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Saliency-directed image interpolation using particle swarm optimization

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A R T I C L E I N F O

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A B S T R A C T

In this study, a saliency-directed image interpolation approach using visual attention model and particle swarm optimization (PSO) is proposed. First, a block-based saliency map of an image to be interpolated is generated by the proposed visual attention model in an effective manner. Then, based on the block-based saliency map, bilinear interpolation and PSO interpolation are employed for the pixels in non-saliency blocks and saliency blocks, respectively, to obtain the final interpolation results. Various interpolation filtering mask weights are determined by off-line PSO, which are applicable for horizontal, vertical, and diagonal image interpolation types of saliency pixels in saliency blocks with arbitrary magnification factors (*MF*s). Based on the experimental results obtained in this study, the interpolation results of the proposed approach are better than those of four comparison methods.

1. Introduction

Image interpolation plays an important role in many applications, such as digital zooming and high definition TV. In general, there are two kinds of image interpolation methods, namely, non-edge-directed and edge-directed methods. Non-edge-directed image interpolation methods, such as bilinear and bicubic interpolations, have low computational complexity, whereas they usually produce image artifacts and edge blurring in edge regions. Some non-edge-directed image interpolation methods can be found in [1–3]. To cope with image artifacts and edge blurring in edge regions, many edge-directed interpolation methods are proposed. Li and Orchard [4] proposed an edge-directed interpolation algorithm to estimate local covariance coefficients from a low-resolution image and used local covariance coefficients to adapt each higher resolution image based on the geometric duality between the low-resolution covariance and the high-resolution covariance. Jensen and Anastassiou [5] presented a non-linear interpolation scheme for still image resolution enhancement. The scheme is based on a source model emphasizing the visual integrity of detected edges and incorporates a novel edge fitting operator. Carrato and Tenze [6] provided an edge-sensitive data interpolation method, which can provide high quality 2 $\times$ interpolation results on both synthetic and real world images.

Magnification factors (*MF*s) of edge-directed interpolation methods [4–6] are conventionally limited to the power of 2. Recently, edge-directed interpolation algorithms with arbitrary *MF*s [7–9] are proposed. Hwang and Lee [7] proposed adaptive interpolation methods by applying an inverse gradient to bilinear and bicubic interpolations. Cha and Kim [8] proposed an edge-forming method to form clear and sharp edges by applying partial differential equations of anisotropic diffusion. Cha and Kim [9] also proposed an error-amended sharp edge (EASE) scheme to amend the interpolation error by using the classical interpolation error theorem in an edge-adaptive fashion. Although edge-directed interpolation

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methods have better interpolation results, they usually need higher computational complexity to detect the edges in images and perform different interpolations for different types of edges. In this study, visual attention region detection (saliency-directed), different to edge detection (edge-directed), extracts few attended regions (not just the edges) with precise object positions and rough object shapes from an image. In comparison with edge-directed interpolation, saliency-directed interpolation is more noise-free and efficient.

In this study, a saliency-directed image interpolation approach using visual attention model and particle swarm optimization (PSO) is proposed. First, a block-based saliency map of an image to be interpolated is generated by the proposed visual attention model in an effective manner. Then, based on the saliency map, bilinear interpolation and PSO interpolation are employed for the pixels in non-saliency blocks and saliency blocks, respectively, to obtain the final interpolation results. Once the weights in filtering interpolation masks are determined by off-line PSO, they are applicable for horizontal, vertical, and diagonal image interpolation types of saliency pixels in saliency blocks with arbitrary *MF*s.

This paper is organized as follows. In Section 2, some related works for image interpolation, visual attention model, and PSO are briefly described. In Section 3, the proposed image interpolation approach is addressed. Experimental results are described in Section 4, followed by concluding remarks.

2. Related works, visual attention model, and PSO

2.1. Some interpolation methods

Let E, G, and g be the original low-resolution image, the interpolation function, and the interpolated image, respectively. Then

$$g(x,y) = G(x/m, y/m), \tag{1}$$

where m is the magnification factor (*MF*) and (x,y) is the image coordinate of g. As shown in Fig. 1, suppose that the boundary padding image O is obtained from E with two boundary padding pixels and A is an image pattern containing 5×5 original (known) neighboring pixels centered at the known pixel (i,j) in O, i.e.

