the image objects or features, structuring element (SE) is used by setting the size and shape according to their shape or spatial orientation. In this paper, we give an idea of how to process the morphological processing based on erosion operation for the boundary extraction by constructingmulti-SEaccording to the concept of anytime algorithm.

This paper is organized into 5 sections. In section 2, the previous works of our research including basic framework and the general explanation of anytime algorithm are described. In section 3, the proposed morphological method is expressed. In section 4, discussion about the proposed method including experimental results, and how toevaluatethe performance are described. Finally, conclusion and future works are expressed in section 5.

2. Previous Works

2.1. Basic Framework

A system can be composed of many tasks which involves with low, mid and high level processing performed by many steps. In such systems, there are some restrictions like processing time and memory requirement to extract the useful information e.g., extract image attribute for the classification.

Figure 1describes that the basic framework of our research work. As shown in this figure anytime algorithmic low level image processing method is constructed and it is applied in noise reduction by convolution and linear spatial filtering [4][5]. Then, anytime algorithmic mid level image processing is applied in edge detection, and thinning [3]. In this paper, anytime algorithmic morphological processing is proposed as a part of this research work and it is applied to erosion operation for the boundary extraction.

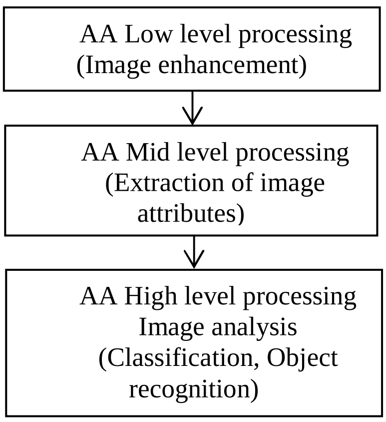


Figure 1. The basic framework

Note: AA = Anytime Algorithmic

Then, we will propose how to apply anytime algorithm in high level image processing task for e.g., feature extraction for the classification of object in an image and object recognition. After that we will combine our anytime algorithmic approach in the low, mid and high level image processing to construct the image processing library by anytime algorithmic approach for the real-time image processing.

2.2. Anytime Algorithm

Anytime algorithm is an algorithm, which canimprovesthe qualityof result gradually as computation time increases.It is offered a trade-off between the resource consumption and the output quality. It is suited for the problem which has the trade-off between the processing time and the accuracy of result since the accuracy improves as increase of computation time. In general, anytime algorithm has the properties that satisfy the following features [6].

(1) *Measurable quality*:
The quality of result can be defined exactly.

(2) *Recognizable quality*:
The quality of an approximate result can easy to determine at processing time.

(3) *Monotonicity*:
The quality of result is an increasing function of time and input quality.

(4) *Consistenc*y:
The quality of result is connected with computation time and input quality.

(5) *Diminishing returns*:
The solution quality improves much larger than previous stages of computation and diminishes over time.

(6) *Interruptibilit*y:
The algorithm can be stopped at anytimeand give some answer.

(7) *Preemptability*:
The algorithm can be stopped and started again at anytimewith minimal overhead.

3. Proposed Morphological Method

3.1. Anytime Algorithmic Morphological Processing

Mathematical morphology is a useful tool dealing with various problems in image processing and computer vision. The basic morphological operations i.e., erosion and dilation are usually time consuming operations when using large size structuring element (SE) e.g., 15x15, and 27x27, and the combination of such operations i.e., opening and closing could lead to inefficient algorithms depends on the particular application. However, mathematical morphology flexibility can be used with the benefit to decompose a large structuring element into smaller ones and the operations with a large size e.g., 9x9 SE can be replaced by a series of operations with small size 3x3 SE.

Suppose that

A = input image
B = 3x3 SE
C = 9x9 SE i.e., twice the size of B
Θ = erosion symbol

The result of erosion of input image A performed by C is approximately equal to the result of erosion of input image A performed by B two times.In mathematical form, it can be expressed by

$$(A \Theta C) \approx (A \Theta B) \Theta B \qquad (1)$$

Erosion of an image A by SE$B$is a set of all z in A such that B is in A when origin of $B = z$, i.e.

$$A \Theta B = \{z|(B)_z \subseteq A\} (2)$$

Conventional method

In the conventional method, Fig. 2(a) is theinput image $A$and Fig. 2(b) is the 3x3 structuring element$B$ to perform the erosion operation [2]. Figure3expresses that the output eroded imagesA_1 and A_2which are obtained fromthe input image A performed by B, 1 time i.e., $A_1 = (A \Theta B)$by Fig. 3(a) and 2 times i.e., $A_2 = (A \Theta B) \Theta B$ by Fig. 3(b) respectively.

