# A Mathematical Morphological Method to Thin Edge Detection in Dark Region

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***Abstract*—The performance of image segmentation depends on the output quality of the edge detection process. Typical edge detecting method is based on detecting pixels in an image with high gradient values, and then applies a global threshold value to extract the edge points of the image. By these methods, some detected edge points may not belong to the edge and some thin edge points in dark regions of the image are being eliminated. These eliminated edges may be with important features of the image. This paper proposes a new mathematical morphological edge-detecting algorithm based on the morphological residue transformation derived from dilation operation to detect and preserve the thin edges. Moreover, this work adopts five bipolar oriented edge masks to prune the miss detected edge points. The experimental results show that the proposed algorithm is successfully to preserve the thin edges in the dark regions.**

***Index Terms*—Mathematical morphology, edge detection, and threshold.**

## I. Introduction

EDGE detection is the fundamental process in image segmentation. In the past two decades, there are several methods have been proposed for detecting the edges of the considering images. For examples, Sobel detector used a local gradient operator that is only able to detect edges having certain orientations and is performed very poorly when the edges were blurred and noisy [1]. Prewitt operator tries to fit a least-squares-error quadratic surface over a 3x3 image window and differentiate the fitted surface [2]. Most of these edge detectors are based on the main characteristic of an edge that is to find pixels with the abrupt intensity changes bin gray level.

Conventionally, a thresholding process is applied as post-processing of edge detection to obtain the points of the edge. A global threshold value is utilized to detect the edge of the image after the entire image is transformed into binary code. For an image with apparent edges, the threshold method performs well in extracting edge. But, some points with low gradient values near the dark region are usually removed by the threshold method. In some applications, such as computer vision, these points with slight differences on gradation in an image may be important features for further analyzing. Therefore, it is necessary to develop an algorithm that is able to distinguish small changes both in lightless and dark region, and preserve these thin edges as well as apparent edges under the same final post-processing threshold value.

This paper proposes a novel mathematical morphology based algorithm for thin edge detection in dark region. This algorithm detects the pixels with changing gradation by morphological residue method. This morphological residue method is able to sketch out the all pixels with changing levels by subtracting the original image from its erosion or dilation results. Then the image is decomposed into several sub-images, and different edge enhancement method will be applied on different sub-image. Some unwanted noise pixel might be also enhanced. For that, we defined five bipolar oriented edge masks to eliminate the noise pixels. Because the thin edges are being enhanced by the proposed method, it is only need to apply a global threshold to transform the image into binary image for edge detecting.

This paper is organized as follows: Section II presents the proposed algorithm for thin edge enhancement and the bipolar oriented edge masks for noise pixel pruning strategy. Section III presents comparison results between the proposed algorithm with other edge detection methods. The conclusions are discussed in the last section.

## II. The Proposed Algorithm

### *A. General Description*

The major objective of the proposed algorithm is to enhance and preserve the thin edges, as well as detect them. The proposed algorithm can work well for the apparent edges in bright regions. The image is first processed by the morphological contrast enhancement operation for increasing the gradient values of the pixel, thus the edge detector can detect the edge much easier. Then the dilation residue edge detector is applied to the enhanced image. It produces an image with various grey-level strength detected edges. In order to determine the characteristics of each part of the image, we decompose the image into several sub-images, and calculate the mean value and standard deviation of each sub-image. There are four defined cases that used to enhance the edge of the sub-images according to their mean and standard deviation. Then apply the threshold image into the edge image. After that, there are five bipolar oriented edge masks utilized to prune the miss-detected pixels and reduce the noise of the final result image. The proposed solution algorithm is illustrated in Fig. 1.

### *B. Formal Description*

As illustrated in Fig. 1, there are five steps in the process of the proposed algorithm. Let $F$ denotes the original image, and $B$ denote the structuring element. The detailed information of these steps is discussed step by step as the following.

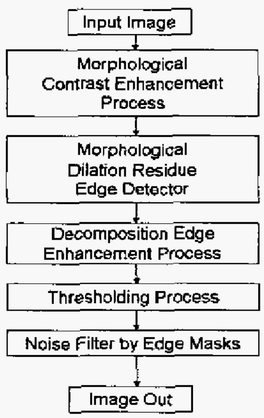


Fig. 1. Process flow chart of the proposed algorithm.

