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Spatial Distance-based Interpolation Algorithm for Computer Generated 2D+Z Images

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Abstract

Computer generated 2D plus Depth (2D+Z) images are common input data for 3D display with depth image-based rendering (DIBR) technique. Due to their simplicity, linear interpolation methods are usually used to convert low-resolution images into high-resolution images for not only depth maps but also 2D RGB images. However linear methods suffer from zigzag artifacts in both depth map and RGB images, which severely affects the 3D visual experience. In this paper, spatial distance-based interpolation algorithm for computer generated 2D+Z images is proposed. The method interpolates RGB images with the help of depth and edge information from depth maps. Spatial distance from interpolated pixel to surrounding available pixels is utilized to obtain the weight factors of surrounding pixels. Experiment results show that such spatial distance-based interpolation can achieve sharp edges and less artifacts for 2D RGB images. Naturally, it can improve the performance of 3D display. Since bilinear interpolation is used in homogenous areas, the proposed algorithm keeps low computational complexity.

Introduction

Depth image-based rendering (DIBR) is one of the main technologies in 3D displays [1-3]. In this method, multiple virtual views can be reconstructed by using a 2D image signal and the corresponding depth map, namely 2D+Z format. The texture of a scene is recorded by 2D RGB image, while the relative distance of each object in the 2D RGB image is represented by depth map.

In recent years, TVs continue to shift to higher resolution and larger screen size. 3D displays are of no exception. With the increases of screen size and resolution, high-quality virtual-view image generation has been becoming a challenging task, since it requires high-resolution 2D+Z image.

Image interpolation is used in 2D+Z image upscaling. In general, the interpolation of 2D part and Z part in a 2D+Z image uses the linear methods such as bilinear interpolation and bicubic convolution interpolation. While linear interpolation algorithms have advantages in simplicity and fast implementation, they suffer from some inherent defects, including zigzag, blurred details and ringing artifacts around edges [4-5]. As well known, the human visual system (HVS) is highly sensitive to distortions of spatial coherence of edges [5-6]. Thus, many algorithms focus on edge-directed interpolation methods [4,6-8]. The main idea of these methods is to classify the original images into homogenous areas and edge areas, then to accomplish image interpolation in the two kinds of areas with linear methods and edge-directed methods respectively.

2D+Z images carry more reliable edge information if they are generated from computer graphics [3,9]. Tools of 3D computer graphics can output not only high-resolution 2D color image but also high-accuracy depth map. Though the 2D+Z images own low resolution after downsampling or compression, the corresponding depth in Z part for each pixel in 2D part is still relatively accurate. Comparatively speaking, we can detect edges more accurately from depth map.

This paper proposes an interpolation algorithm for computer generated 2D+Z images. In this algorithm, the first step is to interpolate pixels in depth map with linear methods. Then RGB image is interpolated by using the interpolated depth map. We also perform interpolation for homogenous areas in the RGB image with common linear methods. For edge areas in the RGB image, we use the proposed interpolation method, in which the spatial distances between new pixel and its surrounding edge pixels are utilized to obtain the weight factor for each surrounding pixel. The interpolation algorithm can achieve higher-quality 2D color images and further improve the 3D visual experience.

The rest of the paper is organized as follows. Section 2 presents the motivation of the proposed interpolation algorithm. Then Section 3 describes the interpolation for depth map. The proposed algorithm for 2D RGB image is presented in Section 4. Experimental results are reported in Section 5. Finally, Section 6 concludes the paper and gives future work.

Motivation

For low-resolution RGB image, we can interpolate new pixels to generate high-resolution RGB image just by using four adjacent pixels for bilinear interpolation, or 16 adjacent pixels for bicubic interpolation in 2D space. However, for low-resolution 2D+Z image, the interpolation method could be different. With the help of depth map, we know the spatial positions of the 3D points corresponding to the pixels in RGB image. Thus, more accurate results can be possibly achieved for the interpolation of 2D color part in 2D+Z image.

