A Method for High Resolution Color Image Zooming using Curvature Interpolation

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Abstract—We introduce a new zooming algorithm curvature interpolation method(CIM) based on partial differential equation, which produce high resolution(HR) color image by solving a linearized curvature equation. Partial Differential Equations (PDEs) have become an important tool for interpolation methods in image processing and analysis. CIM first evaluates the curvature of the low-resolution image, after interpolating the curvature to the high-resolution image domain, to minimize the artifacts such as image blur and the checkerboard effect. The results demonstrate that our new CIM algorithm significantly enhances the quality of the interpolated images with sharp edges over linear interpolation methods.

Index Terms—Curvature interpolation method (CIM), higher resolution (HR). Image zooming, interpolation, partial differential equation (PDE).

I.INTRODUCTION

Images with high resolution and fine and shape edges are always venerable and required in many visual tasks. The major benefit of interpolation techniques is that it may cost less and the existing equipment's can be utilized. Resampling of images is necessary for discrete image geometrical transformation. Interpolation method should be applied for resampling technique, which evaluate by two basic steps. The first one is transformation of discrete function into continuous function and second step is sampling evaluation. Image interpolation in image zooming required some basic mission such as generation, compression, and zooming [2] ,[6],[7],[13].

Interpolation techniques are classified into three methods: linear, non-linear, and variation. Linear interpolation methods are may bring up image blur or check board effect. So various non-linear methods are introduced to overcome the artifacts of linear methods. Nonlinear methods is fit the edges of images with some templates, and integrate that edges with partial differential equation (PDE). Many interpolation methods for high visual quality have been developed in image zooming process [1-3], and problems still exist. These problems are highly related to image edges, including the blurring of edges, blocking artifacts in diagonal directions and inability to generate fine details [3].

For the importance of edge-preserving in application fields, a large number of edge-directed interpolation methods have been presented [3-12]. In a new edge-directed interpolation which takes geometric duality to estimate the covariance of targeted high resolution (HR) area from that of local window pixels in low resolution (LR). a HR image with well clear edges is obtained by fourth-order linear interpolation [20]. A zooming algorithm takes as .input an RGB picture and provides as output a picture of greater size maintaining the information of the original image as much as conceivable. Unfortunately, the methods mentioned in the passage above, can preserve the low frequency content of the source image well, but are not equally well to enhance high frequencies in order to produce an image whose visual sharpness matches the quality of the original one.

The CIM based on PDE method can produce zoomed image, which have the same curvature profile as in the original image in lower resolution then can be formed in high resolution. Edge forming schemes for the image zooming of color images by general magnification factors. The basic outline of our paper is as follows. Section II shows us linear interpolation methods and edge-forming method. In section III CIM method for color image zooming is discuss with its three steps. In section IV the numerical examples and peak signal to noise ratio(PSNR) analysis are given. Section V concludes our paper and its effectiveness.

II.PRELIMINARIES

A ephemeral review of linear interpolation and edge forming method is present below.

(A)Linear Interpolation Method

Interpolation method is to construct a continuous function u(x,y) from discrete function u(k,l), where x,y are real numbers and k,l are integers. Then the continuous function expressed as

$$u(x,y) = \sum_{k} \sum_{\ell} u(k,\ell) H_{2D}(x-k, y-\ell).$$

To reduce the computational complexity, the interpolation kernel should be separable is shown as below

$$H_{2D}(x,y) = H(x) \cdot H(y)$$

$$H(0) = 1, \qquad H(x) = 0, |x| = 1, 2, \ldots$$
$$\sum_{k=-\infty}^{\infty} H(d+k) = 1, \qquad \text{for all } 0 \le d < 1. \tag{1}$$

