A Wavelet-Based Image Enhancement Algorithm for Real Time Multi-resolution Texture Mapping

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Abstract. In order to get better rendering effect, we proposed a wavelet transform based image enhancement algorithm for real time multi-resolution texture mapping in this paper. In this algorithm, we proposed a concept of weighted pyramid. Texture images to be synthesized are weighted enhanced by wavelet transform. Comparing with original ones, the edges in this image is much clearer and the contrast of this image is more evident. And when dealing with the maps with their particular characteristics, we also proposed some method for algorithm improvement. By using this method, current multi-resolution texture mapping method will be much more improved. It can give us a more realistic and efficient rendering effect by using lower resolution image to replace higher resolution one.

Keywords: wavelet, image enhancement, texture mapping, multi-resolution.

1 Introduction

Virtual reality techniques have been widely used in many areas such as entertainment, aeronautics and etc. They have changed the life of people in many aspects. Reality and real time are the two key attributes of Virtual reality techniques. Without them we have no felling of being as in a real world when we browse in a virtual environment. Texture mapping is one of the most widely used techniques for realistic rendering in virtual reality systems. In order to reduce the computation in texture mapping process, multi-resolution texture mapping techniques [1], [2], such as mip-map, has been proposed, which gave us a way for fast rendering. As Virtual reality techniques being used further more and the resolution of devices for data acquiring being much larger, the number of data to be rendered in virtual environment has enlarged more and more, not only including the polygons of virtual environment but also the size of texture images. For example, the size of one satellite texture image used in a terrain rendering system[3] is 30G bytes or some even much larger. It exceeds the loading ability of the RAM in PC and graphics cards. We have to piece the large image into smaller patches and load one patch each time. The rendering efficiency is much influenced by the

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process of data IO. In order to debase the frequency of data IO process, many people have to use lower resolution texture image to replace higher resolution one for texture mapping. Consequently this method reduces the rendering quality. It not only blurs the final rendering image but also introduces some match artifacts between different layers of the multi-resolution texture image for the reason of detail lost. Our suggestion to resolve this problem is to use the technique of image enhancement [4], [5]. Facing the problem of how to debase the resolution of the texture image with the least loss of detail about the edges, we choose the wavelet transform [6] method at last after experimenting in many methods.

The organization of this paper is as follows: In the next section, we will give the process of constructing our multi-resolution texture pyramid by edge detection and also introduce a new concept named weighted pyramid. In Section 3, we will present a new method of constructing weighted pyramid by using wavelet transform. In last section, we will present the results of our experiments and give the conclusions.

2 The Real-Time Rendering and Weighted Pyramid

2.1 The Real-Time Rendering

When reviewing the history of computer graphics, we find it is the reality and high quality of the image that traditional algorithms focus on. However the virtual reality system nowadays requires limited rendering time. Because of the huger and huger amounts of data need to be rendered in complicated and veracious scenes, the way we mostly used for speeding is often to lose some quality. Here the “lose” mainly means the debasing of the image reality and the growing of the alias. For example, we adopt simply local lighting model [1] or multi-resolution texture mapping [1], [2] techniques to improve our rendering speed.

Based on the visual character of people, the object seems smaller when it is far away from our eyes. And just few pixels are covered when projected on the screen. So, we needn’t to render all the details for such object. The same thing occurs in texture mapping. Because the number of pixels projected on screen is often much smaller than number of pixels in texture images being mapped on object. We needn’t to use high resolution texture in such cases. Or it will be a waste of resource. For this, the multi-resolution texture mapping is feasible. It makes us create different levels of image with different resolution based on one texture image (if we pick up every four neighbor pixels on the first level to create a new one on the next level, then the scale is debased by 2 exponential) . Then we get a pyramid constructed by the different sub levels of image. When mapping the texture, we can choose the corresponding one according to its distance from our eyes. And the farther the object goes, the smaller resolution we choose.

