Image restoration with morphological erosion and exemplar-based texture synthesis

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***Abstract*—Image restoration provides a means to reconstruct damaged regions of an image. The paper presents a new restoration algorithm, which implements the filling of damaged region with morphological erosion, and propagates structure/texture features of the known region into the damaged region with exemplar-based texture synthesis. The method can retain the continuity of image isophotes between the known region and the restored damaged region, and output a complete, natural-looking image. Through comparative experiments with some existing methods, we demonstrate the effectiveness of the algorithm in removing large objects as well as thin scratches.**

Keywords- Image reconstruction, image restoration, texture synthesis

I. Introduction

Image restoration, also known as image inpainting, provides a means to reconstruct damaged regions of an image, such that the image looks complete, natural and logical after reconstruction. Image restoration has a wide range of applications, such as the restoration of deteriorated images by removing scratches or stains, the removal of text and logos from digital images or the creation of artistic effects. Since BSCB inpainting algorithm [1] is developed, image restoration has received considerable attention and many restoration methods have been developed. The problems which those algorithms want to solve are focused on two main classes: 1) to fill in small or long and thin missing regions, 2) to fill in large and thick damaged regions (large holes). Several classical interpolation-based methods [1,2,3] belong to the first group and some texture synthesis-based methods [4,5] belong to the other. Image restoration mostly encounters difficulties for the restoration of large and thick damaged regions with composite textures, for which one can stress out two main issues:1) how to preserve isophote continuity while propagating both texture and structure characteristics information of the known patch into the damaged region, and 2) how to guarantee the high efficiency and reliability of restoration. Criminisi et al. developed a restoration algorithm [6] which can propagate the information from known areas into damaged areas along the isophote directions based on the priorities of isophote directions and exemplar-based texture synthesis. It can restore the linear structures features and composite textures in large and thick damaged regions, but sometimes its restoration results are suspicious because it's very difficult to get and preserve the directions of isophotes properly if composite textures are too complex or the quality of damaged images is poor. We proposed a restoration model based on morphological erosion and exemplar-based texture synthesis [7], which can restore some structure features (linear contours or curves with small curvature). Through comparative experiments with some existing methods, we demonstrate the effectiveness of the algorithm in removing large objects as well as thin scratches.

The organization of the paper goes as follows. We present the formulation of the proposed image restoration method generally in section 2, and then explain the method in section 3 and section 4. In section 5, we demonstrate the effectiveness of our algorithm through several examples of its two major applications - image restoration and aesthetic photo retouching. We then conclude the paper and list some future work.

II. Formulation of the Restoration Method

As for the restoration of large and thick damaged regions, any restoration methods should answer two main questions: 1) How to fill the damaged regions in order to maintain the reliability of restoration, and 2) What information (structure and texture features) can be chosen reliably for the damaged regions to be restored to remain the isophote continuity. Accordingly our image restoration model includes two parts: 1) The filling of damaged region based on morphological erosion, and 2) Restoration of structure/texture features based on exemplar-based texture synthesis. The process of morphological erosion can imitate the process of manual restoration with a very high similarity and manual restoration is considered the most trusted method, so it can guarantee the high efficiency and reliability of restoration process. The restoration of the damaged region by exemplar-based texture synthesis can preserve isophotes continuity between the known region and the restored damaged region, and output a complete, natural-looking image.

III. Region Filling with Morphological Erosion

Morphology is a broad set of image processing operations that process images based on shapes. Morphological erosion can be defined as follows. If A is an input binary image and B is a structuring element, the erosion of A by B, denoted by $A \Theta B$, is given by

$$A \Theta B = \{ x \in A \mid (B)_x \subseteq A \} \tag{1}$$

where $(B)_x$ designates the structuring element B centered at pixel x. An essential part of the erosion operations is the structuring element used to process the input image. The center pixel of the structuring element, called the origin, identifies the pixel of interest -- the pixel being processed.