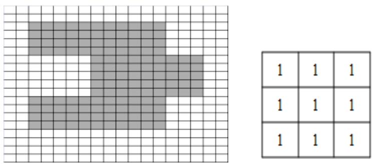
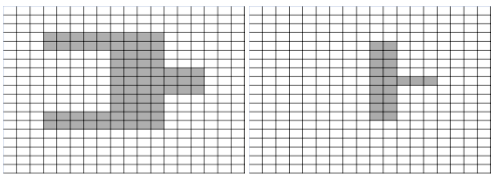


Figure 2. (a) Input image *A* (b) 3x3 structuring element *B*

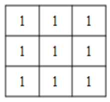


(a) (b)

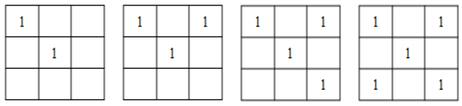
Figure 3. Output images (a)$A_1$and (b) A_2

Proposed method

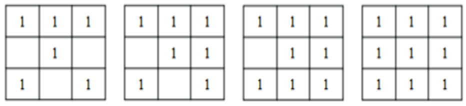
In this proposed method, anytime algorithmic morphological method based on anytime algorithm is performed in order to provide the partial but usable result under time restriction. SE can be presented in different shapes like a line or a square, and different sizes like 3x3, and 5x5. In this method, SE in square shape with size 3x3 is used with the origin at its center.In order to reduce the computational time and memory usage, the different patterns of multi-SE are constructed by changing the direction as shown in Fig.4. Figure 4(a) is the 3x3 SEBin the conventional method and (b) is thedifferent patterns ofmulti-SE i.e., B_1 to B_8 of B in the proposed method. Thus, morphological erosion by anytime algorithm is performed by using B_1 to B_8 step by step.



(a)Conventional



B_1 B_2 $B_3 B_4$

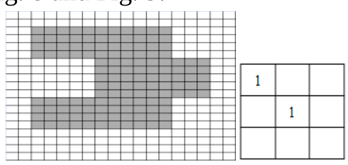


B_5 B_6 $B_7 B_8$

(b) Proposed

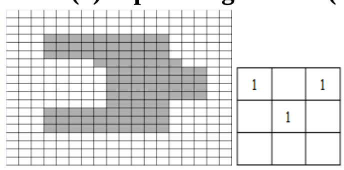
Figure 4. (a) SE*B* in the conventional method (b) Multi-SE B_1 to B_8 of *B* in the proposed method

Here isthe example of anytime algorithmic erosion and its related results. Figure5(a) is theinput image Awhich is performed by B_1 as shown in Fig.5(b) as a first step. So, the initial output of eroded image $A_1 = (A \Theta B_1)$ is obtained as shown in Fig.6 (a). In the second step, the output image A_1 is performed by B_2 as shown in Fig. 6(b). Thus, the second output eroded image $A_2 = A_1 \Theta B_2$ as shown in Fig. 7 (a) can be obtained. Similarly, the output images $A_3 = A_2 \Theta B_3$by B_3as shown in Fig. 7(b) in third stepand $A_4 = A_3 \Theta B_4$ by B_4in fourth steprespectively can be obtainedas shown in Fig. 8 and Fig. 9.



