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Performance Analysis of the Effects of Non-Adaptive Image Scaling on Image Edges

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Abstract: changing the dimensions of an image by increasing or decreasing is called image scaling or image resizing. There are many techniques aim at achieving this process with minimal distortions and good quality. Non-adaptive techniques such as nearest neighbor interpolation, bilinear interpolation, bicubic interpolation, Lanczos interpolation, and B-spline interpolation are good examples of achieving a reasonably good quality when the fine details of an image and the edges are not of great concern. The process of image resizing results in unequal proportions of image details and edges. Adaptive image scaling produce images with reasonably good quality at the cost of processing time. The non-adaptive interpolation is preferred in real time applications due to its fast processing time and reasonably good quality. In this paper, the non-adaptive interpolation techniques will be introduced and compared. New methods for evaluating the performance of these techniques will be introduced. The ratio of the pixels of image edges to the total image pixels will be calculated.

Index Terms: Digital images, Image processing, Image scaling, Non-adaptive interpolation, Image quality.

I. INTRODUCTION

Image interpolation is a process by which a new data points can be generated from known data points. These new data points or pixels are emerged with the existing data points to get a new enlarged image. Image scaling or image interpolation techniques can be utilized in many image processing areas. One of the most important applications for the image scaling is digital display devices which uses image interpolation techniques to scale up and scale down digital images. The resized image is lower in quality when compared to original image. Most current researches are focused on approximating the quality of resized image with the original image. Image interpolation techniques have simple methods to enlarge the size of low resolution images. The image interpolation concepts are utilized in many applications such as image and video coding and face recognition [1], image zooming [2], medical image processing [3], scan converter [4], computer graphic [5], online videos and image scaling.

Image interpolation techniques can be divided into two techniques, the non-adaptive interpolation technique and the adaptive interpolation technique. The non-adaptive techniques such as nearest neighbor interpolation, bilinear interpolation, bicubic interpolation, Lanczos interpolation and B-spline interpolation are based on resizing images without concern to the image contents[6]. Due to low complexity of algorithm computations, the non-adaptive interpolation techniques are mainly used in real time applications. Adaptive interpolation techniques are based on operations on the local structure of the image and its intensity variations [7]. These algorithms have their own advantages and disadvantages. As adaptive interpolation algorithms need much more hardware resources which are very expensive. The resolution of an image plays an important role in calculating the performance of the technique used. Linear interpolation techniques are simple methods to resize images with acceptable quality where the fine details of an image is not a crucial requirement. Adaptive and non-adaptive interpolation techniques are proposed to enhance the subjective and objective qualities of the resized images by imposing new complicated algorithms. The non-adaptive techniques will be discussed and analyzed in this paper due to its wide spread applications and low complexity of implementations. The rest of the paper will be organized as follows: section II introduces the different types of non-adaptive interpolation techniques. Section III provides the comparisons and results. Conclusion will be provided in section IV.

II. NON-ADAPTIVE INTERPOLATION TECHNIQUES

The non-adaptive interpolation techniques are implemented based on approximated formulae independent of the local structure of the image such as nearest neighbor, bilinear, bicubic interpolation techniques. These techniques determine the value of new image pixels from the neighboring pixels by calculating the weighted average value of the neighboring pixels. The Nearest neighbor technique is very simple method to resize image by repeating the value of the nearest neighbor [8 - 10]. The simplest non-adaptive interpolation technique is the nearest neighbor, which is considered to be the ground for most non-adaptive techniques. This technique requires least processing time compared to other techniques due to the fact that, it deals with one pixel for creating each new pixel. The idea of this technique is to repeat certain pixels to achieve the desired scale ratio. The resolution of an image and edges limits the quality of the final image after scaling up the original image. If all edges are vertical, the new image will preserve the same quality as the original image. In most images the edges are random and therefore the quality is poor compared to the original image.

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Assume the image pixel color level is $s_1, s_2, \dots s_u$ (for 8 bit u takes values from 0 to 255) where u refers to the total number of different color indices of pixels. The estimated pixels color indices are $t_1, t_2, \dots t_v$ (v is the total number of new added color levels) which are calculated as a function of original pixel value s_i (i =1, 2, … u). The maximum resize ratio can be obtained with minimum error is twice the size of the image X. With this scale up level, the estimated pixel is calculated only from the original image pixels. In next neighbor interpolation, the estimated pixel color level t_i is the same as s_i. The distribution of the color levels in the scaled image is different and is calculated as $f(s_i)$ where $f(s_i)$ equals to the total number of pixels of color level s_i.

$$p(s_i) = \frac{f(s_i)}{MN} \qquad (1)$$

$$q(s_i) = \frac{f(g_i s_i)}{G^2 MN} \qquad (2)$$

Equations (1) and (2) are the probabilities before and after scaling the image respectively. g_j is the resize ratio of color index i which is an integer value. A value of 1 means no scale up and a value of 2 means the image color level is doubled in size. G is the resize ratio of the image. M and N are the dimensions of the image. $f(g_i s_i)$ is the total number of pixels that have the color level s_i after scaling up.

