Image Processing Methods for the Restoration of Digitized Paintings

Abhilekh Gupta, Vineet Khandelwal, Abhinav Gupta and M. C. Srivastava

Dept. of Electronics & Communications,
Jaypee Institute of Information Technology University Noida (U.P.), India
abhilekhg@gmail.com, [vineet.khandelwal, abhinav.gupta, mc.srivastava]@jiit.ac.in

Abstract

Several methods have been proposed for detection and removal of cracks in digitized paintings [1-5]. Cracks not only deteriorate the quality of painting but also question its authenticity. In this paper, a morphological methodology (MAO) is proposed which is a variant of recently published morphological methods to identify cracks [1]. After detecting cracks, a modified adaptive median filter (MAMF) is used to fill the cracks. The order of the median filter to be applied on crack pixels is computed on the basis of the number of crack pixels in its neighbourhood. This methodology of detection and elimination of cracks in digitized paintings is shown to be very effective in preserving the edges also.

Keywords: Digital image processing, digitized paintings, crack detection, crack filling, modified adaptive median filter, virtual restoration of paintings.

1. Introduction

Image processing techniques have recently been applied to analysis, preservation and restoration of artwork. Ancient paintings are cultural heritage for ones country which can be preserved by computer aided analysis and processing. These paintings get deteriorated mainly by an undesired pattern that causes breaks in the paint, or varnish. Such a pattern can be rectangular, circular, spider-web, unidirectional, tree branches and random [2] and are usually called cracks. Cracks are caused mainly by aging, drying and mechanical factors like vibration, and human handling.

Computer aided tools can be used to implement image processing technique for the elimination and detection of cracks in ancient digital paintings. Though this methodology produces a digitally restored version of the artwork, it can still prove to be a useful guide for historians, and museum curators. A technique that is able to track and fill a crack is proposed in [3] but it requires the user to manually start with the initial point of the crack pattern to fill them. A method for the elimination of the cracks using an infrared reflectogram of the painting is presented in [4]. In this approach a viscous morphological reconstruction technique, based on a-priori information about the thickness of the cracks and its preferred orientation, is assumed for crack elimination. Abas and Martinez [2] have proposed a technique for the detection and classification of cracks using content based analysis. This method uses a morphological top-hat operator to detect the crack and fuzzy k-means clustering technique to classify the various crack patterns. A similar problem of detection and filling of cracks has been treated by Giakoumis and Pitas [5]. Their process first detects the crack using a morphological top-hat operator and then fills them using a trimmed median filter [6], and an anisotropic diffusion filter.

Morphological Area Opening (MAO) is one of many techniques for obtaining the crack map [7]. In section 2 of this paper we propose a new crack detection model which utilizes bottom hat operation followed by thresholding before applying to MAO for obtaining crack map. Next we present in section 3 a technique for successive filling of the cracks using Modified Adaptive Median Filter (MAMF) on digitized paintings. Concluding remarks are discussed in section 4.

2. A New Crack Detection Model

Cracks haring low luminance pixels with elongated structural characteristics are considered as local minima [5]. The proposed crack detection model employing a bottom-hat transform followed by thresholding and MAO is shown in Fig.1.

The detection process first involves bottom-hat transform (BHT) over luminance component of the image to detect dark pixels, given by:

$$BHT = cr_{\text{closing}}(x) - cr(x) \qquad (1)$$

where $cr_{\text{closing}}(x)$ represents closing of luminance component of the image $cr(x)$ using a structuring element.

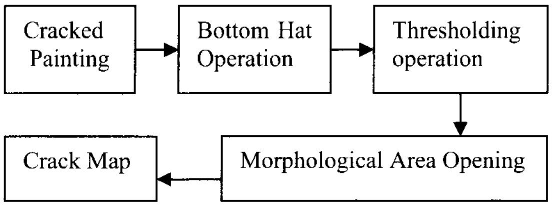


Figure 1. Crack Detection Model

The BHT operator is optimized using the following parameters:

- The type and size of the structuring element: A square type structuring element is used with a size of 3×3.
- Number of operations in (1): 1

These parameters are carefully chosen such that misidentification of cracks does not take place. However, they are of low significance due to the thresholding and MAO procedure, which identifies the crack map.