2.2 Weighted Pyramid

By comparing the two images in figure 1 and figure 2, we find that it becomes blurry while the resolution falling down. In fact, when this falling process goes on the loss of edge information will reach some degree and breaking will occur in lower resolution image. This will introduce some match artifacts between different layers of the multi-resolution texture mapped rendering image [3].

Fig. 1. The standard image called "house"

For keeping enough more detail information, we hope the new born pixel can contain more edge information when we construct the multi-level pyramid. Then we propose a concept of weighted pyramid by adding a weight to each pixel in the process of constructing pyramid. This can make some information outstanding and is useful for our rendering.

First we do the edge detection [7], [8] to the image. All pixels are marked with edge point and non-edge point based on the result of the detection. When building the pyramid, we add a weight to each four neighbor pixel--bigger weight to edge point, and smaller weight to non-edge point, which depend on the result of the edge detection. So the new born pixel on the next level by averaging the four weighted pixels will comparatively keep more edge information.

There are many existent edge detecting operators. Figure 3 gives the result of low resolution enhanced image by using Sobel operator. In this algorithm, all our behaviors take place in the space area and we deal with the pixels in image. For parting the two kinds of pixels, we need to set up a threshold of gray value. But the threshold value is often not accurate. And because of its inherent mathematics disadvantage, this method may bring more blur. Although those shortcomings, by comparing the histograms of the two images in figure 2 and figure 3, we can see that the result image in figure 3 not only keep higher pixel values but also distributes grey values more uniformly. This means that it contains more detail information and has better rendering effect. However, this result is still need to be improved for us.

After studying and analyzing many other existent techniques, we lead the wavelet technique into our weighted pyramid at last.

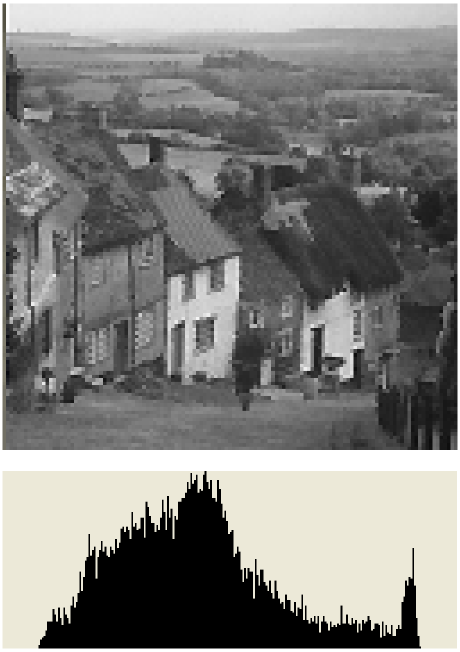

Fig. 2. The half-resolution image and its histogram

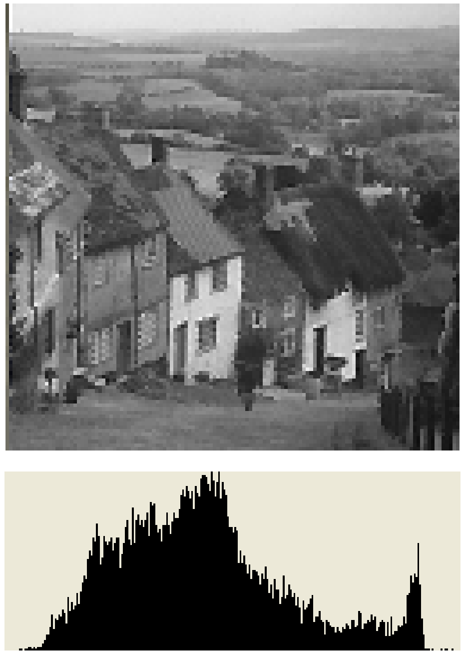

Fig. 3. The half-resolution image enhanced by Sobel detector and its histogram

3 Wavelet Decomposition Used for the Image Enhancement

3.1 Characteristics of the Wavelet Transform

Wavelet transform [6] is an analysis technique for non-stationary signal processing. By using this method we can use a set of functions to approximate one function wanted. The set of functions used are called wavelet functions. In real application we often chose dyadic wavelet transform. Give a function f (t) in space $L^2(R)$, its dyadic wavelet transform is

