# An Adaptive Morphological Edge Detection Algorithm Based on Image Fusion

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*Abstract*—**Edge detection is a core technology in image processing and recognition. Because classical edge detection operators such as Roberts, Sobel and Canny operator are sensitive to noise, and traditional edge detection algorithm based on mathematical morphology is insufficient for complex features, this paper proposes a multi-structure and multi-scale morphological adaptive algorithm based on image fusion that can reasonably consider noise reduction and preserve the detailed edge information. Finally, the experiment results indicate that the novel algorithm ensures the continuity, integrity, and accurate location of image edge when being applied to iris recognition and AGVs vision navigation.**

***Keywords-Mathematical morphology; Structure element (SE); Edge detection; Adaptive algorithm; Image fusion***

## I. INTRODUCTION

Edge detection is an important basis of image segmentation, image understanding and image retrieval. It is also the focused area of image processing, which has not been successfully resolved. The classical edge detection methods, such as Roberts operator [1], Sobel operator [2], Canny operator [3], are sensitive to noise, and are difficult to meet the real-time requirements. Given the defects above, these classical edge detection operators are impractical in actual image processing.

Mathematical morphology is a nonlinear filtering method. In the traditional edge detection algorithm based on morphology, the structure element (SE) is fixed, symmetric, and single, so the extracted edge has the deficiency of discontinuity and blurring. Based on this, a lot of researchers propose fuzzy morphology [5], soft morphology [6], multi-structure morphology [7-9], multi-scale morphology [10-12], etc, and do a lot of researches on their applications in different field. Li et al. apply morphology to detect gastric tumor pathologic cell image, and analyze the influence of changing SEs and gray-scale values [13]. Zhang et al. present a local-peak-value-based adaptive de-noising algorithm to extract impulsive features, and employ simulated impulsive and vibration signals of two defective roller bearings to achieve the goal of fault diagnosis [14]. Kennell et al. investigate a binary morphology and "center of mass" technique for the pupil boundary, and a local statistics approach for the limbic boundary in the image preprocessing of iris recognition [15]. Considering the low signal-to-noise ratio and high complexity of corridor image of a building, Fan et al. use a novel morphology-based algorithm to test with corridor image of a teaching building in mobile robot to meet the needs of robot vision system [16].

However, for a complex image with noise of different intensity, the single edge detection method can only reflect the edge information from certain aspect, and it is not effective to extract the edge with only one structure or only one scale. This paper proposes a multi-structure and multi-scale morphological adaptive edge detection algorithm based on image fusion. It integrates the edge extracted by multi-structure elements with the one detected by multi-scale elements to get the final binary edge image with optimal threshold segmentation. The experimental results indicate that the new edge detection algorithm can reasonably consider noise reduction and accurate edge location.

## II. THE PRICIPLE OF MATHEMATICAL MORPHOLOGY

Mathematical morphology is established on set theory, and its basic idea is to use a certain SE to extract the corresponding shape in the image to achieve the goal of image analysis and recognition.

The basic operations of mathematical morphology are dilation, erosion, opening and closing, which are the interactions between shape and SE. It is supposed that the original image is $f(x,y)$, the SE is $b(x,y)$, $D_f$, $D_b$ are the definition domains of $f(x,y)$ and $b(x,y)$, respectively. The fundamental morphological operations are given as follows:

(1) $f \oplus b$ is expressed as dilation to eliminate dark details and enhance bright edge, which is given as

$$(f \oplus b)(x,y) = \max\{f(x-i,y-j)+b(i,j) \mid f(x-i,y-j)\in f, b(i,j)\in b\} \quad (1)$$

(2) $f \Theta b$ is expressed as erosion to eliminate bright details and weaken bright edge, which is given as:

$$(f \Theta b)(x,y) = \min\{f(x+i,y+j)-b(i,j) \mid f(x+i,y+j)\in f, b(i,j)\in b\} \quad (2)$$

(3) $f \circ b$ is expressed as opening to eliminate bright details

of smaller size compared with SE, which is given as:

$$f \circ b = (f \Theta b) \oplus b \tag{3}$$

(4) $f \bullet b$ is expressed as closing to eliminate dark details of smaller size compared with SE, which is given as:

$$f \bullet b = (f \oplus b) \Theta b \tag{4}$$

Morphology has been widely used in edge detection, and has been made a number of edge detection operators which are given as follows:

Dilation operator: $O_1 = f \oplus b - f$ (5)

Erosion operator: $O_2 = f - f \Theta b$ (6)

Dilation-erosion operator: $O_3 = f \oplus b - f \Theta b$ (7)

It can be seen from the definitions above that the images extracted from dilation and erosion operators are the inner and outer edge of original image, respectively. Morphological opening and closing operation can smooth the signals, filter out noise that is smaller than SE. According to the Characteristics, the anti-noise morphological edge detection operators are given as follows:

Anti-noise dilation operator: $O_4 = f \oplus b - f \bullet b$ (8)

Anti-noise erosion operator: $O_5 = f \circ b - f \Theta b$ (9)

Anti-noise dilation-erosion operator:

$$O_6 = (f \circ b) \oplus b - (f \bullet b) \Theta b \tag{10}$$

From the above we can see that the response of anti-noise dilation operator to positive pulse is zero, and the response of anti-noise erosion operator to negative pulse is also zero, they all have some inhibitory effects on the noise.

## III. A Multi-Structure And Multi-Scale Morphological Adaptive Edge Detection Algorithm Based On Image Fision

Because of the unicity and fixity of SE in traditional morphology-based edge detection, there are two main deficiencies: on the one hand a single SE can only detect the edge of the same direction with the SE, but is not sensitive to different directions; on the other hand large-scale SE has strong ability to restrain noise, but the detected edge image is rough, small-scale SE is good at checking the details of the edge, but weak at noise suppression. In order to effectively restrain noise and preserve image edge information, we use multi-structure morphological adaptive algorithm and multi-scale morphological adaptive algorithm respectively to get the edge images, and integrate the two edges based on image fusion with the optimal threshold segmentation to get the final binary edge image. The steps of the new algorithm are showed as Figure 1.

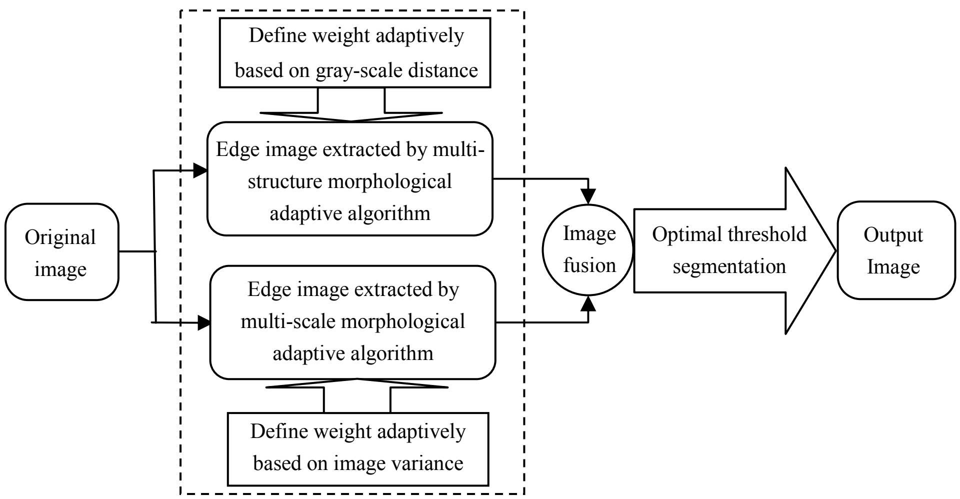



Figure 1. The steps of the new algorithm

### A. A Multi-Structure Morphological Adaptive Edge Detection Algorithm Based on Gray-Scale Distance

According to the best matching relations, namely when edge direction is vertical to SE, the detection effect is the best, and contrariwise, the poorest. We calculate the Mahalanobis gray-scale distance of original image to adaptively define the weights of SEs. Considering the requirement of calculation speed, this paper choose four 3×3 SEs as Figure 2.