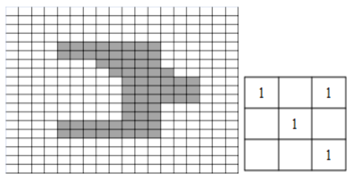
(a)(b)

Figure 5. (a) Input image *A* and (b) B_1



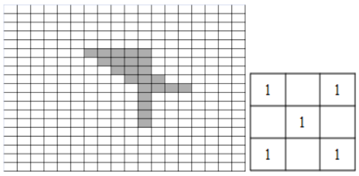
(a) (b)

Figure 6. (a) Output image$A_1$and (b) B_2



(a) (b)

Figure 7. (a) Output image $A_2$and (b) B_3



(a) (b)

Figure 8. (a) Output image A_3 and (b) B_4

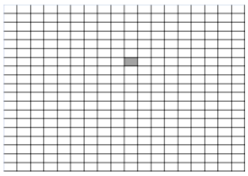
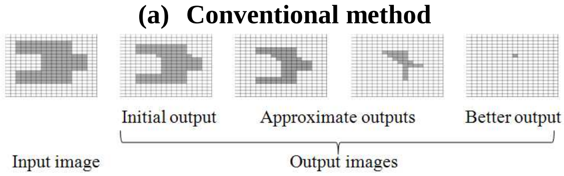


Figure 9. Output image A_4

Comparison of results

(a) Conventional method



(b) Proposed method

Figure 10. Output erosion results by (a) Conventional and (b) Proposed methods

Figure 10(a) and (b) shows that the comparison oferosion results, i.e., (a) the result applied by B 1 timein the conventional method and (b) the result applied by B_1 to B_4 in the proposed method.By comparing these results, the result of proposed method is better than the conventional method. In addition, the proposed method can be reduced the processing time.

3.2. Algorithms

Algorithm 1: *Anytime Algorithmic Erosion*

Step-1: Read input gray image$A$ then convert it to the binary image A_0.

Step-2: Perform the erosion operation using the binary image A_0 with SEB_1, i.e. $A_0 \ominus B_1$ then output the eroded image i.e. $A_1 = A_0 \ominus B_1$.

Step-3:Perform the erosion operation again using the previous output image A_1 as input image by B_2. Then, output the eroded image A_2i.e. $A_2 = A_1 \ominus B_2$.

Step-4: Repeatstep-3using the corresponding SEB_3 to B_8 until the output image $A_8$is obtained by B_8. Then, output the final eroded image A_8i.e. $A_8 = A_7 \ominus B_8$.

In general, the anytime algorithmic erosion operation can be evaluatedby

$$A_i = ((A_{i-1}) \ominus B_i) \quad (3)$$

where $i = 1, 2, \ldots, 8$

Dilation of an image A by SEB is a set of all z in A such that Bhits$A$ when origin of $B = z$, i.e.

$$A \oplus B = \{z | (B^s)_z \cap A \neq \Phi\} (4)$$

where B^s =the symmetric or reflection of B

Dilation and erosion are duals of each other with respect to complementation:

$$(A \oplus B)^c = A^c \ominus B^s \text{ and } (A \ominus B)^c = A^c \oplus B^s (5)$$

That is, dilation with the reflected SE of the complement of a binary image isthe complement of the erosion. Erosion with the reflected SE of thecomplement of the image is the complement of the dilation. It follows that,$A \oplus B = (A^c \ominus B^s)^c$and $A \ominus B = (A^c \oplus B^s)^c$i.e.dilation can be performed with erosion and vice versa. Similarly, anytime algorithmic dilation operation can be performedlike algorithm 1.Thus, anytime algorithmic dilation operation can also be evaluated by

$$A_i = ((A_{i-1}) \oplus B_i) \quad (6)$$

where $i = 1, 2, \ldots, 8$

Like this way, the other morphological operations such as opening i.e. erosion followed by dilation, closing i.e. dilation followed by erosion and the combination of morphological operations e.g.hit-or-miss transform, and thinning can be performed by using anytime algorithm.Thus, the following algorithm 2 describeshow to perform the boundary extraction by anytime algorithm as an example.

Algorithm 2: *Anytime Algorithmic Boundary Extraction*

Step-1: Input gray scale image and convert it to binary image A_0.

Step-2:Perform the erosion operation of input image by B_1 and store the eroded result in A_1 i.e. $A_1 = A_0 \ominus B_1$.

Step-3: Perform the operation $(A_0 \ominus B_1)^c$ i.e. the complement of $A_0 \ominus B_1$.

Step-4: Performboundaryextraction operation$\beta_1(A_1)=A_1 \cap (A_0 \ominus B_1)^c$.

Step-5:Output the extracted boundary image $\beta_1(A_1)$.