The above equations guarantees for resampling of images on the same grid, and these equations are called Interpolators and approximates respectively. It maintains energy that means interpolation does not change the brightness of original image. Here the fewer kernels are discussed such as the linear, cubic, cubic B-spline kernels for the image zooming

$$H_{\text{linear}}(x) = \begin{cases} 1 - |x|, & 0 \le |x| < 1, \\ 0, & \text{elsewhere} \end{cases}$$
$$H_{\text{cubic}}(x) = \begin{cases} (a+2)|x|^3 - (a+3)|x|^2 + 1, & 0 \le |x| < 1 \\ a(|x|^3 - 5|x|^2 + 8|x| - 4), & 1 \le |x| < 2, \\ 0, & \text{elsewhere} \end{cases}$$
$$H_{\text{B-spline}}(x) = H_3(x) * \sum_{m=-\infty}^{\infty} \sqrt{3}(\sqrt{3}-2)^m \, \delta(x+m)$$

where a is a parameter, $*$ denotes the convolution, and

$$H_3(x) = \begin{cases} \frac{2}{3} - \frac{1}{2}|x|^2(2-|x|), & 0 \le |x| < 1 \\ \frac{1}{6}(2-|x|)^3, & 1 \le |x| < 2 \\ 0, & \text{elsewhere.} \end{cases}$$

The cubic kernels satisfying the basic conditions of interpolation. The interpolator and approximates set the values of pixels consequently in correct order.

(B)PDE- based Edge-Forming Method

HR image can be zoomed by linear interpolation method is inscribed by

$$\widehat{v}^0 = u + r$$

Where u denotes desired image and r denotes artifact. At the time of interpolation and sampling evaluation, arising artifacts indicates by this equation. The PDE based denoising model form

$$\frac{du}{dt} + \mathcal{L}(u) = \beta(\widehat{v}^0 - u) \tag{2}$$

The required zoomed image with sharp edges can be obtained by satisfying the above conditions which denoted as edge forming anisotropic diffusion methods. Much iteration are required to form the clear and sharp edges with the large magnification factor α. Edges carry heavy structural information which leads to detection, classification and determination. Edges carry heavy structural information which leads to detection, classification and determination. Edge detection method is to preserve the structure properties with reduced amount of data. Three aspects of basic edge forming is given. First, it maximizes the probability to mark real points and decreases the number of non-edge points. Second, detected edge points are close to the center of edge, and better than that detected from other edge detectors. Finally, the detected edges are of one pixel width. It has become one of the standard edge detectors for its effectiveness, accuracy and robustness.

III.CURVATURE-INCORPORATING METHOD

A new interpolating method, CIM with basic two steps is present below. The original LR image domain magnified HR image domain, ideal zooming and numerical interpolation is analyzed by below basic steps.

(A) Curvature in Color Image Zooming

Image zoomed by magnification factor α. The zoomed HR image has the clear curvature is written as

$$u(\mathbf{x}) = \widetilde{u}(\widetilde{\mathbf{x}}), \quad \widetilde{\mathbf{x}} = \alpha \mathbf{x}$$

Where α is magnification factor of LR image and X=(x,y) are the coordinates of the LR and HR image. The gradient operator in the LR and HR coordinate are related as by Δ value. The curvature of the HR image is smaller than LR image is expressed by below equation

$$\nabla_{\mathbf{x}} \cdot \left(\frac{\nabla_{\mathbf{x}} u}{|\nabla_{\mathbf{x}} u|}\right) = \alpha \nabla_{\widetilde{\mathbf{x}}} \cdot \left(\frac{\nabla_{\widetilde{\mathbf{x}}} \widetilde{u}}{|\nabla_{\widetilde{\mathbf{x}}} \widetilde{u}|}\right). \tag{3}$$

An effective method for color image zooming that utilizes the above method. The very smooth curvature is obtained by PDE based models, when the original image zoomed by α factor [5].This is called stair casing. This paper mainly concentrated on gradient of image, so we go for gradient-weighted (GW) curvature method to support our paper, is shown by

$$\mathcal{K}(u) = -|\nabla u| \, \nabla \cdot \left(\frac{\nabla u}{\nabla u}\right) \tag{4}$$

The degree of curving of the image surface the above equation employees an important part. An algebraic system is basically easy to implement, shown in the below section. And the numerical experimental result gives us the clear idea to implement this interpolation efficiently. Scaling factor between the gradient weighted method, because of the gradient magnitude the image in;

$$\mathcal{K} = \mathcal{K}(v^0) \quad \text{on } \Omega.$$

$$\nabla_{\mathbf{x}} u |\nabla_{\mathbf{x}} \cdot \left(\frac{\nabla_{\mathbf{x}} u}{|\nabla_{\mathbf{x}} u}\right) = \alpha^2 \, \nabla_{\tilde{\mathbf{x}}} \tilde{u} |\nabla_{\tilde{\mathbf{x}}} \cdot \left(\frac{\nabla_{\tilde{\mathbf{x}}} \tilde{u}}{\nabla_{\tilde{\mathbf{x}}} \tilde{u}}\right).$$

