Image Noise Suppression Using Color Morphological Filter

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Abstract

Morphological filtering is a useful technique for processing and analyzing binary and grayscale images. These filters are effective in impulsive noise filtering, feature extracting, and images enhancing. So it is important to find out method for applying morphological technique on color image and keep the colors unchanged at the same time. This paper deals with the use of morphological filters for suppression *"salt & pepper"* noise in color images. We have used *"component-wise approach"*, in which grayscale morphological operations are applied to each of the three colors image components independently. We present experimental results of applying this approach for the application of noise suppression in color images.

Introduction

Mathematical morphology is an ensembles theory used in image processing [1]. It provides an approach to digital images processing based

on geometrical shape [2]. The original theory developed by Matheron and Serra was restricted to binary images, and later it was extended to grayscale morphology by Sternberg, Nakagawa and Rosenfeld [3]. The extension of the concepts of binary and grayscale morphology to color image is not a straightforward task. However, it is possible to extend some techniques to define morphological operators on color images [2].

The theory of morphology is built on two basic operators: the erosion and dilation [1], which are the base of most morphological operations such as opening and closing [4]. Generally, the morphological operators transform the original image into another image through the interaction with the other image of certain shape and size, which is known as the *structure element*. Geometric features of the image that are similar in shape and size to the structure element are preserved, while other features are suppressed [5].

Mathematical morphology is useful for the analysis of geometrical structures in images, the reduction of clutter in images, images enhancement and segmentation. It used widely in images analysis (i.e. edge detection, shape analysis, image coding, smoothing and thinning) [6].

The rest of this paper organized as follows: sections 1 and 2 begin with binary morphology that is based on set theory. The following grayscale morphology can be regarded as the extension of binary morphology as the three-dimensional space. In section 3, the part of color morphology is introduced. Section 4 explains morphological filtering approach. The experimental results are presented in section 5 finally; section 6 is dedicated to the conclusions.

1. Binary Morphology

The theoretical foundation of binary mathematical morphology is set theory. In binary images, those points in the set are called the *'foreground'* and those in the complement set are called the *'background'*. We need three general definitions that are used extensively to extend morphological operations [6].

Translation: it supposes that A is a set of pixels in binary image and $w=(x,y)$ is a particular coordinate point. Then as in equation (1), A_w is the set A *"translated"* in direction (x,y) [7].

$$A_w = \{(a,b)+(x,y):(a,b)\in A\} \quad .... \quad (1)$$

Reflection: if A is set of pixels, then its *reflection*, denoted by $\hat{A}$, is obtained by reflecting A in the origin [7]. As shown in equation (2)

$$\hat{A} = \{(-x,-y):(x,y)\in A\} \quad .... \quad (2)$$

Structure Element (SE): in morphological operations, structuring element is a small image that is overlapped on input image to compute a certain definition [6]. It has an origin. This origin is used to apply the structuring element at a point of the image [8]. The basic operation of binary and grayscale images morphology depend on what structure elements are used [6].

1.1 Binary Morphological Operations

Dilation and erosion are the basic operations of morphology, in the sense that other operations are built on a combination of these two [7]. Dilation is the morphological translation that combines two sets by using vector addition of this element set's [3]. As shown in equations (3) & (4) dilation and erosion of a binary image A by structure element B, denoted by $A \oplus B$ and $A \Theta B$ respectively [5].

$$A \oplus B = \{a + b \mid for \ a \in A \ and \ b \in B\} \ ....\ (3)$$

$$A \Theta B = \{p \mid p + b \in A \ \ \forall b \in B\} \ ....\ (4)$$

Generally, dilation has an effect of expansion the object shape, fills gaps between objects and connects them together. Erosion shrinks the object in original image and eliminates small enough peaks [6].

Opening and closing operations may be considered as "second level" operations in that they build on the basic operations of dilation and erosion[7].

As shown in equation (5) in opening, the original image is first eroded by a structuring element and then dilated by the same one [6]. The opening of a binary image A by structuring element B, denoted by A∘B [5].

$$A \circ B = (A \Theta B) \oplus B \ ....\ (5)$$

Analogous to opening, closing may be considered as dilation followed by erosion, denoted by A●B [7]. As shown in equation (6)

$$A \bullet B = (A \oplus B) \Theta B \ ....\ (6)$$

Opening generally smoothes the contour object, breaks narrow isthmuses, and eliminates thin protrusions. Closing also tends to smooth sections of contours but is opposed to opening; it generally fuses narrow breaks and long thin gulfs, eliminates small holes and fills gaps in the contour [9].