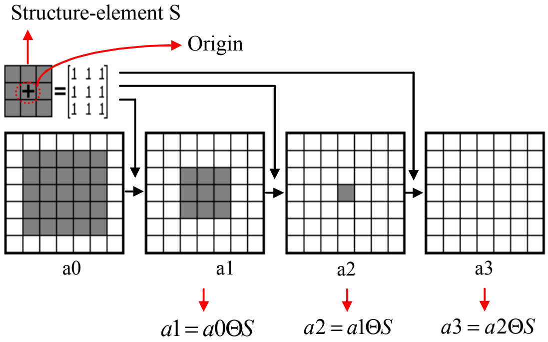

Figure 1. Example of erosion for a binary image

The erosion process is illustrated in Figure 1. By compared image a1 with image a0, we can find one layer pixels of black region is eroded by structure-element S, and the black region in image a1 is shrunk. From this process we can see easily the region filling process of image restoration is more similar with the process of erosion for binary image if we consider black regions in a binary image as damaged regions.

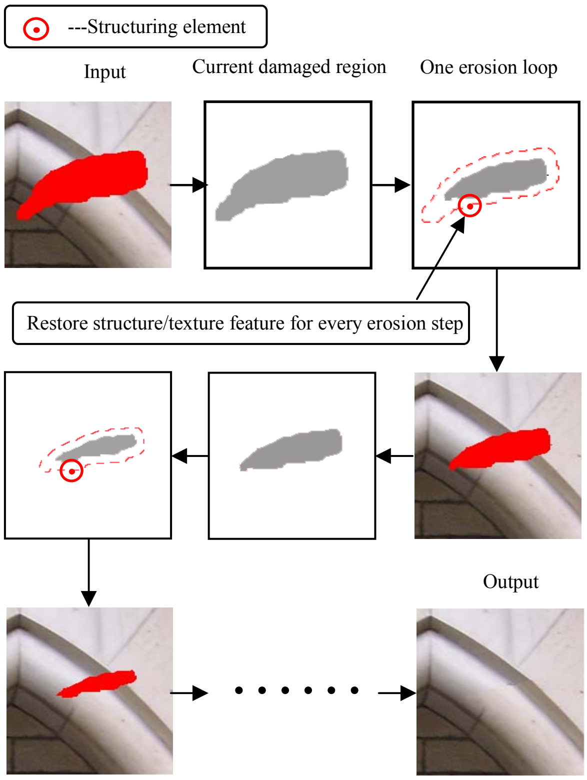

Figure 2. Region-filling process with morphological erosion

As for gray or color damaged images, if the gray or color information of the unknown pixels can be restored based on information from the neighborhood, image restoration of a damaged region can also be performed using the erosion process. The region filling process based on morphological erosion is illustrated in Figure 2. In the process, a structuring element is iteratively applied to erode the boundary pixels of a damaged region. In the process of this erosion, the boundary pixels covered by structuring element, which specifies the current position of the patch of boundary pixels to be restored, are restored by exemplar-based texture synthesis, as described in the following section. The restoration process of gray or color images is not completed until all pixels are filled and the structure/texture features are restored.

IV. Region Restoration of Structure/Texture Features with Exemplar-Based Texture Synthesis

As for the structure/texture features of an image, texture features designates gray or color values of different regions which are perceived to be similar or alike, while structure features are the contour lines of different texture areas, and each pixel has a strong relation to the pixels along the contour line. Texture synthesis involves automatically generating large textures from a small example image (known as a texture sample or exemplar). The exemplar-based texture synthesis takes an exemplar and generates additional content based on that exemplar to create much more content than is contained in the exemplar. Traditionally, exemplar-based texture synthesis includes a correction process that compares neighborhoods of each synthesized pixel with neighborhoods of the exemplar.