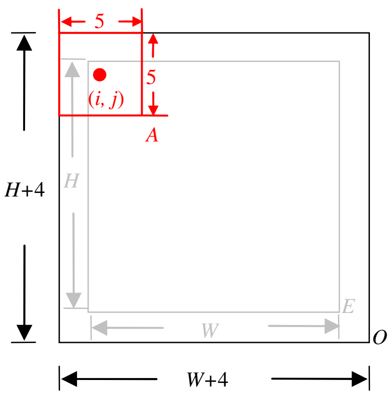

Fig. 1. The relationship between the original low-resolution image (E), the boundary padding image (O), and image pattern A.

$$A = \begin{bmatrix} o_{i-2,j-2} & o_{i-1,j-2} & o_{i,j-2} & o_{i+1,j-2} & o_{i+2,j-2} \\ o_{i-2,j-1} & o_{i-1,j-1} & o_{i,j-1} & o_{i+1,j-1} & o_{i+2,j-1} \\ o_{i-2,j} & o_{i-1,j} & o_{i,j} & o_{i+1,j} & o_{i+2,j} \\ o_{i-2,j+1} & o_{i-1,j+1} & o_{i,j+1} & o_{i+1,j+1} & o_{i+2,j+1} \\ o_{i-2,j+2} & o_{i-1,j+2} & o_{i,j+2} & o_{i+1,j+2} & o_{i+2,j+2} \end{bmatrix}, \tag{2}$$

where $i = \lfloor x/m \rfloor + 2$, $j = \lfloor y/m \rfloor + 2$, and $\lfloor z \rfloor$ denotes the integer floor of z. If $s=(x \bmod m)/m$ and $t=(y \bmod m)/m$, then bilinear interpolation can be realized by

$$G(x/m, y/m) = (1-t)((1-s)o_{i,j} + s o_{i+1,j}) + t((1-s)o_{i,j+1} + s o_{i+1,j+1}), \tag{3}$$

and bicubic interpolation can be realized by

$$G(x/m, y/m) = \sum_{c=-1}^{2} \sum_{d=-1}^{2} W_{d+1}(s) W_{c+1}(t) o_{i+d,j+c}, \tag{4}$$

where

$$W_0(v) = (-v^3 + 2v^2 - v)/2, \quad W_1(v) = (3v^3 - 5v^2 + 2)/2,$$

$$W_2(v) = (-3v^3 + 4v^2 + v)/2, \quad W_3(v) = (v^3 - v^2)/2. \tag{5}$$

Non-edge-directed image interpolation methods usually produce image artifacts and edge blurring in edge regions. To cope with image artifacts and edge blurring in edge regions, many edge-directed interpolation methods are proposed. For example, gradient interpolation [7] can be realized by

$$G(x/m, y/m) = w_0^v(w_0^h o_{i,j} + w_1^h o_{i+1,j}) + w_1^v(w_0^h o_{i,j+1} + w_1^h o_{i+1,j+1}), \tag{6}$$

where

$$w_0^h = H_l(1-s)/D^h, \quad w_1^h = H_r s/D^h, \quad w_0^v = V_u(1-t)/D^v,$$

$$w_1^v = V_l t/D^v, \quad D^h = H_l(1-s) + H_r s, \quad D^v = V_u(1-t) + V_l t. \tag{7}$$

Gradient interpolation [7] is an adaptive bilinear interpolation method and the inverse gradient weights are given by

$$H_l = 1/\sqrt{1+\alpha(|o_{i,j} - o_{i-1,j}| + |o_{i,j+1} - o_{i-1,j+1}|)},$$
$$H_r = 1/\sqrt{1+\alpha(|o_{i+1,j} - o_{i+2,j}| + |o_{i+1,j+1} - o_{i+2,j+1}|)},$$
$$V_u = 1/\sqrt{1+\alpha(|o_{i,j} - o_{i,j-1}| + |o_{i+1,j} - o_{i+1,j-1}|)},$$
$$V_l = 1/\sqrt{1+\alpha(|o_{i,j+1} - o_{i,j+2}| + |o_{i+1,j+1} - o_{i+1,j+2}|)}, \tag{8}$$

where α in the range [0,1] is the sharpness constant. If α is increased, the gradient interpolation will result in a sharper image.

For the edge-directed interpolation method, namely, EASE [9], the one-dimensional (1D) EASE scheme can be applicable for 1D signal interpolation on the x-axis. That is

$$G_x(x/m) \approx (1-s)o_{i,j} + s o_{i+1,j} + (1/4)M_{i+s}, \tag{9}$$