2. Grayscale Morphology

In this section, binary morphology is extended to the grayscale case. Through the discussion below, we will see that the key issue is to use the 'maximum' and 'minimum' functions to define grayscale morphological operators [6].

When applied to a binary image, dilation and erosion operations cause an image to increase or decrease in spatial extent, respectively. To generalize these concepts to a grayscale image, it is assumed that the image contains visually distinct grayscale objects set against a gray background. In addition, it is assumed that the objects and background are both relatively spatially smooth [10].

The differences between binary and grayscale morphology results from the definitions of dilation and erosion because other operations depend on them [6].

2.1 Grayscale Morphological Operations

Grayscale erosion and dilation use 'min' and 'max' operators, respectively [3]. The minimum (min) operator will interrogate a neighborhood with a certain domain and select the smallest pixel value to become the output value. This has the effect of causing the bright areas of an image to shrink or erode. Similarly, grayscale dilation is performed by using the maximum (max) operator to select the greatest value in a neighborhood [6].

The dilation and erosion of grayscale image f(r,c) by a grayscale structure element g(r,c) are shown in equation (7) & (8), respectively [5]:

$$(f \oplus g)(r,c) = \max_{(i,j)} (f(r-i,c-j) + g(i,j)) \quad \text{................} \quad (7)$$

$$(f \ominus g)(r,c) = \min_{(i,j)} f(r+i,c+j) - g(i,j)) \quad \text{.................} \quad (8)$$

The grayscale dilation causes the brighter regions in an image to grow and causes regions darker than background to shrink. In contrast, grayscale erosion causes the darker regions to grow, and the brighter regions to shrink [3].

Grayscale closing realized by first performing grayscale dilation with grayscale structuring element, then grayscale erosion with the same structuring element. Similarly, grayscale opening is accomplished by grayscale erosion followed by grayscale dilation [10].

The effect of grayscale closing and opening is shown in figure 1. Both operations make an original image smooth along to the nature of minimum and maximum functions [6]. Note that opening decreases sizes of the small bright detail, with no appreciable effect on the darker gray levels, while the closing decreases sizes of the small dark details, with relatively little effect on bright features [9].

a) Original   b) Opening   c) Closing

Figure 1: Grayscale Opening and Closing

3. Color Morphology

After introducing binary and grayscale morphology, the task turns on dealing with the color image morphology. The application of mathematical morphology to color image is difficult, due to the vectorial nature of the color data [11]. In this paper, I deal with images in RGB color space. You can think of images in RGB color space as a three separate pixel images. Technically, these are three images in the grayscale mode that represent respectively, red, green and blue [12]. Each pixel in a color RGB image can be viewed as a three-component vector

xi=[xi1, xi2, xi3] in the color RGB space. Where samples *xi* with *xik* denoting the *R(k=1), G(k=2)* and *B(k=3)* component. Thus, the color image is a vector array or a two-dimensional matrix of three-component [13]. In this paper, I introduce component-wise approach for color morphology.

In a component-wise approach, the grayscale morphological operator is applied to each channel of the color image separately. For example, component-wise color dilation of *f(x,y)=[f_R(x,y),f_G(x,y),f_B(x,y)]* by the structure element *h(x,y)=[h_R(x,y),h_G(x,y),h_B(x,y)]* in RGB color space is defined as in equation (9):

$$(f \oplus_C h)(x,y) = [(f_R \oplus h_R)(x,y),(f_G \oplus h_G)(x,y),(f_B \oplus h_B)(x,y)] \quad \text{.......} \quad (9)$$

Where the symbol $\oplus_C$ represents component-wise dilation.

Similarly component-wise color erosion defined in equation (10):

$$(f\Theta_C h)(x,y) = [(f_R\Theta h_R)(x,y),(f_G\Theta h_G)(x,y),(f_B\Theta h_B)(x,y)] \quad \text{..............} \quad (10)$$

Component-wise color opening, and closing can be defined in the same way [5]. The use of this approach in color image processing is the most straightforward [14].