Step-6: Repeat step 2 to 5 by replacing the input image by A_1, A_2, …, A_8 and SE by B_2, B_3, …, B_8until the extracted boundary images$\beta_2(A_2)$ up to $\beta_8(A_8)$ are obtained.

Step-7: Outputthe final extracted boundary image $\beta_8(A_8)$.

In general, the result of the boundary extraction can be evaluated by

$$\beta_i(A_i) = A_i \cap (A_{i-1} \ominus B_i)^c \qquad (7)$$

where $i = 1, 2, \ldots, 8$

4. Discussion

In this section, we describes about the experimental results, and the performance curve of erosion.

4.1. Experimental Results

Experiments are done by using the gray scale images with *pgm* format and size is256x256. The standard images as shown in Fig. 11for the morphological operations are used from the following link*http://www.imageprocessingplace.com/root_files_V3/image_databases.htm*

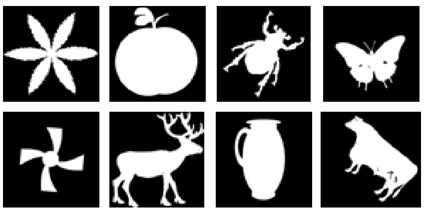
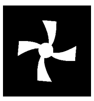
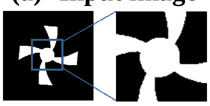


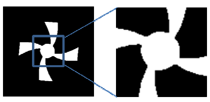
Figure 11. Some of the tested images



(a) Input image



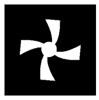
(b) Eroded image applied by *B*2 times by conventional method



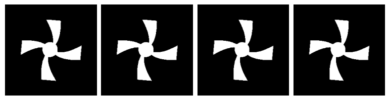
(c)Eroded Image Applied by $B_4$by Proposed Method

Figure 12. (a) Input image and (b) and (c) are the results oferoded images

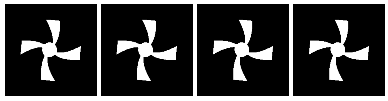
As shown in Fig.12, (a) is the input image and (b) eroded image applied by SE*B*2 times by conventional method and (c) eroded image applied by SE$B_4$by proposed method.We can see that the result of conventional method isapproximately equal to the result of eroded image applied by proposed method.



(a)



(b) (c) (d) (e)

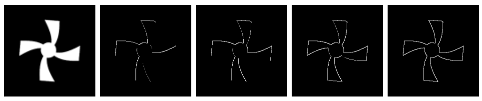


(f) (g) (h) (i)

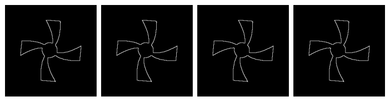
Figure 13. (a) Input image (b) to (i) are eroded images applied by multi-SEB_1 to B_8

Figure 13 (a) is the input image and Fig.13 (b) to (i) are the eroded images appliedby multi-SE B_1 to B_8. As shown in Fig. 13, the coarse-to-fine results are obtained and the results becomebetter than the previous.

(a) Input and boundary extracted images by conventional method



Input image Step 1Step 2Step 3Step 4



Step 5 Step 6 Step 7 Step 8

(b) Input and boundary extracted imagesby step 1 to 8 by proposed method

Figure 14. (a)Conventional method(b) Proposed method

Figure 14 (a) shows that input and boundary extracted images by conventional method and Fig. 14(b) shows that input and boundary extracted imagesperformed by step 1 to 8usingmulti-SEB_1 to B_8 by proposed method. As we can see that the approximate boundary extracted result at step 4 by B_4 by proposed method is nearly equal to the boundary extracted result by conventionalmethod. These experimental results are obtained by using the algorithm 1 with single iteration. The experimental results show that the approximate but coarse-to-fine results can be obtained at each step and the results become better than the previous step as the processing time increases, so it is satisfied the properties of anytime algorithm.

Furthermore, the boundary extractionapplied by multi-SE, there is no need to check all neighborhood pixels which are surrounded to the center pixel at each stepexcept from step 8 by B_8. After scanning the entire imageat step 1 by B_1,the initial result can be obtained earlier than the conventional method.In addition, the approximatebut coarse-to-fine resultscould be obtainedatanytime with low memory requirement.As shown in the figuresi.e. Fig.(12), (13),and (14), we know the fact that the proposed method is better than the conventional method.