A thresholding operation is performed on the output of the BHT image to separate crack pixels from the background. A global thresholding technique [8], operating directly on the BHT histogram, is used to produce the binary image. Instead of using a global threshold, the crack image can be locally processed using grid-based automatic thresholding [2].Thereafter, the MAO process produces a crack map consisting of true cracks. Thus, the MAO filter removes from the binary image, the components with area smaller than a predefined parameter a. This filter is defined as:

$$f \circ (a)Bc = \bigvee_{B \in B_{Bc,a}} f \circ B$$

$$B_{Bc,a} = \{X \subset E : X \text{ is } B_{c-connected}, \ Area(x) \geq a\}$$

where f is the binary image from which an area smaller than parameter a is removed, using connectivity given by B_c. This operator is generalized to binary images by applying the operator successively on slices of f taken from higher threshold levels to lower threshold levels, producing a crack map. The parameter a is selectively chosen from the thresholded output image and B_c is taken as 8-connected.Three crack maps processed through our model are shown in Figs. 2 (b), 3(b), 4(b) and 5(b) along with cracked painting Figs.2 (a), 3(a), 4(a) and 5(a) (religious icons from the Byzantine era and other paintings).

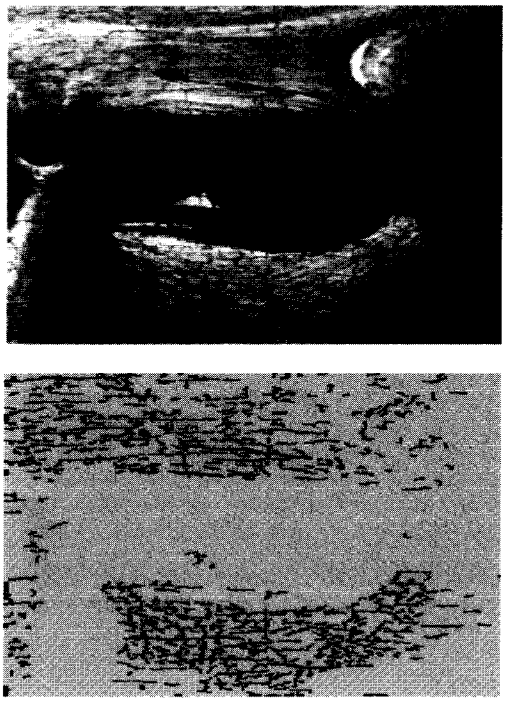


Figure 2 (a). Cracked Painting **(b).**Crack Map

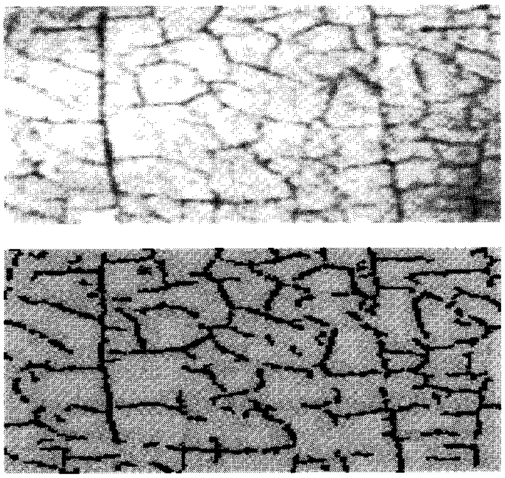


Figure 3 (a). Cracked Painting **(b).** Crack Map

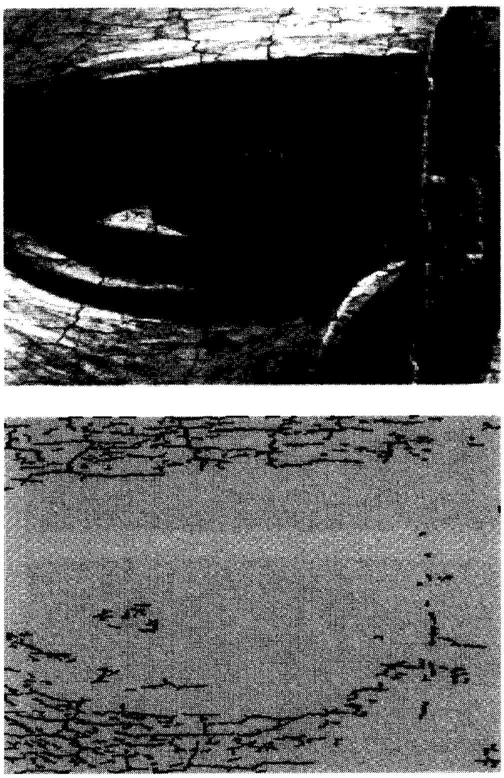


Figure 4(a). Cracked Painting **(b).** Crack Map

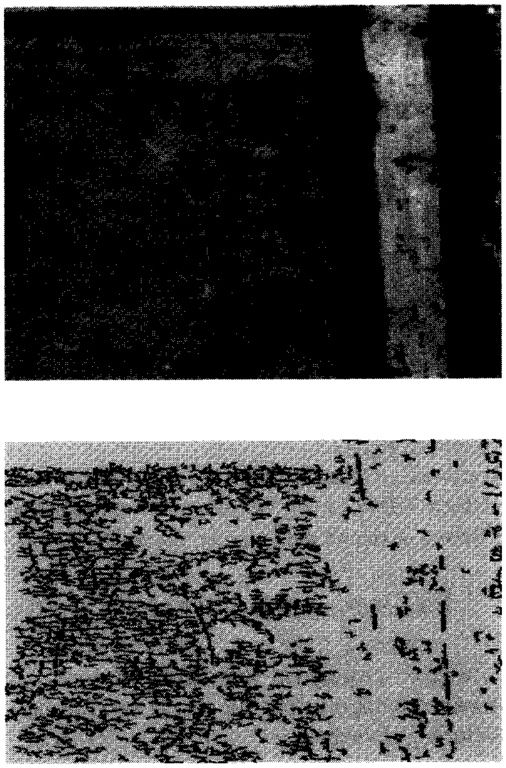


Figure 5(a). Cracked Painting **(b).** Crack Map

3. Modified Adaptive Median Filter (MAMF) for Crack Filling

Once a crack map is obtained our next step is to fill the cracks based on the local information from the region surrounding the crack pixel. We propose a new filter known as a Modified Adaptive Median Filter (MAMF) which works on each RGB channel independently only on the crack pixel locations, so that quality of the content in other pixels is not affected. This nonlinear filter, in addition to crack filling, preserves the edges of the paintings. Since we intend to use ancient paintings whose original version is not known for detection and elimination of cracks, our method of filling can be judged qualitatively just by visual inspection only.