4. Morphological Filtering Method

Morphological filter by reconstruction has the property of suppressing noise, preserving the contours of the remaining objects. The use of this filter in color image requires an ordering relationship among the pixels of the image [11]. Its basic idea is to probe an image with a structuring element (SE) and to quantify the manner in which the SE fits (or does not fit) within the image. The information probed depends on both the size and shape of the SE. If the size of the feature is smaller than the SE or the shape differs from the SE, the feature will be eliminated. As emphasis by Matheron, the nature of that information is therefore dependent on the choice of the structure element [3].

Morphological filter can be constructed using opening (erosion followed by dilation) operation followed by closing (dilation followed by erosion) operation. This filter can attenuate or completely eliminate positive, negative, or both positive and negative impulsive noise from an image [2]. The advantages of using this filter: first, it can be simply implemented. Second, it has geometric filtering property, which can filter out or preserve geometric features controlled by filter design. Furthermore, it can be easily implemented by simple hardware. The shortcoming of color morphological filter for de-noising is the opening followed by the closing operator cannot remove the noisy point at edge location.

5. Experimental Results

In this section, we present results of experiments involving noise suppression in color images. I see from the experiments that the shape and the pixel values of the structuring element that used play a very important role in morphological image filtering approach.

In this paper, several different objective measures utilized for performance comparison of noise suppression filter. These measures must

show some degree of closeness between two images by exploiting the differences in statistical distributions of pixel values. Tables 1, and 2, list results of applying the morphological filtering method on the images in figures 2(b) & 3(b) where, the original image in figures 2(a) & 3(a) has been contaminated by 8% impulsive noise of type "salt & pepper".

Impulsive noise can appear during image capture, transmission or storage. Common sources of impulsive noise include lightening, industrial machines, faulty or dusty insulation of high-voltage power lines, and various unprotected electric switches [2]. I have used the *Normalized Mean Square Error (NMSE)* measure [10]. As in equation (11):

$$NMSE = \frac{\sum_{i=0}^{M}\sum_{j=0}^{N} |f_{i,j} - g_{i,j}|^2}{\sum_{i=0}^{M}\sum_{j=0}^{N} |f_{i,j}|^2} \quad \ldots\ldots\ldots\ldots \quad (11)$$

Where $f_{i,j}$, is the original image, and $g_{i,j}$ is the noisy image after filtering its components with the proposed method at *(i,j)* pixel. M and N denote the dimensions of *f* and *g* image pixels, respectively.

To measuring the restoration quality, the commonly used *Peak Signal-to-Noise Ratio (PSNR)* is used. It is a good measure of impulsive noise suppression efficiency [10]. The PSNR defined as in equation (12):

$$PSNR = 20\log_{10}\left(\frac{255}{MSE}\right), \quad \ldots\ldots\ldots\ldots\ldots \quad (12)$$

Where,

$$MSE = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} [f_{i,j} - g_{i,j}]^2}{MN} \quad \ldots\ldots\ldots\ldots \quad (13)$$

As shown in equation (14), to evaluate the detail preservation capability, the *Mean Absolute Error (MAE)* is used [2].

$$MAE = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} |f_{i,j} - g_{i,j}|}{MN} \quad \ldots\ldots\ldots\ldots \quad (14)$$

In figures 2, and 3, I have performed the proposed morphological filter using the color images of "Parrot", "Boys", and "Flower" for impulsive noise suppression purpose.

Table 1: Result of applying component-wise approach on 256×256 images contaminated with 8% salt & pepper noise, using SE in fig. 2(d)

Images	NMSE	MSE	MAE	PSNR
Parrot	0.076	56.750	7.887	30.052
Boys	0.055	40.697	5.419	36.702
Flower	0.097	73.787	8.914	24.801

Table 2: Result of applying component-wise approach on 256×256 images contaminated with 8% salt & pepper noise, using SE in fig. 3(d)

Images	NMSE	MSE	MAE	PSNR
Parrot	0.146	109.549	15.333	16.898
Boys	0.121	88.971	10.923	21.059
Flower	0.183	139.763	16.080	12.026