In manual image restoration, the damaged areas closest to known areas are restored first, which means that only the information in a narrow band along the boundary of the known areas is reliable and has a strong correlation with the information to be restored in the damaged areas. A structure/texture features synthesis algorithm based on exemplar-based texture synthesis is introduced in this section. This algorithm, illustrated in Figure 3, can restore some structure features (some ordinary structures such as linear contours or curves with small curvature) both for large and thick or long and thin damaged regions without blurring. It includes two steps as follows:

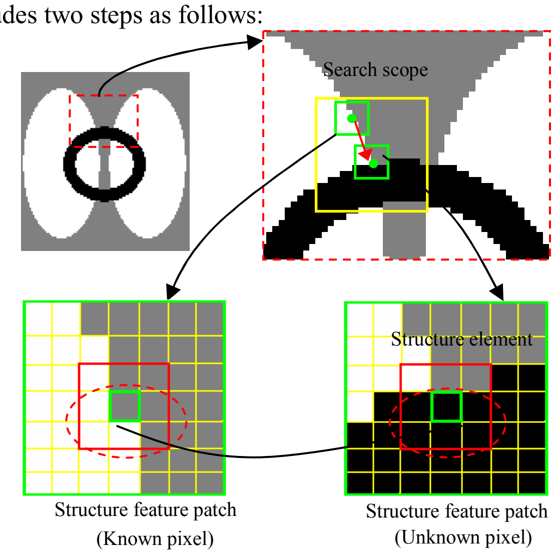

Figure 3. Structure/texture features matching with exemplar-based texture synthesis

First, inside a search scope, a patch of each unknown pixels, which is covered by structuring element currently, is compared with that of known pixels left to right and top to bottom, to find the one with maximal similarity based on the Sum of Squared Distance (SSD).

Then, when the structure features patch around a known pixel with maximal similarity (minimal SSD) is found in the search scope, the value of the known pixels in the scope of the structuring element are put into the unknown pixels covered by the structuring element, thus completing one step of restoration. In this way, the structure/texture features of the known areas are propagated into the damaged areas, and the damaged patch at every erosion step is restored.

After one loop of restoration along the boundary, a new narrow band along the boundary between the damaged area and known area is formed, which is the restored damaged area actually and formed with structure/texture features of last formed narrow band. Thus doing, we can see from the outcomes of some restoration results that an error accumulation phenomenon sometimes occurs, as shown in Figure 4(b). If for some reason the information in the old narrow band is wrong, the error might propagate to the new narrow band step by step.

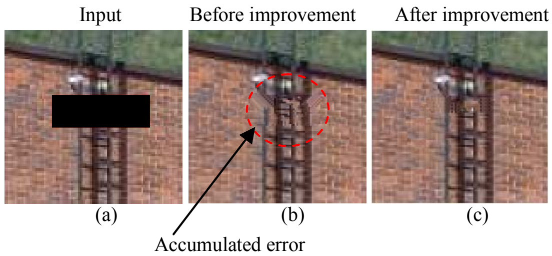

Figure 4: Example of error accumulation

In order to solve this issue, the restoration of structure/texture features for every erosion step is improved: the center of the search scope is adjusted to the original boundary all along, and only the part of the search scope inside the original image is used to reflect the fact that only the information from the original image is reliable. This process is illustrated in Figure 5, and includes the two following steps: first, a center pixel for the search scope is searched on the original boundary closest to the unknown pixel; then, the search scope is defined based on the center pixel, excluding the parts of the original damaged area between the original boundary and the advanced boundary, which have already been restored. Error accumulation can in this way be avoided to some extent (Figure 4(c)).

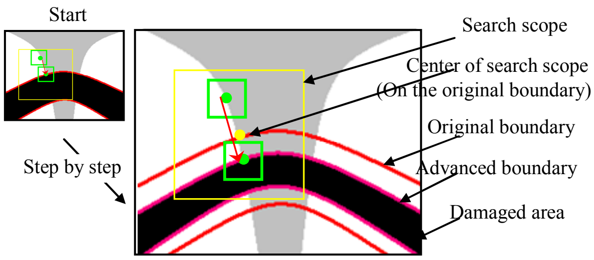

Figure 5: Solving error accumulation

V. EXPERIMENTAL RESULTS

The proposed restoration method is applied to restore a variety of images and a series of comparison with some existed restoration methods are preformed. A testing set of 120 damaged images is also built, which has those characteristics:1)The testing images have different size and are taken by the writer himself; 2)The testing images are damaged randomly, and include mainly large and thick damaged regions and a little of small or long and thin gaps; 3)By compared with original images (non-damaged), the damaged regions were consisted of linear structures and composite textures (multiple textures interacting spatially in some images).