The standard median filter could be used for filling the crack, but the problem with this method lies on its fixed window size and that there could always be a possibility that crack pixel count in the local region may exceed the non crack pixel count. This may however, result in replacing a crack pixel by another crack pixel, thus, failing in our aim. We therefore propose a modified version of an adaptive median filter with varying the window size surrounding the crack pixel. This variation depends on the nature of pixels surrounding the crack pixels in the local region of window. MAMF runs only over the crack pixels so that information in other pixel is kept intact. The size of the filter window surrounding each crack pixel is evaluated based on the number of crack pixels in the local region of the window. If the number of crack pixels in the local region exceeds some threshold value, the size of the window is expanded till it falls below the threshold. In our case, a threshold value is set to be equivalent to 25% of the number of pixels in the window, having examined the effect of the threshold on the window size. When the number crack pixels in the local region falls below this threshold level, the size of the window satisfying the condition is treated as the order *N* of the filter for processing the crack pixel under observation. *N* will be different for all crack pixels in the painting and is evaluated adaptively. 'Processing' here refers to replacement of crack pixel under observation by the median of the local observations, i.e., equal to one, among the neighbouring pixels. The filled crack pixels are defined by:

$$y_i = med(x_{i-j} \ldots\ldots x_i \ldots\ldots x_{i+j}) \qquad (3)$$

where x are the pixels in the local region of the window and j= (N-1)/2 .

For colour paintings the same process is used on three independent channels individually and then combined to obtain crack filled colour paintings.

Based on experimentation on various digitized paintings (both Gray and Colour) it has been found that our method gives results which can be judged qualitatively by observing restored paintings shown in Figs. 6(b), 7(b), 8(b) and 9(b) against the associated cracked paintings (Figs.6(a), 7(a), 8(a) and 9(a)). Further, our method along with filling cracks is able to preserve sharp edges of the paintings as is evident from comparison of restored painting of Figs.10 (b) and 11(b) against its counterpart in Figs. 10(a) and 11(a) respectively. This is verified using Canny's edge detection technique.