<div align="center">(a)   (b)   (c)</div>

$$\begin{matrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{matrix}$$
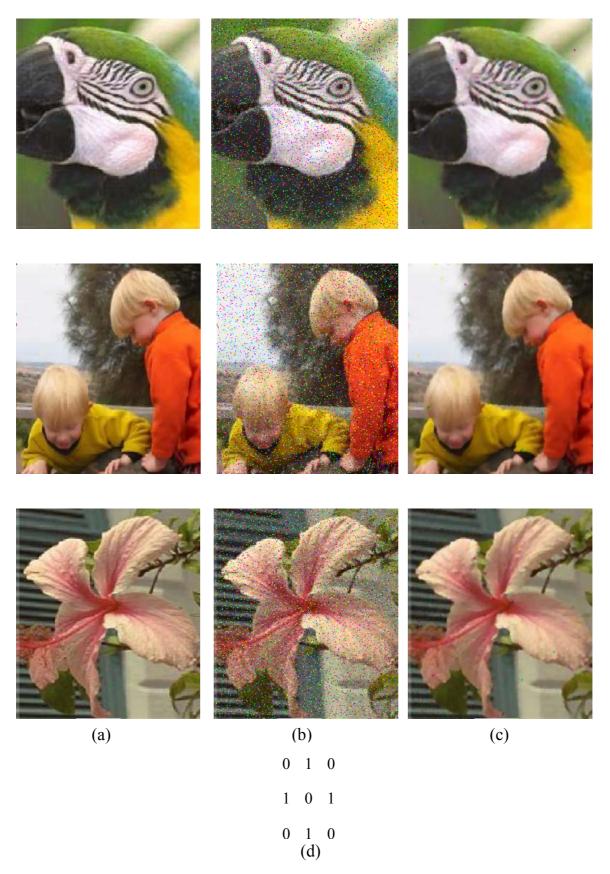
<div align="center">(d)</div>

Figure 2: Result of noise suppression (a) Parts of color test images: 'Parrot', 'boys' and 'Flower'.(b) Images contaminated by 8% salt & pepper noise. (c) Filtered results by component-wise approach. (d) 3×3 Structure element
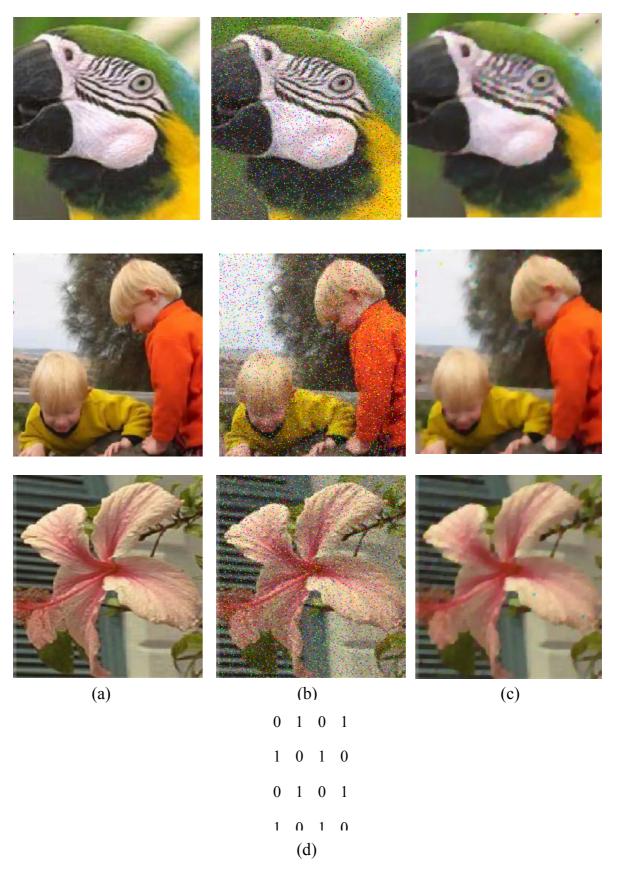
| (a) | (b) | (c) |

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0  1  0  1

1  0  1  0

0  1  0  1

1  0  1  0
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(d)

Figure 3: Result of noise suppression (a) Parts of color test images: 'Parrot', 'boys' and 'Flower'.(b) Images contaminated by 8% salt & pepper noise. (c) Filtered results by component-wise approach. (d) 4×4 Structure element

6. Conclusions

In this paper, I proposed color morphology filter for salt & pepper noise suppression from RGB color images. The combination of opening followed by closing techniques was applied to attenuate the noise component in noisy image. The proposed operators, like their grayscale counterparts, achieve detail preservation, it can be easily implemented by simple hardware, and it is simple to implement. A best elimination of noise can be obtained if the morphological elemental operations of the connected filters are made with a large structuring element, but the best conservation of structures and details in the image are achieved with a smaller structuring element.

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