The basic outline of our zooming method is as follows

$$\mathcal{K}(u) = \frac{1}{\alpha^2}\widehat{\mathcal{K}}, \qquad u|_{\widetilde{\Omega}^0} = v^0. \tag{6}$$

GW curvature measured from the LR image, which interpolated the driving force for the same GW curvature model. This driving force useful to construct clear HR image. Curvature interpolation method produces HR images with fewer artifacts. Our new interpolation method is different from existing work. To reduce the artifact, arising by the zooming. Method can be avoid by zero padding method in high frequency based interpolation technique. One best example for the interpolation method with high magnification factor is Lena image, is less oscillatory by itself.

(B) Image Interpolation by CIM

CIM evaluate by using three steps is shown below-1: Curvature evaluation on the given image, 2: HR image domain interpolation, 3: zoomed image construction by using constrained curvature.

Step 1: Evaluation of K: for the LR image is

$$\mathcal{K}(v^0) = -|\nabla v^0|_1 \left(\frac{v_x^0}{|\nabla v^0|}\right)_x - \nabla v^0|_2 \left(\frac{v_y^0}{|\nabla v^0|}\right)_y \tag{7}$$

The above basic equations are specifically designed for resulting algebraic system to have same positive edges in all diagonals, for computing the second-order approximations. PDE based method mainly designed for obtain the noiseless figure (without any artifacts such as blur and check board effect) in zooming algorithm. The second order finite approximation of each pixel in an original image is follows

$$\begin{aligned} d_{ij,W} &= \left[(v_{i,j}^0 - v_{i-1,j}^0)^2 + (v_{i-1,j+1}^0 + v_{i,j+1}^0 - v_{i-1,j-1}^0 - v_{i,j-1}^0)^2/16 + \varepsilon^2\right]^{1/2} \\ d_{ij,E} &= d_{i+1,j,W} \\ d_{ij,S} &= \left[(v_{i,j}^0 - v_{i,j-1}^0)^2 + (v_{i+1,j}^0 + v_{i+1,j-1}^0 - v_{i-1,j}^0 - v_{i-1,j-1}^0)^2/16 + \varepsilon^2\right]^{1/2} \\ d_{ij,N} &= d_{i,j+1,S} \end{aligned} \tag{8}$$

(8)

Where the original image consists I x J pixels and ε > 0 (ε is regularization parameter), which introducing for product the differences tends to zero. The directional curvature terms in the original image on the every pixel point is stated as below

$$\begin{aligned} \left(\frac{v_x^0}{\nabla v^0}\right)_x (\mathbf{x}_{ij}) &\approx \frac{1}{d_{ij,W}} v_{i-1,j}^0 - \left(\frac{1}{d_{ij,W}} + \frac{1}{d_{ij,E}}\right) v_{ij}^0 + \frac{1}{d_{ij,E}} v_{i+1,j}^0, \\ \left(\frac{v_y^0}{\nabla v^0|}\right)_y (\mathbf{x}_{ij}) &\approx \frac{1}{d_{ij,S}} v_{i,j-1}^0 - \left(\frac{1}{d_{ij,S}} + \frac{1}{d_{ij,N}}\right) v_{ij}^0 + \frac{1}{d_{ij,N}} v_{i,j+1}^0. \end{aligned} \tag{9}$$

Then, the gradient magnitude as rewritten as

$$\begin{aligned} \nabla v^0{}_1(\mathbf{x}_{ij}) &\approx \left[\frac{1}{2}\left(\frac{1}{d_{ij,W}} + \frac{1}{d_{ij,E}}\right)\right]^{-1} \\ \nabla v^0{}_2(\mathbf{x}_{ij}) &\approx \left[\frac{1}{2}\left(\frac{1}{d_{ij,S}} + \frac{1}{d_{ij,N}}\right)\right]^{-1} \end{aligned} \tag{10}$$

