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A study of digital image enhancement for cultural relic restoration

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***Abstract*— Digital restoration of cultural relics is very important for the continuation of world civilization for future generations. In this paper, a multitasking mixed enhancement algorithm is proposed to enhance relic images combining several methods of image denoising, sharpening and magnification. In particular, to remove blurs on edges of a magnified image, an adaptive edge-sharpened image interpolation is used, which fits image edges of any direction, slope and width, utilizing the gradient information of edge and a hyperbolic tangent function. Experiments show that the proposed techniques produce results with appealing visual quality, which are good for the retrieval and interpretation of implied value information of cultural heritage.**

***Index Terms*— Cultural heritage, information retrieval, image restoration, noise removal, edge sharpening, contrast enhancement.**

I. INTRODUCTION

The world cultural heritage is witness of world history and civilization, and it has an important impact on people's identity. However, due to wars and other negative impacts, many cultural heritages have been damaged and corroded: monuments, groups of buildings, sites, cultural landscape, human beings verbal, and intangible cultural heritage. The protection and preservation of cultural heritage is our responsibility for the continuation of civilization for future generations. Moreover, the preservation of cultural heritage and historical legacies is a key foundation to keep cultural bonds between people, and to maintain cultural pluralism and creativeness while promoting development together in the world [1,2].

An important strategy of preserving cultural heritage is to use advanced computer technology with information, control, management, and decision-making, to record precious, endangered and historic cultural heritages in a vivid, systematic and comprehensive way, to perform virtual representation, and to build permanent relic files and databases [1-4].

To use information technologies to protect and save cultural heritage is a very important task for digital preservation of cultural heritage, which combines information technologies with digitization procedures, including digital capture and collection, model representation and operation, digital processing and restoration, virtual display, digital management and web based retrieval [1, 4-7].

Cultural heritage can be divided into material cultural heritage and intangible cultural heritage. An image is a record of different material or intangible cultural objects with combined regions of similar texture and gray levels. If the objects are small in size or low in contrast, one may normally examine them at high resolutions; if they are large in size or high in contrast, a coarse view is enough for visual inspection. When both small and large objects or objects with low and high contrasts are recorded simultaneously, one may need a multi-resolution processing of the image to study them at several resolutions [8,9].

In this paper, a multitasking mixed enhancement algorithm is proposed combining several methods to enhance relic images by removing noise, enhancing contrast and resolution, in order to facilitate the display of information of traditional cultural heritage contained in relic images [8]. In particular, image magnification is used by gaining a high-resolution image from its low-resolution version. Standard methods for image interpolation are based on attempts to mathematically fit a function (e.g., piecewise constant, linear, cubic, etc.) to existing pixels. However, based on the simple polynomial function models, these schemes produce necessarily results with blurred edges and annoying artifacts ("jaggies" and "mosaics") [10-16]. An adaptive edge-sharpened image interpolation utilizes the gradient information of edges and a hyperbolic tangent function to reduce edges width in interpolated image, which produces satisfied visual effects [10, 12].

II. PROPOSED METHODS

The acquired relic images are often a degraded observation of unknown latent image, while the degradation comes from various factors, such as noise corruption, camera shake, object motion, resolution limit, hazing, rain streaks, or a combination of them [8]. As a fundamental ill-posed inverse problem in image processing and low-level vision, image enhancement and restoration aims to reconstruct the latent high-quality image from its degraded observation.

Many methods have been proposed to enhance images, such as Gaussian smoothing, mean and median filters, histogram equalization and its adaptive improvements, power filter, unsharp mask filter and recent nonlocal means filter [8,9,17,18]. To enhance image resolution, function- based, model-based and learning-based are proposed [19].

In the following, we focus on a hyperbolic tangent function based image interpolation (HTBI) method [10] for highlighting displayed cultural information in relic images.

Considering the importance of edges in images, the method [10] divides the algorithm into two steps: edge detection and gray level interpolation. Let I ($m \times n$) be an original image, one wants to magnify it into J ($M \times N$, $M=2m-1$, $N=2n-1$) (see Fig. 1), where four circle pixels from the original image I remain the same, other five cross pixels need to be interpolated. One can calculate gray levels of pixels (i-1, j), (i+1, j), (i, j-1) and (i, j+1), by interpolating I between every two pixels of its rows or columns, and then deal with pixel (i,

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j), reseparately.