Figure 6 (a). Cracked painting **(b).** Restored painting

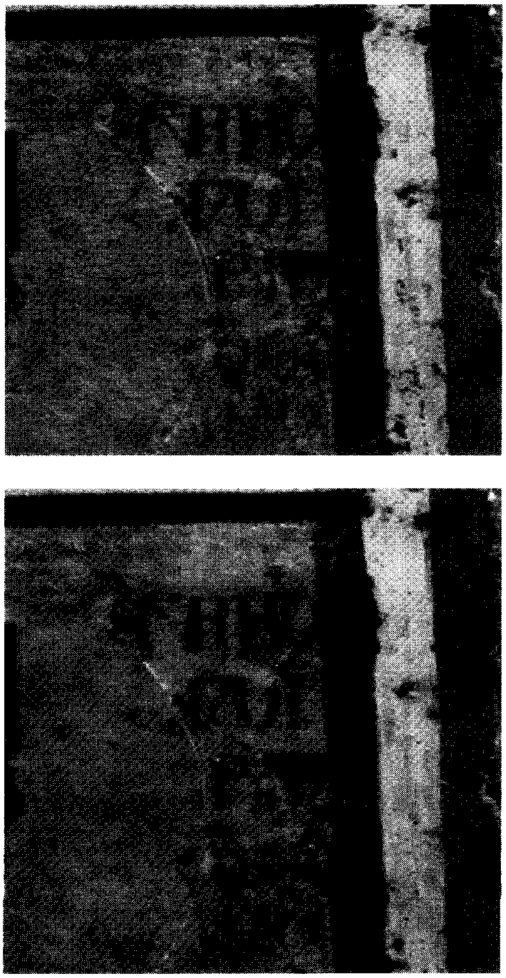
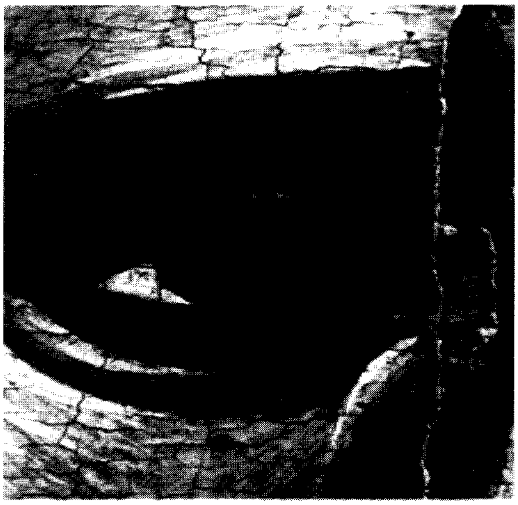