In equation (2), $f(s_i)$ represents the total number of pixels that have color level s_i in an image which increases in both rows and columns. This has the effect of simply making each pixel bigger. This method is very simple and requires less computation as it utilizes nearest neighbor's pixel to fill interpolated point. This method is just copies available value, not interpolated value as it doesn't change values [11 - 12]. When all color pixels scaled with the same ratio, $q(s_i) = p(s_i)$. There are two bounds of the color levels which are minimum and maximum probabilities of each color pixel and is given as follows:

$$\min q(s_i) = \frac{f(s_i)}{G^2 MN} \qquad (3)$$

$$\max q(s_i) = p(s_i) \qquad (4)$$

Equation (3) describes the minimum probability of a color pixel s_i when this color pixel is not scaled up. Equation (4) is satisfied when every color pixel is scaled with the same ratio.

$$y(i,j) = \begin{cases} x(i-1,j), & \text{i=m, 2m, … M, j=1,2,…N} \\ x(i,j-1), & \text{i=1,2, … M, j=n, 2n, … N} \end{cases} \qquad (5)$$

Where: x (i, j) is the original image matrix pixels, y (i , j) is the estimated image pixels using nearest neighbor method. M x N is the dimension of the original image. m and n are two integer values. Equation (5) shows the relation between the original image and the estimated image pixels. Figure 1 and figure 2 show the original image and the scaled image using nearest neighbor technique. The vertical edges has been shifted to the right and the tilted edges is completely distorted with resizing ration of only 2.

$$y(i,j) = \begin{cases} \sum_r \sum_c a_{rc} x(i+r, j+c) & \text{i=m, 2m, … M, j=1,2, .. N} \\ \sum_r b_r x(i+r, j) & \text{i=m, 2m, … M, j=1, 2, ….N} \\ \sum_c b_c x(i, j+c) & \text{i=1, 2, … M, j=n,2n, .. N} \end{cases} \qquad (6)$$

Where a_{rc}, b_r and b_c are the weighted averages of the pixels.

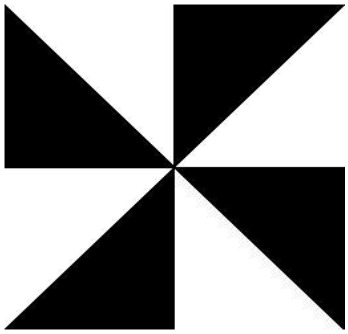

Figure 1 Original image

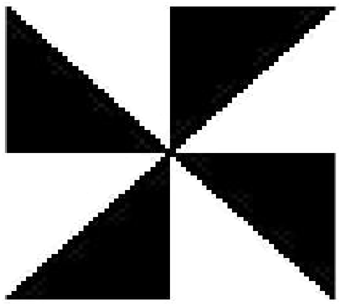

Figure 2 Nearest Neighbor

In bilinear interpolation technique, the estimated pixel is calculated as the weighted average of the four neighboring pixels. In this method, two linear interpolations are used that is one in horizontal direction and the other in vertical direction. The estimated image pixels will be very close in values to the original image with some new values generated from the color pallet of the original image [9]. The equation is given as follows (see (6)).

New color levels are generated in this technique due to calculating the weighted average value of the estimated color pixel. In this case $f(t_i)$ will represent the new color levels added to the image. The image now will have $f(s_i)$ and $f(t_i)$ color levels which affects the quality of the image and make it looks blurred and noisy. The probabilities of repeating each color level after resizing the image is given as:

$$q(s_i) = \frac{f(s_i)}{G^2 MN} \qquad (7)$$

$$q(t_i) = \frac{f(t_i)}{G^2 MN} \qquad (8)$$

The best quality can be obtained if every color level is scaled with the same ratio as the original image.

This is hardly to obtain due random distribution of color levels. There is a maximum and a minimum color levels for the original and scaled images that is calculated as follows.

$$\min q(s_i) = \frac{f(s_i)}{G^2 MN}$$
$$\max q(s_i) = \frac{f(s_i)}{GMN} \qquad (9)$$
$$\min q(t_i) = zero$$
$$\max q(t_i) = 1 - \min q(s_i)$$

Equation (9) describes the minimum and maximum of the color distribution of the scaled image. This equations are general limits for any type of non-adaptive image interpolation technique.

In bilinear interpolation technique, a maximum number of points (M-1) (N – 1) can be calculated from the original image pixels. For a double scaled image, there are new pixels 3MN added to the image. The rest of the points which is 2MN +M+N-1 is calculated from the estimated pixels. To simplify the calculations, the last column and row will be a repeat of the previous ones. With equal distance points, the maximum error in color level be average value of the surrounding four pixels[13 -14].