$$\underset{b_1}{\begin{pmatrix} 0 & 0 & 0 \\ 1 & 1 & 1 \\ 0 & 0 & 0 \end{pmatrix}} \underset{b_2}{\begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{pmatrix}} \underset{b_3}{\begin{pmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{pmatrix}} \underset{b_4}{\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}}$$

Figure 2. The SEs of different directions with the size of 3×3

$$\begin{pmatrix} a_5 & a_4 & a_3 \\ a_6 & a_1 & a_2 \\ a_7 & a_8 & a_9 \end{pmatrix}$$

Figure 3. Image sub-block with the size of 3×3

Figure 3 shows the sub-block with the size of $3\times3$, in which $a_1$ is the gray-scale value of the center pixel, and $a_2, a_3, \ldots, a_9$ stand for its neighborhood gray-scale value, then the gray-scale distance of $a_1$ and its neighborhood can be performed as:

$$d_k = |a_1 - a_k|, k = 2,3,\ldots,9 \quad (11)$$

The gray-scale distance reflects the differences between center pixel and its neighborhood, the larger differences, the higher extent of saltation, and the bigger possibility that the pixel is an edge point. Supposing $(x, y)$ is the coordinate of $a_1$, then the edge gray-scale distance of $a_1$ can be defined as Table 1:

TABLE I
THE EDGE GRAY-SCALE DISTANCE DIFFERENT DIRECTION

| The Edge Gray-Scale Distance of $a_1$ | The Corresponding Direction |
|---|---|
| $D_1(x,y) = \sum_{k=3}^{5} d_k + \sum_{k=7}^{9} d_k$ | $b_1$ |
| $D_2(x,y) = \sum_{k=4}^{6} d_k + \sum_{k=8}^{9} d_k + d_2$ | $b_2$ |
| $D_3(x,y) = \sum_{k=2}^{3} d_k + \sum_{k=5}^{7} d_k + d_9$ | $b_3$ |
| $D_4(x,y) = \sum_{k=2}^{4} d_k + \sum_{k=6}^{8} d_k$ | $b_4$ |

As for the whole image, the gray-scale distances of each edge and adaptive weights of SEs can be calculated as below:

$$ED_k = \sum_{x=2}^{M-1} \sum_{y=2}^{N-1} D_k(x, y), k = 1,2,3,4 \quad (12)$$

$$w_k = ED_k \Big/ \sum_{k=1}^{4} ED_k, k = 1,2,3,4 \quad (13)$$

Then substitute (3) into the anti-noise dilation-erosion operators to get the edge $E_1$ extracted adaptively by multi-structure morphology:

$$E_1 = \sum_{k=1}^{4} w_k [(f \circ b_k) \oplus b_k - (f \bullet b_k) \Theta b_k] \quad (14)$$

*B. A Multi-Scale Morphological Adaptive Edge Detection Algorithm Based on Image Variance*

Multi-scale morphology overcomes the contradictions of large-scale SEs, which are good at de-noising but the extracted edge is coarse, while small-scale SEs are good at keeping edge information but weak at de-noising. This operator takes advantages of de-noising property of large-scale SE to identify edge reliably, as well as location property of small-scale SE to track edge from coarse to fine, then uses the approach of adaptively determining weight based on image variance to synthesize the edge image.

Multi-scale SEs in this paper are defined as:

$$b^k = b \oplus b \oplus b \ldots \oplus b \quad (15)$$

where $k$ and $b$ are scale parameter and limited SE, respectively. The equation expresses that large-scale element is derived from a series of dilation operations of small-scale SEs. In this paper $b$ was taken as $3\times3$ crisscross.

According to the principle that the weight of large-scale SE is larger than that of small-scale one, the edge extracted by multi-scale adaptive morphology is given by following equation:

$$E_2 = \sum_{k=l}^{n} w_k [(f \circ b^k) \oplus b^k - (f \bullet b^k) \Theta b^k] \quad (16)$$

where $[l, n]$ is the definition domain of $k$, which is usually valued from 2 to 5, and $w_k$ is the adaptive weight based on image variance, which can be achieved through the following steps:

*Step1* Obtain the mean value images using open-close and close-open morphological filters under different scales:

$$f_k(x, y) = (f \circ b^k \bullet b^k + f \bullet b^k \circ b^k)/2 \quad (17)$$

*Step2* Use the mean value images got in step1 to calculate the image variances under different scales:

$$\Delta_k^2 = \left| f - f_k \right|^2 \quad (18)$$

*Step3* According to the image variances above, determine the weighting coefficient：

$$w_k = \Delta_{n-l}^2 \Big/ \sum_{k=l}^{n} \Delta_k^2 \quad (19)$$

where $\Delta_{n-l}^2$ is image variance value of the $(n-l)^{\text{th}}$ SE.