Edge detection. Fixing a threshold t, for everyone of pixels (i-1, j), (i+1, j), (i, j-1) and (i, j+1), one calculates its gradient magnitude by its nearby six pixels (see equation (2)) in the interpolated image J; while for the pixel (i, j), one does by its nearby four pixels. If its gradient magnitude is smaller than t, this pixel is considered as in a flat area, and a standard interpolation (e.g., bilinear) is used; otherwise, it is considered as located in an edge area, and a weighted interpolation based on gradient information is designed. Below the corresponding gradient magnitude is calculated by the central difference scheme.

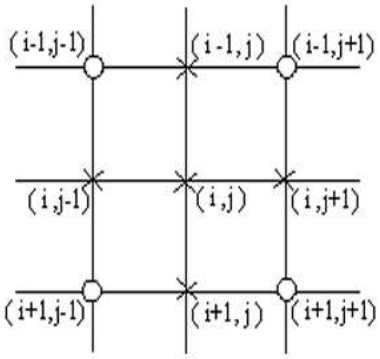

Fig. 1 The layout of image interpolation. ○ original pixels, × pixels to be interpolated.

For circle pixel (i, j), one does in I:

$$|\nabla I(i,j)| = ((I(i,j+1)-I(i,j-1))^2 + (I(i+1,j)-I(i-1,j))^2)^{\frac{1}{2}}; \quad (1)$$

for cross pixel (i, j), one does in J, taking pixel (i-1, j) for example:

$$|\nabla I(i-1,j)| = ((I(i-1,j+1)-I(i-1,j-1))^2 + (I(i+1,j-1)+I(i+1,j+1) - I(i-3,j-1)-I(i-3,j+1))^2/16)^{\frac{1}{2}} \quad (2)$$

Gray level interpolation. The interpolation should avoid image blur and preserve edge sharpness. Take I (i-1, j) for example, and the others are similar. Let $\nabla I(i-1,j-1)$, $\nabla I(i-1,j+1)$ be gradients of pixels (i-1, j-1) and (i-1, j+1), whose ratio is $r = |\nabla I(i-1,j-1)| / |\nabla I(i-1,j+1)|$, then one has

$$I(i-1,j) = (1-f(r))\, I(i-1,j-1) + f(r)\, I(i-1,j+1), \quad (3)$$

where $f(r) = (\tanh(s(r-1))+1)/2$ is the weighted coefficient, and $\tanh(x) = (e^x - e^{-x})/(e^x + e^{-x})$ is a hyperbolic tangent function, whose center is (1, 0.5) varying between 0 and 1, with parameter s to control its slope.

As interpreted by the paper [10], this algorithm makes the edge sharpened by the HTBI interpolation through reducing the width of edge. Because of the continuity of used hyperbolic tangent function, above scheme adapts to different edges with arbitrary direction, slope and width.

In a word, for degraded relic image, the proposed multitasking mixed enhancement algorithm first uses the nonlocal means filter to remove image noise; then, the adjustment of gray levels or unsharp mask filter is employed to enhance image; finally, the HTBI interpolation is used to enhance image resolution.

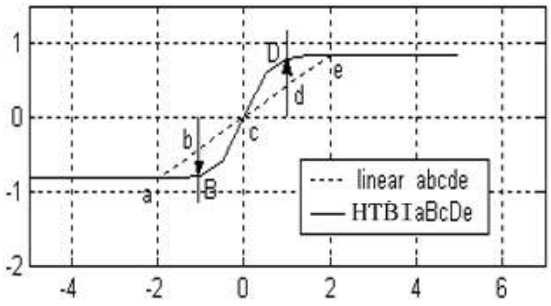

Fig. 2 The hyperbolic tangent based interpolation (HTBI) on an edge. (a,c,e): original pixels; (b,d,B,D): pixels to be interpolated. – – –bilinear interpolation, ——HTBI.

III. Results and Analysis

A number of cultural relic images have been enhanced and restored to test the proposed multitasking mixed enhancement algorithm. Examples shown in Fig. 3-5 are old building, painting and inscription images. All methods are implemented using the MATLAB programming with gray scale range from 0 to 1. It is generally agreed that peak signal-to-noise ratio (PSNR) does not always provide an accurate measure of the visual quality for natural images [8, 17]. Therefore, we shall only rely on subjective evaluation to assess the visual quality of the enhanced images in this paper.