Fig. 1 illustrates the possibility of image interpolation with depth information. In the figure, black dots represent available pixels in low-resolution image, white dots represent interpolated pixels in high-resolution image, and red dots means the pixel currently being interpolated. We assume that the depth values for pixels along Y-axis in Fig. 1(a) are the same. Thus, we can see the Z-axis positions of 3D points corresponding to available pixels in low-resolution image from side view, which is shown in Fig. 1(b) and (c). Actually, Fig. 1(b) and (c) present depth interpolation with two different methods. As shown in Fig. 1(b), the red dot in Z-axis should be located in the middle of two adjacent dots in column if depth map is interpolated by using bilinear method. However, if bicubic method is used in interpolation for depth map, the red dot should be located higher in Z-axis because of the influence of the other two nonadjacent available dots in column, which is shown in Fig. 1(c). Different interpolation methods in depth map can cause changes in the distances between interpolated point and adjacent available points in 3D space. The red dot is closer to left black dots in Fig. 1(c). In principle, the left pixels should have larger influence on the interpolation of red dot in Fig. 1(a).

To achieve a more realistic image, the RGB value should be dependent on the spatial distance to its neighboring RGB pixels. The lesser the distance, the more influence the available pixel should have on the interpolated pixel, and vice versa. The distance acts as a weight factor that represents the contribution factor of neighboring RGB pixels. In the paper, we propose a 3D interpolation method based on spatial distances between interpolated point and adjacent points in 3D space.

Suppose there are four available pixels in coordinate (1,1), (1,2), (2,1) and (2,2), and five interpolated pixels in coordinate (1.5,1.5), (1.5,1), (1.5,2), (1,1.5) and (2,1.5) in Fig. 2. From 2D+Z image, we know the RGB and depth values of four available pixels. Firstly, a scaling factor is introduced between the depth value of "1" in depth map and the pixel location difference of "1" in RGB image to keep equal unit length in XYZ axes. We can consider z and Z as scaled depth and the depth in depth map, which can be obtained as below

$$z = kZ. \tag{1}$$

Then we can get the spatial distances between interpolated pixel and available pixel as bellow

$$d_n = \sqrt{(x_n - x)^2 + (y_n - y)^2 + (z_n - z)^2}, \tag{2}$$

where (x_n, y_n, z_n) denotes the location of the n^{th} available pixel in 3D space, and n is from 1 to N. While N is 4 for the interpolated pixel at (1.5,1.5), it is 2 for other interpolated pixels like those at (1.5,1) and (1,1.5). In next step, the weight factor of each available pixel can be obtained as

$$w_n = \frac{\frac{1}{d_n^2}}{\sum_{i=1}^{N} \frac{1}{d_i^2}}. \tag{3}$$

Thus, the RGB values of interpolated pixel are solved by

$$RGB' = \sum_n^N w_n RGB_n. \tag{4}$$

If the scaling factor k equals to zero, the method would become common bilinear interpolation.

In this paper, we use iterative scheme to reconstruct high-resolution images. For example, in order to get a 3840x2160 image from a 960x540 image, we can use two steps to complete the interpolation. Firstly, a 1920x1080 image is generated by interpolating the 960x540 image. Then, by using the same way, we can get the 3840x2160 image.

Interpolation for Depth Map

Bilinear and bicubic interpolations are the most commonly used linear interpolation algorithms. Compared with bilinear method, bicubic interpolation takes more pixels into account, thus preserves fine detail and have fewer interpolation artifacts. Bilinear interpolation is easy to implement, especially for hardware solution. In order to keep the simplicity of bilinear interpolation and the accuracy of bicubic interpolation, we will perform bilinear interpolation in homogenous areas and bicubic interpolation in edge areas.