Another technique is based on non-adaptive calculations which is bicubic interpolation technique. In this technique, the estimated points are calculated as the weighted average of the closest 4x4 points [15 - 17]. The bicubic interpolation technique equation is give as follows:

$$y(i,j) = \begin{cases} \sum_r \sum_c a_{rc} x(i+r, j+c) & \text{i=m, 2m, … M, j=1,2, .. N rows} \\ \sum_r \sum_c b_{rc} x(i+r, j+c) & \text{i=1, 2, … M, j=n,2n, .. N columns} \end{cases} \qquad (10)$$

Where r and c have the values -1, -2, +1, +2 respectively, a_{rc} and b_{rc} are the weighted averages of the rows and columns pixels respectively.

$$y(i,j) = \begin{cases} \frac{x(i-1,j) + x(i+1,j)}{2} & i = 2,4, \ldots M, j = 1,2, \ldots N \\ \frac{x(i,j-1) + x(i,j+1)}{2} & i = 1,2, \ldots M, j = 2,4, \ldots N \end{cases} \qquad (11)$$

The edges (last two columns and rows) of the estimated pixels are calculated using four or two neighboring pixels or even one pixel due to the lack of original pixels.

III. COMPARISON AND RESULTS

The non-adaptive interpolation techniques depend mainly on finding the estimated pixels by calculating the weighted average of the neighboring pixels, which results in new color levels that are not equal to the original color levels. These new color levels affecting the quality of the scaled image[18 – 20]. Figure 3 shows the original image (Lena) with the image resized (resize ratio =2) with nearest neighbor, bilinear and bicubic technique respectively. Nearest neighbor technique affect the fine details with zigzag distribution of the color levels. Bicubic technique provide good quality of the image that is due the weighted average of the neighboring pixels. Bilinear technique on the other hand tends to make the image more greyish by calculating the weighted of four pixels.

The probability of each color level for each technique is calculated. Table 1 shows the maximum probability of a single color level against the technique used. Subjectively, Nearest neighbor technique provides best non change maximum probability. This is due to the fact that the pixels are just repeated with no processing. The number of zeros is the same, since no new color levels are generated. The max probability of color leve s_i of Bilinear an bicubic are smaller than the original image due to the fact the more color levels are generated and it can be seen from the number of zeros in each technique.

Figure 3 Image comparison

Table 1 the Max Prob. And No. of zeros for each non-adaptive technique

	Original	Nearest	Bilinear	Bicubic
MaxP(s_i) x10^{-3}	11.23	11.23	10.13	10
No. of zeros	17	17	12	7

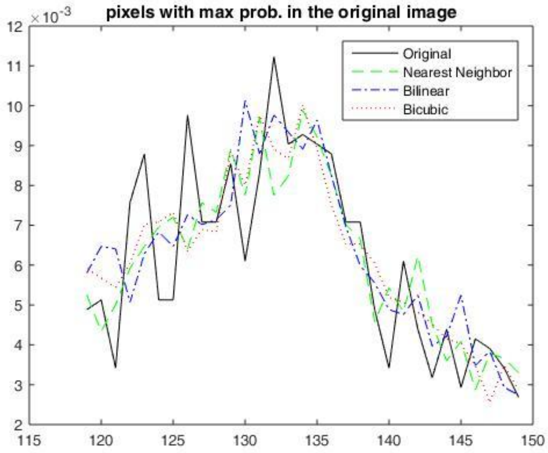

Figure 4 Region of Max prob. of pixels

Figure 4 and 5 show the probability distribution of each technique around the maximum and minimum pixels repetition respectively. Nearest neighbor probability seemed to be not equal to original image pixel probability due to the random distribution of color levels. The two techniques approximate the color levels by adding new color levels due image resizing.

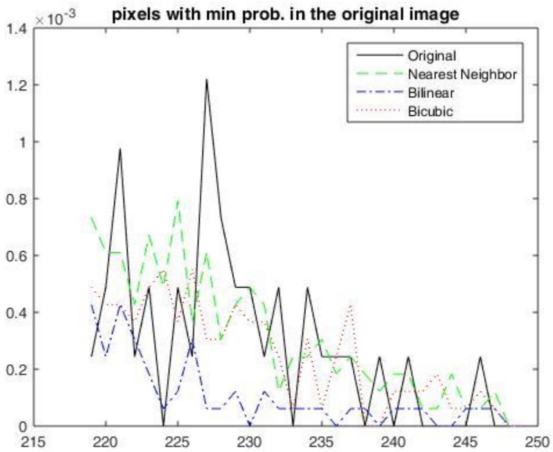

Figure 5 Region of Min prob. of pixels

IV. CONCLUSIONS

The non-adaptive interpolation techniques are based on finding the new colors independently from the local structure of the image pixels. These techniques are suitable for applications that don't require image details such as real time applications. These techniques are failed when image details are of great concern.

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