*Step 1*: *Morphological Contrast Enhancement Process.* In order to increase the contrast level of the original image $F$, the mathematical contrast enhancement process is utilized to $F$ to increase the grey-level difference between dark objects and bright objects. Let $B$ denotes a 3x3-structuring element shows in Fig. 2. $F_c$ denote contrast enhanced image can be formulated as follow:

$$F_c = F + WTH(F) - BTH(F) \tag{10}$$

The white top-hat and black top-hat transformations are performed to obtain the contrast enhanced image $F_c$. The contrast enhancement process is to accentuate or sharpen the image features to make the image more useful for visualization for human eyes, or easier analysis by morphological residue edge detectors.

*Step 2*: *Morphological Residue Edge Detection Process.* Morphological dilation residue edge detector is applied to the image $F_c$ to extract the edge information. $F_e$ denoted edge detected image can be formulated as follow:

$$F_e = (F_c \oplus B) - F_c \tag{11}$$

The resulted image $F_e$ contains grey-level edges with various edge strengths. Although the original image $F$ has been contrast enhanced for the most of apparent edges, which can be easily detected, some thin or smooth edges are easily be eliminated by applying the global threshold value in the whole image. In order to enhance thin or smooth edges, a recursive quad decomposition edge enhancement process is applied to detect the edge image.

| | | |
|---|---|---|
| 0 | 1 | 0 |
| 1 | 1 | 1 |
| 0 | 1 | 0 |

Fig. 2. Structuring element for contrast enhancement and dilation residue edge detection

*Step 3*: *Quad Decomposition Edge Enhancement Process.* Quad decomposition edge enhancement process is applied to the image $F_e$ to sharp thin or smooth edges. In this process, the image $F_e$ is decomposed into four sub-images with same size, and each sub-image decomposed into four sub-images. The process is repeated until the user defined smallest sub-image size $N_s$ is reached. This process is shown in Fig. 3.

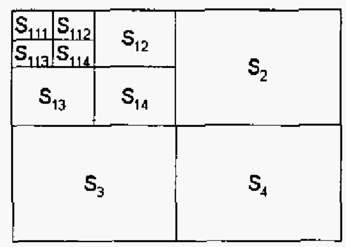


Fig 3. Illustration of quad decomposition of an image.

In this process, we defined four cases for enhancing the thin or smooth edges in a sub-image. Mean and standard deviation in each sub-image are calculated for determining which case should be applied to the sub-image.

$$\mu = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} F_e(i,j)}{M \times N} \tag{12}$$

$$\delta = \sqrt{\frac{\sum_{i=1}^{M}\sum_{j=1}^{N} (F_e(i,j) - \mu)^2}{M \times N}} \tag{13}$$

where $M$ and $N$ are width and height of the sub-image, respectively. By these mean and standard deviation values of each sub-image, we defined four edge point enhancement cases as follows:

*Case 1: Redundant Background*

If the pixel is that its grey-level value $P_{ij}$ is less than the mean value $\mu$ of its belonging sub-image and the sub-image with $\mu$<2 and $\delta$<2, then the pixel is considered to be a background pixel and will be set as grey-level 0 (black).

*Case 2: Thin Edges Enhancement*

If the pixel is that its grey-level value $P_{ij}$ is greater than mean value $\mu$ of its belonging sub-image and less than $\mu+1.5\times\delta$ as well as the sub-image with $\mu$<2 and $\delta$<2, then the pixel is considered to be a thin edge point and its grey-level value will be enlarged to the square of $P_{ij}$ (i.e. $P_{ij}\times P_{ij}$).

*Case 3: Intensive Thin Edges Enhancement*

If the pixel is that its grey-level value $P_{ij}$ is greater than $\mu+1.5\times\delta$ and less than $\mu+3\times\delta$ as well as its belonging sub-image with $\mu$<2 and $\delta$<2, then the pixel is considered to be a intensive thin edge point and its grey-level value will be enlarged to cube of $P_{ij}$ (i.e. $P_{ij} \times P_{ij} \times P_{ij}$).

*Case 4: Thin Edges in Complex Background Enhancement*

If the pixel is that its grey-level value $P_{ij}$ is greater than $\mu + 1.5 \times \delta$ and its belonging sub-images that $\mu$>5 and $\delta$>6, then the pixel is considered to be a thin edge point in a complex background and its grey-level value will be enlarged to square of $P_{ij}$ ($P_{ij} \times P_{ij}$).

Let $F_q$ denotes the image combined from all processed sub-image. All thin edges are enhanced apparently after all sub-images completed this processing step. Similarly, some pixels, which do not really belong to any edge, are been enhanced as well. This phenomenon may cause noise points distributing over the image. To solve this problem, a noise pruning process consisting five bipolar oriented edge masks is applied to the image $F_q$ for reducing noise points.