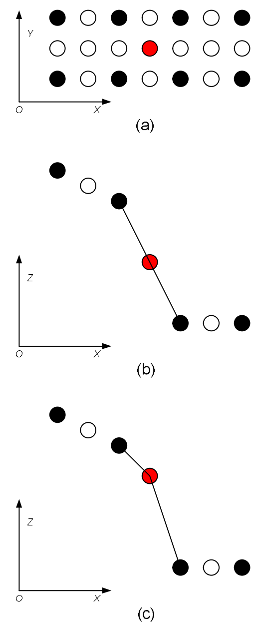


Figure 1. Spatial positions of pixels, (a) top view, (b) side view with bilinear interpolation in depth map and (c) side view with bicubic interpolation in depth map

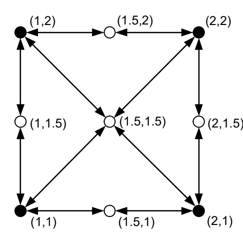


Figure 2. Distance-based interpolation in 3x3 block

However, for the interpolation of depth map, bicubic interpolation cannot be directly used because it causes overshoot beside the edges, as is shown in Fig. 3a. Therefore, we need to clip the overshoot by replacing bicubic interpolation with bilinear interpolation in overshoot areas, as shown in Fig. 3b. Firstly, low-resolution (LR) depth map is interpolated into high-resolution (HR) depth map by bilinear method. Then, whether interpolated pixels in HR depth map are located in edge area are judged by comparing the depth values of interpolated pixels and their adjacent available pixels. If the interpolated pixels belong to edge pixels, the depth values of these pixels need to be recalculated by using bicubic interpolation. There are various methods to detect edge pixels. In this paper, we use one very simple method as bellow

$$\max_{1 \le n \le N} \left| Z_n - \frac{1}{N} \sum_{i=1}^{N} Z_i \right| \ge TH_{edge}, \tag{5}$$

where TH_{edge} is the threshold value for edge detection.

Interpolation for 2D RGB Image

The flowchart of proposed interpolation for 2D RGB image is shown in Fig. 4. In iterative scheme, the processing steps of RGB image are corresponding to those of depth map. Bilinear interpolation is also the first step. Then, the edge position information from edge detection for depth map is directly used to help find the edge pixels in RGB image. For non-edge pixels, no further processing is done. However, for edge pixels, we re-interpolate the pixels by using spatial distance-based interpolation mentioned in Section 2.

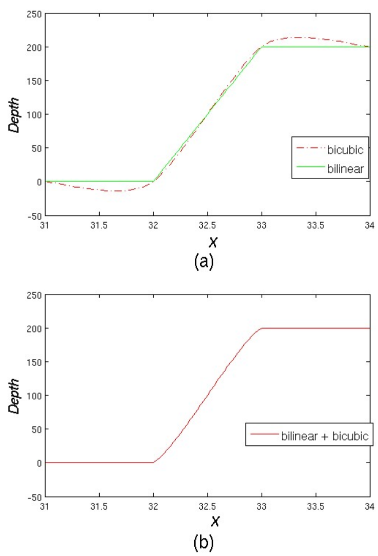


Figure 3. Interpolation and clipping, (a) bilinear and bicubic interpolations, (b) replace bicubic interpolation with bilinear interpolation in overshoot areas

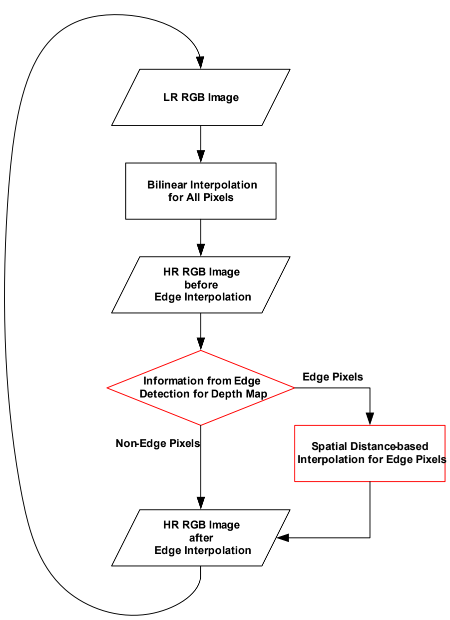


Figure 4. 2D RGB image interpolation with iterative scheme

Experiment Results

To evaluate the effectiveness of the proposed method, we conduct experiments on some 2D+Z images from Youtube [10-11]. Fig. 5 shows two 2D+Z images that Triaxes company drew and uploaded to Youtube. The resolution of the images is 1280x360. That means that the resolution of both depth map and RGB image is 640x360. We interpolate the two images with 8X image enlargement by using bilinear interpolation and the proposed method. Therefore, for the proposed method, 3-loop iteration is used. In addition, the scaling factor k is set to 0.1 and the threshold value TH_{edge} is set to 1 in the examples. Fig. 6 shows the edge pixels in the two samples. Fig. 7 gives the comparison of bilinear and proposed interpolation methods for the details of the two cases. The figure clearly shows that proposed interpolation can achieve sharp edges and less zigzag artifacts.