4.2. Performance

Real-time image processing has a deadline that is restricted for e.g.33 ms i.e. 30 fps.In this proposed method, the erosion operation is performed by anytime algorithmic method using step by step with the different patterns of 3x3 SE as described in section 3. There is a linear relationship between the processing steps and processing time, i.e.when the number of processing steps increases, the required processing time also increases and the quality of result improves. Thus, the quality of result can be expressed by processing time and the probability of correctness and certainty. The performance of anytime algorithmic erosion can be evaluated theoretically from the viewpoint of probability theory.Suppose that the discrete random variable

X =no. of eroded points = $\{x_i\}$

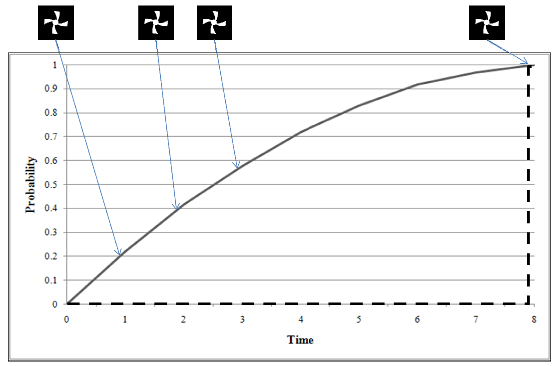
x_i = no. of eroded points at step i, $x_i \in R^2$

where $i = 1, 2, \ldots, 8$.

The previous result is used for the current calculation step,so the probability of x_i at current step is greater than theprobability of x_{i-1}at previous step. Thus, itcan be expressed byCumulative Distribution Function (CDF) of X,i.e. $F(x_i) = P(X \leq x_i)$ by

$$F(x_i) = \begin{cases} 0 & : i \leq 0 \\ x_i / x_8 & : 0 < i < 8 \\ 1 & : 8 \leq i. \end{cases} \quad (8)$$

Initial result Approximate results…Exact result



——— Proposed method

- - - - - - Conventional method

Figure 15. Performance curve of erosion

Figure 15 shows the average performance curve of erosion applied by algorithm 1. As shown in this figure, the initial result can be obtained immediately and the quality of result becomes better when the processing time increases.

Table 1 expresses that the running time comparison between the conventional and proposed methods. In order to express the running time of an algorithm, it is used best, average, and worse cases which express that the resource usage like time and memoryis at least, on average, and at most respectively. Here,the bestcasein efficiency means that the initial result is obtained with at least amount of memory at step 1 and the average case means that the approximateand exact results are obtained with average amount of memory. Next, the average case in performancemeans that the initial result can be obtained at available processing timein every steps, the worse case means that no result is obtained and the best case means that the exact result is obtained atexpected processing time respectively. It shows that the proposed method is better than the conventional method.The time complexity of the proposed algorithmsis$O(n^2)$.

Table 1. Running time comparison between conventional and proposed methods

	Step	Conventional method	Proposed method
Efficien	1	-	best case
	2	-	average case
	3	-	average case
	4	-	average case
	5	-	average case
	6	-	average case
	7	-	average case

cy	8	average case	average case
Performance	1	worse case	average case
	2	worse case	average case
	3	worse case	average case
	4	worse case	average case
	5	worse case	average case
	6	worse case	average case
	7	worse case	average case
	8	best case	best case

5. Conclusion and Future Works

This paper presents anytime algorithmic approach to morphological image processing methodbased on anytime algorithm by constructingmulti-SEfor the RTIP system. The proposed method is expressed by erosion operation for the boundary extraction. The experimental results show that coarse-to-fine results can be obtained at the available processing time. The performance curve of erosion is evaluated from the viewpoint of probability theory for the correctness and certainty.Running time comparison between the conventional and proposed methodsis expressed by table with efficiency and performance. Thus, the effectiveness of the proposed method can be confirmed by the experimental results with acceptable performance curve. So, it is useful for the RTIP system under time constraint and the implementationofembeddedsystem application.

In the future, we will extend this idea to the high level image processing method e.g.image/datacompression for the image transmission system and construct the anytime algorithmic image processing library. We will report about the combination of anytime algorithmic approach in the near future.

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