Figure 7 (a). Cracked painting **(b).** Restored painting



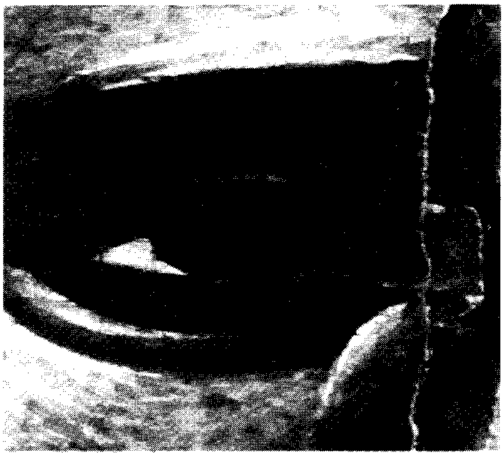


Figure 8 (a). Cracked painting **(b).** Restored painting

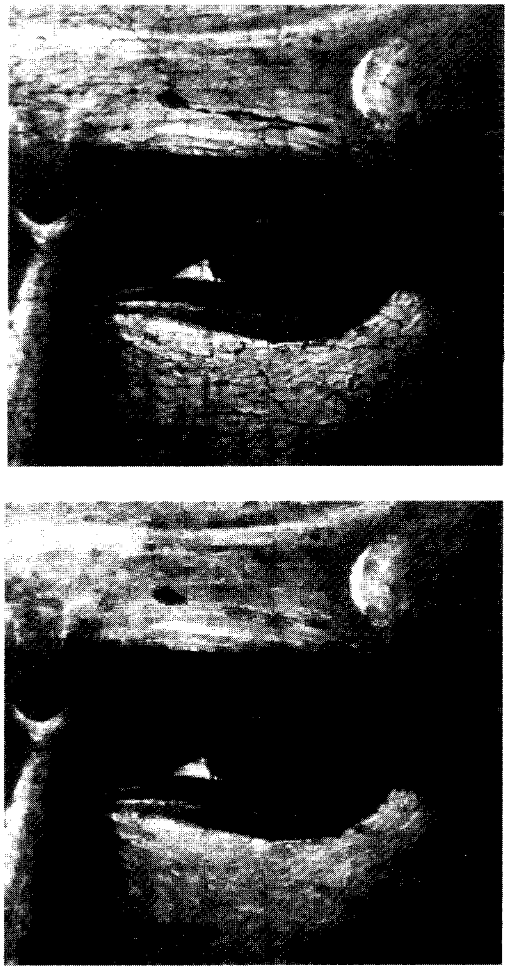


Figure 9 (a). Cracked painting **(b).** Restored painting

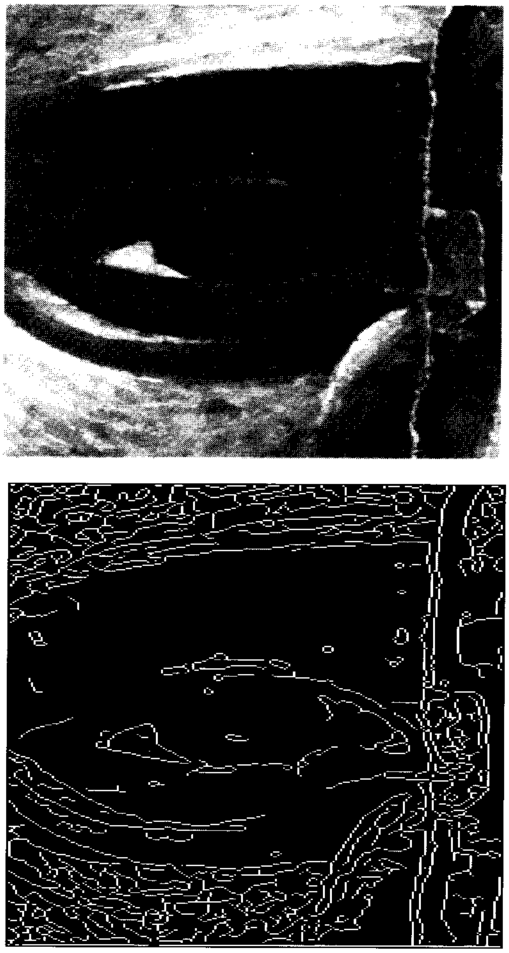


Figure 10 (a). Restored painting **(b).** Restored painting edges

Figure 11 (a). Restored painting **(b).** Restored painting edges

4. Conclusion

This paper presents a new crack detection model employing BHT operation followed by thresholding and MAO. This model produces a crack map consisting of true cracks as illustrated in Figs. 2 to 5. Further, we have employed a new filter MAMF (Modified Adaptive Median Filter) to fill in the thick and thin cracks as shown in Figs. 6 to 9. Figs. 10 and 11 highlight the edges preserved by MAMF employed by us, which has been verified by the Canny edge detection technique.

5. References

[1] I. Giakoumis, N. Nikolaidis, and I. Pitas, Digital Image Processing Techniques for the Detection and Removal of Cracks in Digitized Paintings, IEEE Transactions on Image Processing, Vol.15, No.1, pp.178-188, Jan. 2006.

[2] F.S. Abas, and K. Martinez, Classification of Painting Cracks for Content-based Analysis, in Proc. of IS&T/SPIE's 15th Annual Symposium on Electronic Imaging: Machine Vision Applications in Industrial Inspection, Vol. 11, pp. 149-160, 2003.

[3] M. Barni, F. Bartolini, and V. Cappellini, Image Processing for Virtual Restoration of Artworks, IEEE. Multimedia, Vol.7, No. 2, pp. 34-37, Jun.2000.

[4] A. Hanbury, P. Kammerer, and E. Zolda, Painting Crack Elimination using Viscous Morphological Reconstruction, in Proc. IEEE 12th Int. Conf. Image Analysis and

Processing, Mantua, 17-19, pp. 226-231, Sept. 2003

[5] I. Giakoumis and, I. Pitas, Digital Restoration of Painting cracks, in Proc. IEEE Int. Symp. Circuits and Systems, Monterey, Vol. 4, pp. 269-272, 1998,

[6] I. Pitas, and A. N. Venetsanopoulos, Nonlinear Digital Filters, Principles and Applications, Norwel, MA: Kluwer, 1990.

[7] L. Vincent, Morphological area Opening and Closings for Greyscale Images, in Proc. Springer Verlag Shape in Picture NATO Workshop, Driebergen, Sept. 1992.

[8] N. Otsu, A Threshold Selection Method from Gray-level Histograms, IEEE Transactions on Systems, Man, Cybernetics, Vol. 9, No.1, pp. 62-66, 1979.