Harmonic average of finite approximations in xand y coordinates. Then it's from the above equations is

$$\mathcal{K}(v^0)(\mathbf{x}_{ij}) \approx 4v_{ij}^0 - a_{ij,W} v_{i-1,j}^0 - a_{ij,E} v_{i+1,j}^0 - a_{ij,S} v_{i,j-1}^0 - a_{ij,N} v_{i,j+1}^0$$

Where

$$a_{ij,W} = \frac{2d_{ij,E}}{d_{ij,W} + d_{ij,E}} \quad a_{ij,E} = \frac{2d_{ij,W}}{d_{ij,W} + d_{ij,E}}, \quad a_{ij,S} = \frac{2d_{ij,N}}{d_{ij,S} + d_{ij,N}} \quad a_{ij,N} = \frac{2d_{ij,S}}{d_{ij,S} + d_{ij,N}}.$$

The algebraic expression of GW curvature is conveyed by

$$K = A\mathbf{v}^0 \tag{11}$$

The original given image and finite approximations of GW curvature is written by v and k respectively. Edge is defined restrictedly to edge points in an edge map of the zooming process . To measure the edge-preservation abilities of this new interpolation color zooming methods has not been mentioned.

Step 1: Calculation of GW curvature of given original image

Step 2: Interpolate k value

Step 3: Solving u for following constrained

(b) is obtained by first scaling in order for the maximum of scaling to become 127 and then adding 128

Here, we evaluate it from edge-preserving ratio from illumination and robustness by equating the interpolated images with consistent standard images. Shrewd detector is selected as the tool to excerpt edge from given original images, and the threshold of individual edge points is automated established. This algorithm combined to denoise the LR image, and should not over polished to preserve accurate curvature of HR zoomed image.

Step 2: Interpolation of k:

In this second step the linear interpolation method is simplified by basic algorithm. The obtain curvature is far fewer oscillatory with clear edges(less artifacts).Then we can apply the one of linear (bilinear) method for image interpolation method.

Step 3: Zoomed image construction:

To get the effective and efficient zoomed result in curvature interpolation method, we should solve the equations algebraically. Let consider the true HR image. The general algebraic form as follows

$$\tilde{A}\tilde{u} = \tilde{K}, \quad \tilde{u}_{\tilde{\Omega}^0} = v^0 \qquad (12)$$

Then the true HR image can be get by solving the following equation. The HR image is approximated by solve the algebraic system.

$$\hat{A}\mathbf{u} = \frac{1}{\alpha^2}\hat{K}, \quad \mathbf{u}_{\tilde{\Omega}^0} = \mathbf{v}^0. \qquad (13)$$

Let the original value of u can be get from the k approximated that is adopt a perturbation theory.

$$\tilde{K} = \frac{1}{\alpha^2}\hat{K} + \delta K, \quad \tilde{A} = \hat{A} + \delta A. \qquad (14)$$

Then, from the above equation, this form of k value is obtained by, Re-sampling steps and turns a discrete input image into a continuous zoomed function, which is necessary for geometric transform of discrete input images. Firstly, we should select the GW curvature and secondly bilinear method is applied. The curvature-related term and linear interpolation method deal the zooming process in the right way. Finally the iterative algorithm is to be solved, by introducing the Lagrange multiplier, is rewrite as;

$$\hat{A}(\mathbf{u} - \tilde{\mathbf{u}}) = \delta A\tilde{\mathbf{u}} - \delta K \qquad (15)$$

The right hand side value is approximated to obtain the u value, and then bilinear method is applied for getting A and K value.

$$\hat{A}\mathbf{u} = \frac{1}{\alpha^2}\hat{K} + \beta(\mathbf{v}^0 - \mathbf{u}) \qquad (16)$$

Which is equal to?

$$(\hat{A} + \beta I)\mathbf{u} = \frac{1}{\alpha^2}\hat{K} + \beta\mathbf{v}^0 \qquad (17)$$

Where I is identity matrix and β is LaGrange multiplier. The diagonal of the original image is first noted clearly, and then analysis of each pixel is determined. Then the Jacobi iteration can be formulated is stated below

$$\mathbf{u}^n = \frac{1}{4+\beta}\left(\frac{1}{\alpha^2}\hat{K} + \beta\mathbf{v}^0 - N\mathbf{u}^{n-1}\right). \qquad (18)$$

This Jacobi method can congregate fast is to set a reasonable accuracy. To get the initial value, we should choose the bilinear interpolation of original LR image.