$$C_{m,n} = \int_{-\infty}^{+\infty} f(t)\psi_{m,n}(t)dt \tag{1}$$

where $\psi_{m,n}(t) = 2^{\frac{m}{2}}\psi(2^{m}t \quad n)$, and $\int_{-\infty}^{+\infty}\psi(t)dt = 0$. When we extend the transform to two-dimensional space, it can be used to process or analyze images. The image can be decomposed into four sub-bands which are horizontal, vertical, diagonal and low-frequency half resolution portions through different filters respectively. And the low-frequency part can still be decomposed.

Wavelet has the abilities of multi-resolution analysis about the images and reflecting the local characteristics of the signals. We can get the wavelet coefficient images by using discrete wavelet transform, and the level to be decomposed is depend on the actual effect you want. The coefficient images is composed of several sub-band coefficient images which describe the horizontal and vertical space frequency characteristics of the image. Sub-bands on different level can describe the characteristics in different space resolution of the image. Then through multi-level decomposing, the coefficient images we get can not only show the high-frequency information of the local areas in the image (ex. the edge) but also the low-frequency information (ex. the background). So that we can still keep more detail information about the image even though in the low-bit rate situation. The image described by coefficient of the second level is just half resolution of the first level. So, we can get image (clear or blurry) with any resolution we want.

3.2 Wavelet Enhancement

Through the wavelet transform decomposing, we have got four sub-band coefficient images. Each of them is one quarter of primary image in size. They are one low-frequency approximate image and three high-frequency approximate images of horizontal part, vertical part and the diagonal part. So information of the image is classified very well. Detail information on edge or in texture is mainly collected in the high-frequency sub-band images with higher values. From some existent research results we know that people are sensitive to the change on horizontal and vertical edges, which represent the main edge characteristics of image. On account of those advantages of wavelet transform, we can introduce it into weighted pyramid structure we mentioned in section 2. By adding weights to the horizontal and vertical high-frequency coefficient images on each level we make some adequate enhancements to multi-scale images decomposed by wavelet transform. And a new weighted texture pyramid with more detail information was achieved by reconstructing an enhanced image on each level with modified coefficients. Much different from method working in space area we used in section 2, this method works in the frequency area. In fact, the wavelet decomposition of image separates the whole signal into different sub-bands with different frequency scale. Then we can take different means with those sub-bands to achieve our different goals. Taking image enhancement for example, we will see that it is very flexible and convenient to strengthen the weight of details with different frequency scale and make it obvious visually. Then we can improve its holistic quality and get a better visual effect, as shown in figure 4.

We have three steps to make the enhancement of image f(x, y) by using wavelet transform. First, we decompose the image with wavelet. Then we make some adequate enhancement to the horizontal and vertical high-frequency images on each level. At last, we make the inverse-transform with those results and get a better enhanced image.

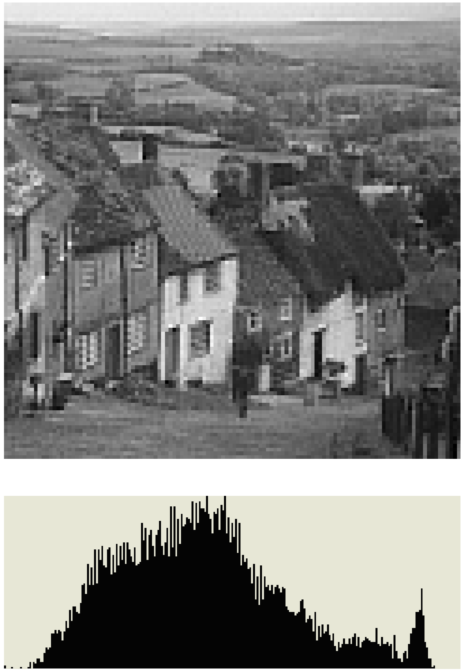

Fig. 4. The half-resolution image enhanced by wavelet algorithm and its histogram