*C. Edge Image Fusion*

Single edge detection method can only reflect the edge information from certain aspect, especially for complex edge feature, it is difficult to meet the requirement only by multi-structure or multi-scale morphology. Recently developed image fusion techniques, which combine variety of means to obtain useful information, direct a new way for edge detection.

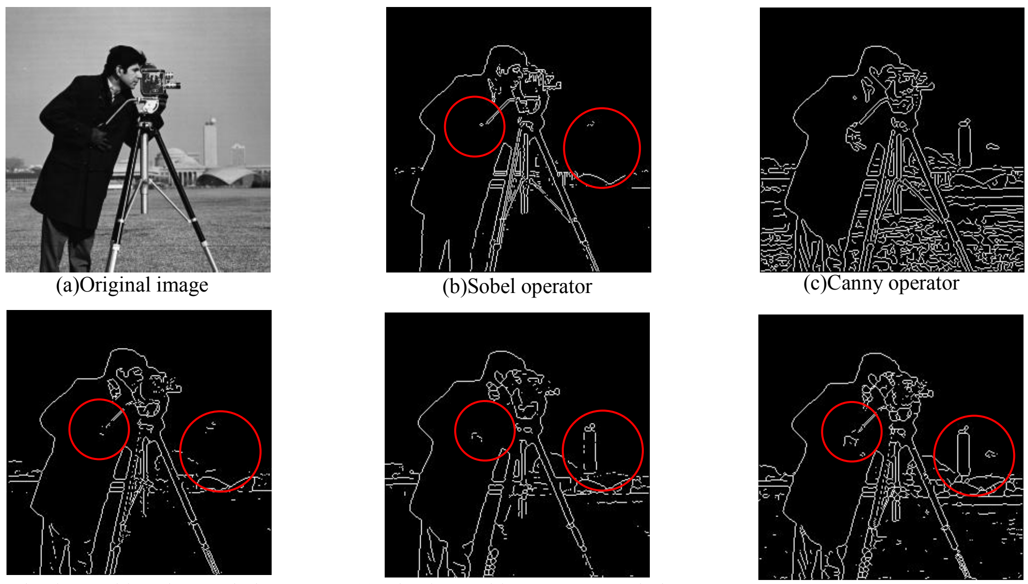
From the two sections above, we get two images of edge detection, in which $E_1$ is the edge image extracted adaptively by multi-structure morphology, and $E_2$ is detected by multi-scale morphology, then use synthetic weighted method to calculate final detected binary edge image with optimal threshold segmentation, in which the weights are both taken as 0.5, that is $E = (E_1 + E_2)/2$.

## IV. EXPERIMENT RESULTS AND ANALYSIS

In order to validate the effectiveness of the novel algorithm, we compare proposed morphological adaptive edge detection algorithm based on image fusion with classical edge detection methods under the ideal and noisy condition in the circumstance of Matlab7.0. As shown in Figure 4 that Sobel operator cannot detect the edge integrally and continually. Though Canny operator detects the edge more continually, it cannot reflect the very true edge information. Figure 4(d) and 4(e) show the outcomes of the adaptive multi-scale and multi-structure morphological algorithm respectively. Figure 4(f) shows that, the edge detected by the image fusion-based algorithm is more pinpointed and continual.

Iris location is very vital in the process of iris recognition, because it determines the accuracy. Figure 5 shows the edge detection results of bovine iris image by adding Salt&Pepper noise, whose density is 0.02. Because of the interference of noise, Sobel and Canny operators failed to obtain the clear edge of inner circle, while the new algorithm can nearly remove all noise to locate the edge.