*Step 4*: *Thresholding Process.* Before we apply the edge masks to the image $F_q$ for removing the noise points that created by *Step. 3*, we have to threshold entire image with a global threshold value to reduce the computational complexity for noise removing process in *Step 5*. The properly threshold value applying to the image can be obtained by experiment. A greater threshold value can extract more thin edges, but also lead to extract more noise points that do not really belong to any edge. A smaller threshold value is still able to extract the enhanced thin edges without producing a huge amount of noise, but it may eliminate some of really thin edges. In this paper, we suggest to apply a threshold value ranging from 20 to 30 for producing the image $F_t$ with the thin edges clearly and without causing too many noise points.

*Step 5*: *Noise Removing Process.* In this step, five bipolar oriented edge masks shown in Fig. 4 are applied to the image $F_t$. The task of this process is to remove unwanted noise pixels, therefore, the mask only applied to the pixel that satisfies the following terms:

1) The pixel is thresholded to be an edge point.

2) The sub-image contains the pixel and its mean and standard deviation obtained in *Step 4* are $\mu$<3 and $\delta$<3, respectively. This step can indicate the sub-image belongs to background or dark region of the original image $F$.

We can obtain the score of each scanned pixel by the summation of multiplying the mask elements by the corresponding covered pixels in image $F_t$. For positive scoring pixel, it is considered to be an edge of the image that can preserve its value. In the other hand, negative scoring pixel is considered to be a noise point, and will be shaded away. By applying these edge masks to the image $F_t$, it is easy to remove the noise points created in background or dark regions.

## IV. The Proposed Algorithm

In this section, the proposed mathematical morphological edge detection algorithm is compared with other famous methods for edge detection. A famous natural scene, "Camera Man" is shown in Fig. 5 that was widely used to compare the performances of image processing algorithms.

$$\begin{bmatrix} -2 & -2 & -2 & -2 & -2 & -2 & -2 \\ -2 & -2 & -2 & -2 & -2 & -2 & -2 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 2 & 2 & 2 & -2 & 2 & 2 & 2 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -2 & -2 & -2 & -2 & -2 & -2 & -2 \\ -2 & -2 & -2 & -2 & -2 & -2 & -2 \end{bmatrix} \begin{bmatrix} -2 & -2 & 1 & 2 & 1 & -2 & -2 \\ -2 & -2 & 1 & 2 & 1 & -2 & -2 \\ -2 & -2 & 1 & 2 & 1 & -2 & -2 \\ -2 & -2 & 1 & -2 & 1 & -2 & -2 \\ -2 & -2 & 1 & 2 & 1 & -2 & -2 \\ -2 & -2 & 1 & 2 & 1 & -2 & -2 \\ -2 & -2 & 1 & 2 & 1 & -2 & -2 \end{bmatrix} \begin{bmatrix} -1 & 1 & 2 & 1 & -2 & -2 & -2 \\ -1 & 1 & 2 & 1 & -1 & -2 & -2 \\ -1 & 1 & 2 & 1 & -1 & -2 & -2 \\ -2 & -1 & 1 & -2 & 1 & -1 & -2 \\ -2 & -2 & -1 & 1 & 2 & 1 & -1 \\ -2 & -2 & -1 & 1 & 2 & 1 & -1 \\ -2 & -2 & -2 & 1 & 2 & 1 & -1 \end{bmatrix}$$

(a) (b) (c)

$$\begin{bmatrix} 2 & 1 & -1 & -2 & -2 & -2 & -2 \\ 1 & 2 & 1 & -1 & -2 & -2 & -2 \\ -1 & 1 & 2 & 1 & -1 & -2 & -2 \\ -2 & -1 & 1 & -2 & 1 & -1 & -2 \\ -2 & -2 & -1 & 1 & 2 & 1 & -1 \\ -2 & -2 & -2 & -1 & 1 & 2 & 1 \\ -2 & -2 & -2 & -2 & -1 & 1 & 2 \end{bmatrix} \begin{bmatrix} -2 & 1 & 1 & 2 & 1 & -2 & -2 \\ 1 & 1 & 1 & 2 & 1 & -2 & -2 \\ 1 & 1 & 1 & 2 & 1 & -2 & -2 \\ 2 & 2 & 2 & -2 & 1 & -2 & -2 \\ 1 & 1 & 1 & 1 & 1 & -2 & -2 \\ -2 & -2 & -2 & -2 & -2 & -2 & -2 \\ -2 & -2 & -2 & -2 & -2 & -2 & -2 \end{bmatrix}$$

(d) (e)

Fig. 4. Bipolar oriented edge masks.
(a) for angel 0 (b) for angel $\pi/2$
(c) for angel $3\pi/8$, and $5\pi/8$ (d) for angel $\pi/4$ and $3\pi/4$
(e) for corner edge

As shown in Fig. 5, the cameraman wears a black coat. The coat has many features on it that is important for analyzing the picture. But it is too dark to see any details in shading part of the coat by human eyes. If we increase the bright level of the picture, shown in Fig. 6, it shows clearly the edge features of hand and pockets in dark region of the coat. But these edge features are still very hard to detect by most of the existing methods for edge detection.