3.3 Improved Wavelet Enhancement

The former wavelet enhancement method still needs to be improved for different images with their own characteristics. For example, if the image has excessive noise, we should set up a soft-threshold filter before wavelet transform. Cause the noises are mainly distributed on small scale wavelet coefficients in scope of wavelet transform, just as the most detail information of image (which is the key point considered in the enhancement) do. If we directly make the enhancement with equation (1), we will strengthen noises in image uniformly. Sometimes, this will lead to terrible rendering effect. To solve this problem, we set up a soft-threshold filter to eliminate most noise before our wavelet enhancement process begins. See equation (2) as below, we set up threshold T_{ij} on each scale level, where i means different sub-band image and j represents the scale.

$$WT_{ij}^{i}(x,y)=\begin{cases} WT_{ij}^{i}(x,y)-T_{j,i} & WT_{ij}^{i}(x,y)\geq T_{j,i} \\ 0 & -T_{j,i}<WT_{ij}^{i}(x,y)<T_{j,i} \\ WT_{ij}^{i}(x,y)+T_{j,i} & WT_{ij}^{i}(x,y)\leq -T_{j,i} \end{cases} \qquad (2)$$

As for the images which are gloomy or blurry, an optimized effect can be achieved through adjusting its lightness for the reason that according to people's visual characteristics people is much more sensitive to lightness than hue. So we can do the image enhancement under the HLS model. Firstly we transform the image from RGB model into HLS model. Then process the wavelet enhancement to L (lightness) component in the same way we do before. I have to say that this maybe acquire amazing effect.

4 Experiment Results and Conclusion

For assuring the universality of the result, we choose another different kind of texture image with Chinese ethical characteristics for the experiment, as shown in figure 5. In the figure 6, we cut it into two parts just in the middle.

Fig. 5. High resolution texture image

Fig. 6. Two parts separated in the middle

We draw two connected rectangles F1 and F2 in 3-D space, where F1 is near to us and F2 is far away. We mapped this texture to them. Left part is mapped to F1 and right part is mapped to F2. Because F2 covers much less pixels on screen than F1, we can use a lower resolution texture instead for speeding. This is very common for two connected faces in real application. Here, we map texture with highest resolution to F1 and map texture on the next level with half resolution to F2.

Figure 7-9 give different results by using different lower resolution images. They are separately normal lower resolution image without enhancement in figure 7, lower resolution image enhanced by Sobel edge detector in figure 8 and lower resolution image enhanced by wavelet transform in figure 9. We can see that our algorithm proposed in this paper gives the best visual effect. Result image in figure 9 is more perfect both at the detail display or lightness balance. And the two

Fig. 7. Texture mapping result using normal lower resolution image without enhancement

Fig. 8. Texture mapping result using lower resolution image enhanced by Sobel edge detector

Fig. 9. Texture mapping result using lower resolution image enhanced by wavelet transform

connected texture image with different resolutions are matched well and joined smoothly.

Based on the life experiences, it is completely feasible to use the low resolution texture image to replace the higher one so that we can improve the mapping efficiency. We finally choose the wavelet enhancement technique processed in the frequency area to improve the low resolution image after many experiments and comparisons. Additionally we propose some methods to improve the wavelet technique for better effect when we are facing images with their own characteristics. For assuring the universality of the result, we do experiments for real time multi-resolution texture mapping separately by using original multi-resolution texture mapping method currently used, Sobel edge enhancement method and wavelet transform based image enhancement method proposed in this paper. Under the condition of same efficiency, all results show that our method give a more realistic rendering image, not only visually but also by image analysis results using histogram. Comparing with other two methods, our method is more perfect both at the detail display and lightness contrast. And image synthesized from adjacent layers are matched more smoothly.

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