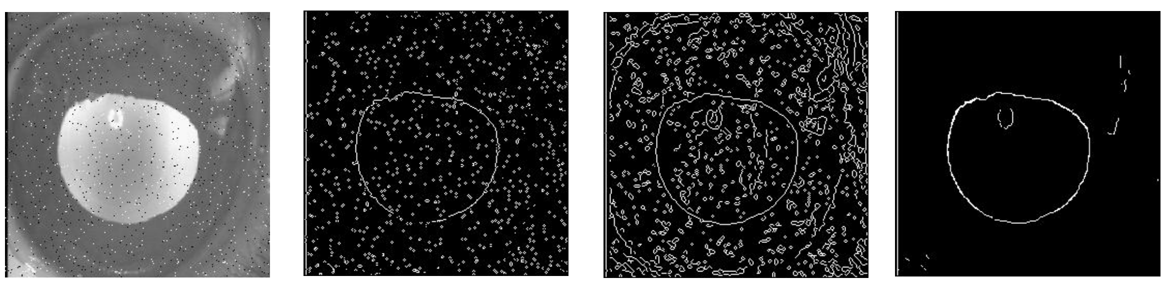
Road recognition is a key step in the course of AGVs vision navigation, and the robustness and accuracy of recognition are largely determined by road edge. Figure 6 is the edge detection results of road image by adding Gaussian noise, whose mean value is 0 and variance is 0.005. It can be seen obviously from the Figure 6 that the result of Sobel operator is discontinuous, even undetected. Canny operator detects too much unrelated information and cannot differentiate the edge from noise. The new algorithm with good real-timing can restrain most noise when being applied to AGVs vision navigation.



(a)Original image (b)Sobel operator (c)Canny operator

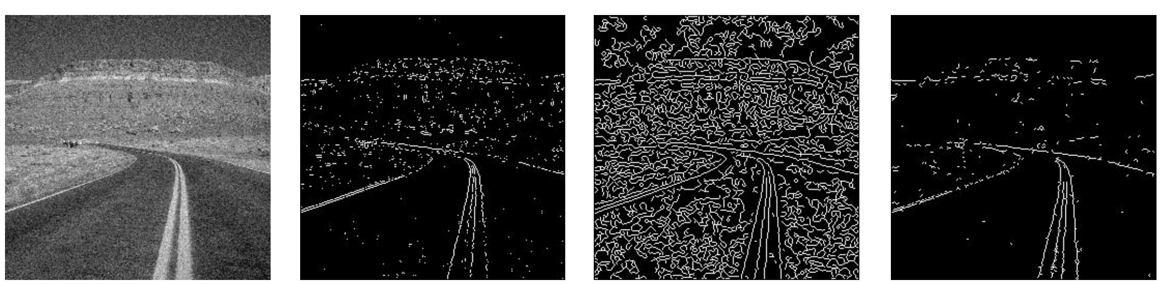
(d)Adaptive multi-scale morphology (e)Adaptive multi-structure morphology (f)Image fusion-based algorithm

Figure 4. The edge detection results of Cameraman under ideal condition



(a)Bovine iris image with Salt& Pepper noise (b)Sobel operator (c)Canny operator (d)New algorithm

Figure 5. The edge detection results of bovine iris by adding Salt&Pepper noise with density of 0.02



(a)Road image with Gaussian noise (b)Sobel operator (c)Canny operator (d)New algorithm

Figure 6. The edge detection results of road by adding Gaussian noise with mean value of 0 and variance of 0.005

## V. CONCLUSION

SEs of different shapes have different effects on preserving image details, and SEs of different scales make different impact on de-noising. According to the fact that single edge detection method can only reflect the edge information from certain aspect, this paper proposes a multi-structure and multi-scale morphological adaptive edge detection algorithm based on image fusion. It integrates the edge extracted by multi-structure elements with the one detected by multi-scale elements to get the final binary edge image with the optimal threshold segmentation. The experimental results show that the novel algorithm is not only more efficient than the classical edge detection operators which are sensitive to noise, but also ensures the continuity, integrity, and accurate location of image edge. Meanwhile, when being applied to iris recognition and AGVs vision navigation, it can achieve quite good results.

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