In Fig. 3, an old murky gray and noisy building image is enhanced to restore implied information of traditional cultural heritage. First, the nonlocal means filter (7×7 search window, 5×5 similarity window and 0.03 smoothing factor) [18] is used to remove noise in the image to avoid enhancing image noise, which can effectively preserve image details while filtering the image. Then, the adjustment of gray levels of the image with a power factor of 0.6 is done to lighten the image for a clear observation. Finally, the unsharp mask filter with a control factor of 0.1 is used to enhance the image. As one can observe that, the proposed mixed denoising and enhancement technique produces a pleasing image easy for retrieving and evaluating of important information of cultural heritage.

In Fig. 4-5, an old clay model image and an old inscription image are enhanced to clearly show wonderful techniques of traditional sculpture and inscription. After enhancing the images by the nonlocal means filter and the unsharp mask filter, the HTBI method is used to further highlight important text information, where the text images are magnified by a factor 4 with parameters: s = 1.5, t = 0.02. Corresponding zoomed parts of results are shown in Fig. 4-5. Compared with conventional interpolation method, it can be seen that the best visual quality is obtained by interpolating images using the HTBI method, which produces sharper edges than other schemes.

IV. Conclusion

To enhance cultural relic images a multitasking mixed enhancement algorithm is proposed including image denoising, resolution enhancement and edge sharpening. Removing image blur and enhancing visual perception by the method facilitate retrieving and evaluating of important information of cultural heritage. The experiments have

verified the effectiveness of the proposed algorithm.

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Fig. 3 Digital enhancement of an old building (from top-left to bottom-right). Original image, results through three steps in sequence: nonlocal means filter, adjustment of gray levels and unsharp mask filter, respectively

Fig. 4 Digital enhancement of an old building (from top-left to bottom-right). Original image, results through three steps in sequence: nonlocal means filter, unsharp mask filter and text interpolations (top, bilinear; below, HTBI), respectively.

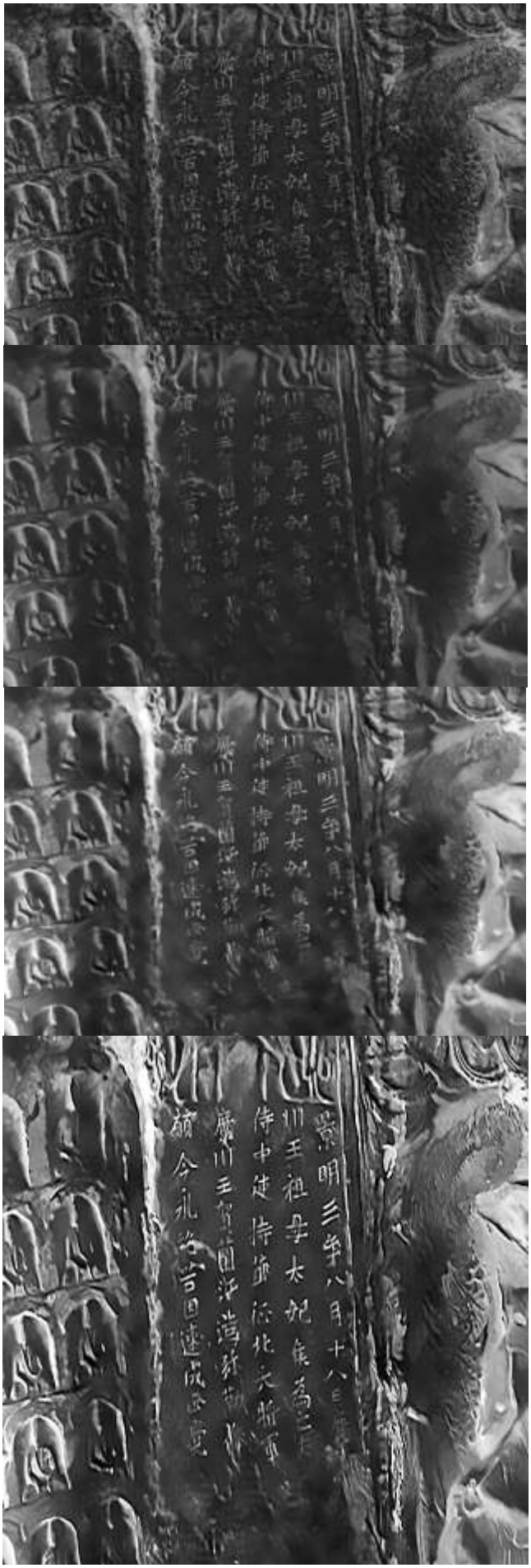

Fig. 5 Digital enhancement of an old building (from top to bottom). Original image, results through three steps in sequence: nonlocal means filter, unsharp mask filter and HTBI interpolation, respectively.