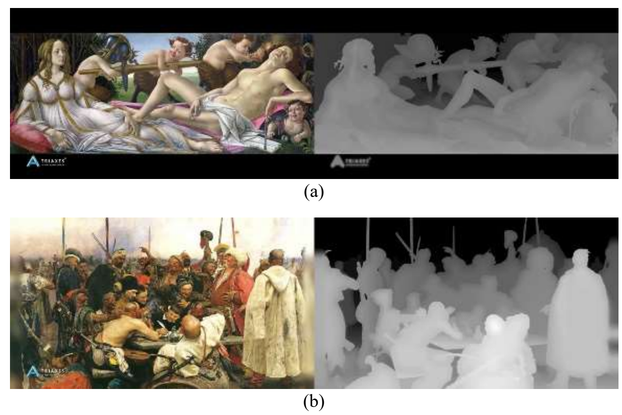


Figure 5. Two samples from Youtube [10] (Triaxes company has permitted us to use the pictures)

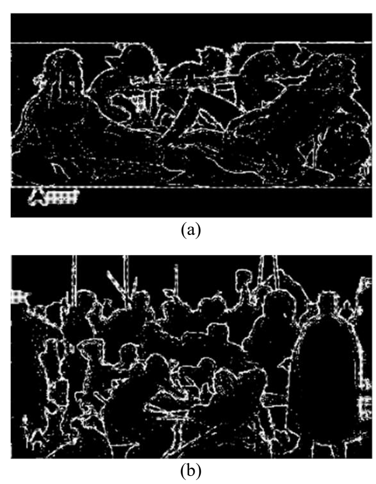
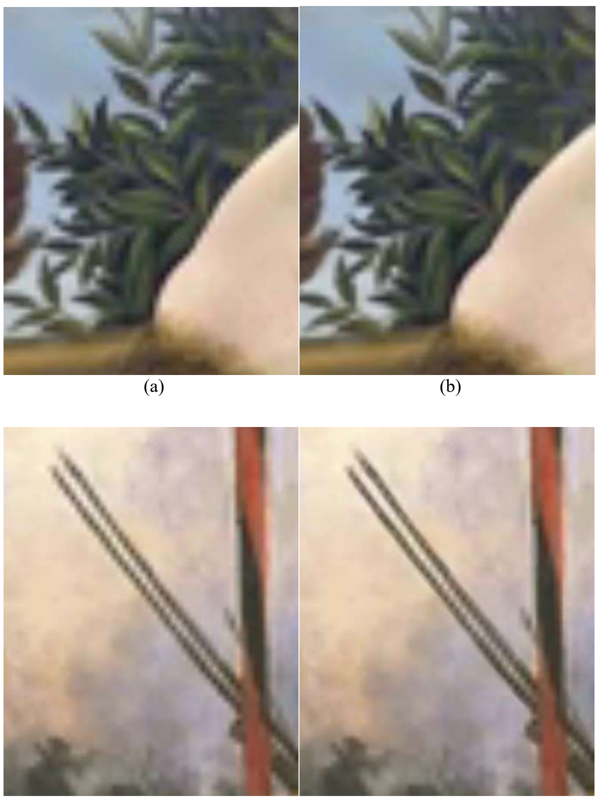


Figure 6. Edge pixels in the two samples

In order to further compare bilinear and proposed interpolation, subjective assessment experiments are presented. In the experiments, twenty-five persons of ages ranged from twenty-one to fifty years old participated in the assessment. There are totally 20 side-by-side interpolated RGB images with the resolution of