IV. NUMERICAL EXPERIMENTS

This numerical results has proved us, the CIM is more effective and easy to implement for all images (synthetic and natural images).This section presents the brief results of zooming process, in various stencil. For example in figure.2 the various natural images are discussed with zoomed images in different stencil. Magnification factor is determined for the enlargement of the image. According to the magnification factor, zoomed image clarity is obtain, which is clearly described in figure.2.

Magnification Factor (α) = 3, 5.

$$\mathrm{PSNR} = 10 \cdot \log_{10}\left(\frac{255^2}{\sum_{i,j}(v_{ij}^0 - u_{ij})^2/(IJ)}\right) \quad \text{(dB)},$$

Where the original image contains of I x J pixel points. From the PSNR analysis table the CIM produce the superior to the bilinear and bicubic methods. However the CIM results proved as the higher PSNR values than the other linear methods from all natural images.

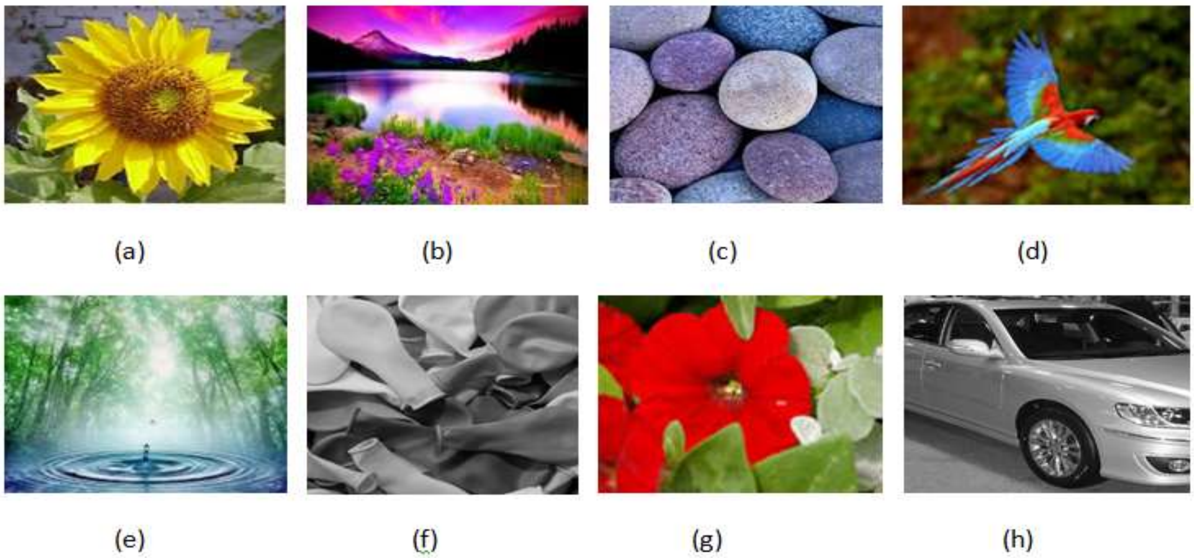

Fig. 2. Sample images. (a) Sunflower. (b) Nature. (c) Stones. (d) Bird. (e) Water drop. (f) Balloons. (g) Red Flower. (h) Car. All are color and grayscale images.

Table 1
PSNR ANALYSI

	α= 3			α= 5		
	Bilinear	Bicubic	**CIM**	Bilinear	Bicubic	**CIM**
Sunflower	8.543	8.023	8.721	6.993	6.761	7.008
Nature	4.998	4.890	5.920	5.006	5.002	5.040
Stones	10.23	10.36	10.51	9.871	9.934	9.997
Bird	13.57	13.39	13.61	12.45	12.137	12.69
Water drop	11.99	11.68	12.80	11.36	11.21	11.49
Balloons	9.783	9.854	10.29	8.765	8.902	9.057
Red Flower	5.745	5.658	6.817	6.012	6.010	6.048
Car	8.457	8.126	8.700	7.450	7.239	7.897