For image restoration mostly encounters difficulties for the restoration of large and thick damaged regions with composite textures, and Criminisi's algorithm [6] can restore the linear structures features and composite textures in large and thick damaged regions, we perform a series of comparison with Criminisi's algorithm based on MSE (Mean-Squared Error) of restoration results versus original images (non-damaged images). Some restoration results are shown in Figure 6, and the analysis of comparison outcomes is shown in Table 1, which shows the high efficiency and reliability of the proposed restoration method in removing large occluding objects.

Figure 6. Restoration results of different methods

TABLE I. ANALYSIS OF COMPARISON RESULTS BASED ON MSE

Restoration method	Better results	Proportion
Criminisi's method[6]	32	26.67%
Our method	88	73.33%

Another comparison is performed. An image is selected from the restoration testing set freely, and then the image is damaged with different widths of damaged region. For example there are three different widths of damaged regions (from about 10 pixels to about 40 pixels) in Figure 7. We compared our method with Criminisi's method [6] and BSCB method [1], the outcome is shown in Table 2, and the relation between the width of damaged regions and MSE for the three restoration methods is shown in Figure 8. We can see that the proposed method can preserve isophote continuity and restore the linear structures features and composite textures both in large&thick damaged regions and in small or long&thin gaps.

About 10 pixels About 20 pixels About 40 pixels

(a) Images with different width of damaged regions

(b) results based on BSCB method[1]

(c) results based on Criminisi's method[6]

(d) results based on our restoration method

Figure 7. Restoration results with three different widths of damaged regions

TABLE II. COMPARISON OF THE THREE RESTORATION METHODS

Inpainting methods	MSE (10~pixels)	MSE (20~pixels)	MSE (40~pixels)
BSCB's method [1]	2601.37	4044.88	5913.75
Criminisi's method[6]	1973.71	2967.99	4722.87
Our method	1751.24	2374.46	3027.90

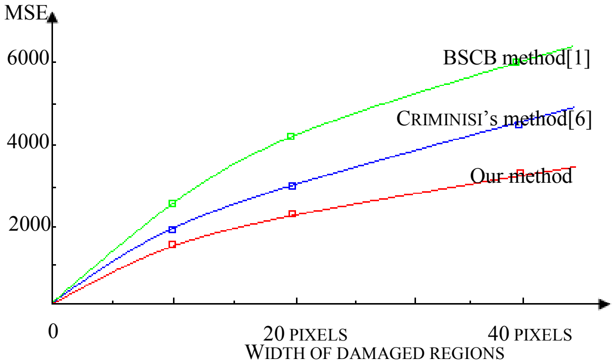

Figure 8. The relation between the width of damaged regions and the value of MSE

VI. CONCLUSION AND FUTURE WORK

As for the restoration of large&thick damaged regions with composite textures, most restoration algorithms published encounter difficulties to preserve image isophote continuity from the known region into damaged region. We presented the restoration algorithm with morphological erosion and exemplar-based texture synthesis. In brief, the method has the following characteristics:

1) With the exemplar-based texture synthesis, the proposed image restoration method can restore some structure features and composite textures both for large and thick or long and thin damaged regions without blurring.

2) Thanks to the implementation of region-filling based on morphological erosion which can imitate the process of manual restoration with a very high similarity, the proposed method can guarantee the reliability of restoration.

Overall, the presented restoration method also has some limitations for which more research needs to be done. We plan to work for example on methods to restore complex structure information, such as corners, curves with large curvature, etc.

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