3840x2160 under test. One side is processed by bilinear interpolation and the other is processed by the proposed method. Both sides are done with 8X enlargement. The order of showing the two version images is not fixed in each test set, so that the participants would not know which one is processed by the proposed method. All the original 2D+Z images came from Triaxes company and our partners and were produced by computer graphics tools. We just ask the participants to choose the better side. There are five levels from 1 to 5, representing bad, poor, fair, good and excellent. All the test images are displayed for 20 seconds on a 50-inch 4K display. The mean scores of the test participants rated for bilinear and proposed interpolations are shown in Fig. 8. The ratings for the proposed method are clearly higher than that of bilinear interpolation.



(a) (b)

(c) (d)

Figure 7. Comparison of bilinear and proposed interpolation, (a) and (c) are interpolated with bilinear method, (b) and (d) are interpolated with proposed method

Conclusions and Future Work

This paper proposes a concept of spatial distance-based interpolation for 2D+Z images generated from computer graphics tools, in which depth map can provide spatial information for the interpolation of RGB pixels. Based on the concept, we design the structure of new interpolation for depth maps and RGB images. In fact, complex interpolation methods for not only RGB image but also depth map are just conducted at edges, so the proposed interpolation keeps a low computation complexity. Experimental results and subjective assessment show that the proposed method can achieve better quality for 2D RGB images.

We make progress in improving the quality of 2D RGB images by using computer generated depth information. This will naturally lead to good 3D images according to our experiences in 3D image enhancement. Therefore, we will utilize the proposed method in 3D display system in next step. Firstly, the proposed method will be directly used for the preparation of 2D RGB images. Secondly, it will play an important role in the interpolation process for multi-view rendering, especially for hardware-based real-time processing solutions.

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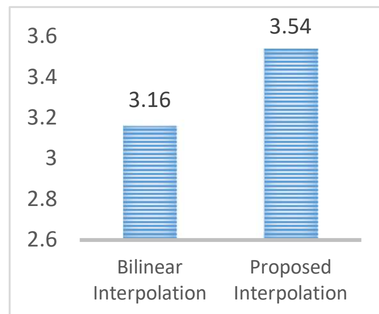

Figure 8. Image quality comparison with images processed by bilinear interpolation and proposed method

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Author Biography

Yuzhong Jiao received his MS in test and measure technology and instrument from Xiamen University (2001) and his Ph. D. in micro-electronics and solid-state electronics from Peking University (2009). From 2001 to 2004, he worked in the State Key Laboratory of Optical Technologies for Micro-fabrication in Chinese Academy of Sciences (CAS). And from 2010 to 2019, he worked in the IC Design Group (ICD) and the Advanced Digital Systems Division (ADS) at the Hong Kong Applied Science and Technology Research Institute (ASTRI). Now he works in United Microelectronics Centre (Hong Kong). His current research interests include auditory/visual immersion, AI chip design and AI applications.

Kayton Wai Keung Cheung received his Bachelor's and Ph.D. degrees in Electronic Engineering from City University of Hong Kong in 2008 and 2012. He has around 8 years R&D experience in image processing, 3D rendering and computer vision. Currently, Kayton is a Senior Engineer of United Microelectronics Centre (Hong Kong) and his research work focuses on the algorithm design and development for AI applications.

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Yiu Kei Li earned his Master's Degree in Computer and Electrical Engineering at the University of Iowa and his MBA at the University of San Diego in the USA. He also earned an Executive Certificate in Management and Leadership from the Massachusetts Institute of Technology. Mr. Li has more than 30 years of management experience in multinational and regional operations in IC design and semiconductor-related industries. Before joining UmecHK, he held important marketing and technical positions in several IC design and manufacturing companies in Hong Kong, China, and the US. He was responsible for strategic planning, supervising commercialization and product innovation activities. Mr. Li is active in his participation in activities organized in the industry. He holds several external appointments including a member of Hong Kong Information and Technology Joint Council, visiting professor of Peking University, Fellow of The Hong Kong Association for the Advancement of Science and Technology, Advisory committee member on Electronic Engineering in CUHK and Senior Member of IEEE.