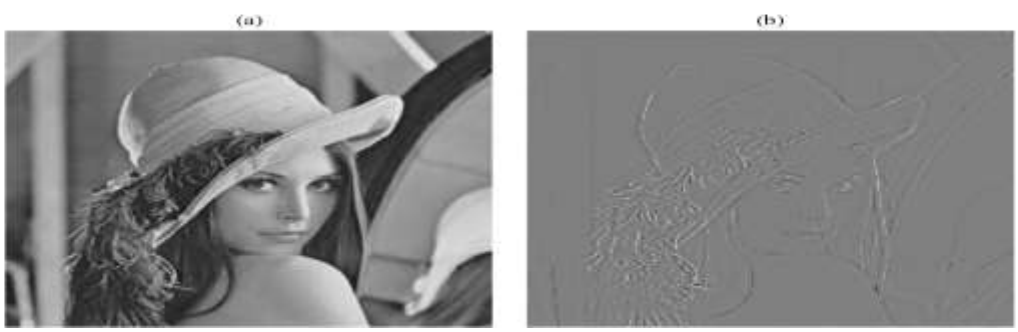

Fig. 1. Lena. (a) Original images (b) Its gradient-weighted curvature.

Based on the zoomed output image, peak signal to noise ratio (PSNR) analysis can be compared for various methods, in different magnification factor. In Table. I the PSNR analysis

results are compared for dissimilar natural images. Figure.2 are firstly reduced by bilinear method. The difference between the original and magnified image is derived by

Figure 3 shows us the zoomed images for a synthetic disk interpolated by the bilinear methods, the bicubic method, and the CIM. Linear methods output zoomed image may produce the blur and check board effect (black spot), thus the CIM

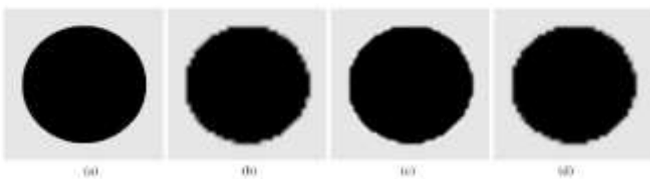

Fig.3: Disk: (a) The original Disk image and downsized-magnified images by a factor by α=6 (b) the bilinear method, (c) CIM, and (d) the bicubic method

Fig.4: Lena shoulder: (a) The original color image in 60x 70 pixels and zoomed images by a factor of by α=6 (b) the bilinear method, (c) the bicubic method, and (d)CIM

images with consistent standard images. Shrewd detector is selected as the tool to excerpt edge from given original images, and the threshold of individual edge points is automated established. This algorithm combined to denoise the LR image, and should not over polished to preserve accurate curvature of HR zoomed image. The required zoomed image with sharp edges can be obtained by satisfying the basic interpolation conditions which denoted as edge forming anisotropic diffusion methods. Much iteration are required to form the clear and sharp edges with the large magnification factor α. Figure.4 presents the zooming output results for Lena color image with α=5. This is also interpolated by same three (bilinear, bicubic, and CIM) methods, which produce clear sharp edges. CIM algorithm employees the basic RGB concept to implement the zooming algorithm. Some time the rising artifacts can be avoid by adapded CIM concept, which shows us the CIM is much extra superior quality to the EFAD algorithm.

Thus the further enquiry of convergence possessions of CIM, a texture image can be sampled. From this we can conclude that CIM produce better result than the bilinear and Bicubic method, for magnification factors α, 2α. Higher reliability and effective interpolation is the CIM for HR image. CIM is constantly resulted in clear image superior to construct reliable zoomed images.

V. CONCLUSION

An easy implementation method for color image zooming is introduced to produce HR image, called as curvature interpolation method. Linear interpolation methods perform the interpolation independently of the image content; therefore they may interpolate images on crossing edges, which can introduce serious interpolation artifacts. In order to eliminate or significantly reduce the artifacts on edges, this new algorithm has introduced. This method consists of three steps: curvature evaluation in LR domain, interpolation of curvature, zoomed image construction by solving algebraic curvature equation. The procedures have been discussed in detail and compared with each other. It can be applicable for both color and gray scale. CIM produced the sharp edges zoomed images than the other methods. The CIM has proved as the superior method, to be an effective and efficient approach for color image zooming.

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