For comparison purpose, classical Sobel edge detector [12], mathematical morphological residue edge detector [13], DoE edge detector [14], and Lum prefilter [15] are applied on this image. Their results are shown as in Fig. 7, 8, 9, and 10, respectively. All of these methods can only detect the contour of the cameraman, but fail to detect sketch of the tower and edge features on the coat.

The result of the proposed mathematical morphological edge detection algorithm is shown in Fig. 11. As in Fig. 11, the algorithm successfully extracts and preserves the edge features in dark regions on the coat.

## V. Conclusion

A new mathematical morphology edge detection algorithm has been proposed. The proposed algorithm is able to detect the features in the dark regions, and preserve them as well as other apparent edges. The mathematical morphological contrast enhancement process is applied to enhance the image contrast for processing. The mathematical morphological dilation residue edge detector is used in this algorithm for detecting the edge information, which can produce various strength of edge in the mage. Then we use a quad decomposition scheme to decompose the image into several sub-images, and used a set of methods to enhance the thin edge that existing in the sub-image. Finally, we use a set of bipolar oriented edge masks to remove the noise pixels. Comprehensive comparison experiments have been carried out on natural scene image named "Camera Man".

Fig. 5. Picture of "Camera Man."

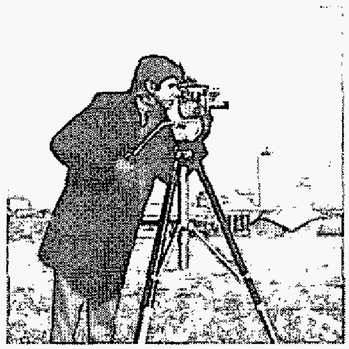

Fig. 6. Picture of enhanced "Camera Man."

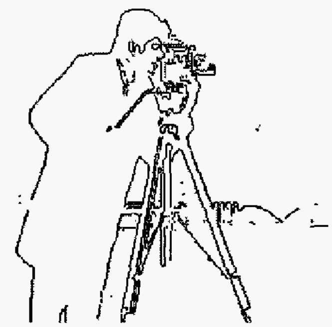

Fig. 7. Processed result by Sobel

Fig. 8. Processed result by Morphological residue.

Fig. 9. Processed result by DoE.

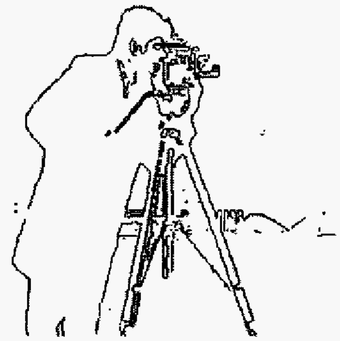

Fig. 10. Processed result by Lum prefilter.

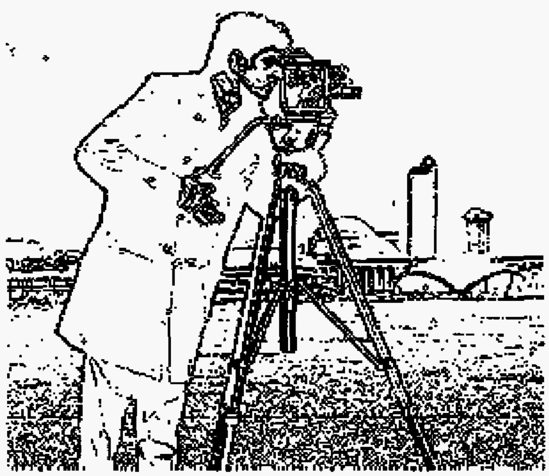

Fig. 11. Process result by proposed algorithm.

Experimental results show that the proposed algorithm outperforms other edge detection methods on detecting detail edge features and thin edge features in dark regions, and these thin edges can be preserved as the same as other apparent edges. The proposed algorithm is suitable for applying to many applications, such as detection object in a lightless place, or edge detection without lighting conditions.

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