Survey: Spline based Interpolation methods For Image Magnification

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Abstract:

Many image interpolation methods have been proposed and used for obtaining high-resolution images. Pixel Interpolation is done at the time of image scaling. It is the process of resizing a digital image that involves a trade-off between efficiency, smoothness and sharpness. When the size of an image is increased, the pixels become increasingly visible, making the image appear soft. Conversely, when an image is reduced it tends to enhance its smoothness and apparent sharpness.

The paper tells about different existing methods for image interpolation techniques. Linear interpolation is typically better than the nearest-neighbor system for changing the size of an image, but causes some undesirable softening of details and can still be somewhat jagged. Better scaling methods include bicubic interpolation using B-Splines. The presented methods are briefly described, followed by comparative discussions. This survey provides information about the existing methods and their improvement, assisting also in the designing of new evaluation methods and techniques.

Keywords- nearest neighbor; bilinear interpolation; bicubic interpolation; spline; image interpolation;

1. Introduction:

In terms of digital image, the process of interpolation is to find the information for undefined pixels or missed pixels in an image based on the information provided by original pixels, so that the image which is interpolated is as close to the actual one as possible. The given information can be anything such as *x* or *y* coordinates, color, gray level or density.

The basic methods used for increasing the resolution of digital images after image magnification includes nearest neighbor, bilinear and bicubic. The basic method for interpolation is the Nearest Neighbor method which does not use interpolation but simply takes the value of the neighboring pixels and adds new pixels without averaging them, which gives more jaggies or stair-case effect. Bilinear takes estimation from the neighboring 4 pixels and gives better results than nearest neighbor. Bicubic is the slowest but produces the best estimation of new pixel values. Bilinear is faster than Bicubic, but does a weaker job. Both Bicubic and Bilinear interpolation result in a blurred image with jaggies. These interpolation methods results in blurring of the resized image, especially in areas with sharp lines and distinct changes in color.

If an image is enlarged beyond its original size, the missing pixels are calculated by interpolation, but it does not add any new detail. Increasing the image resolution in the interpolation methods involves two basic steps. Firstly, the new pixels have to be created, and then the colors have to be assigned to the new pixels. The number of the new pixels is proportional to the amount of enlargement of the image. The more the image is enlarged, the more blurred it becomes. The appearance of an enlarged image depends upon the chosen interpolation method. To change the image size, either some pixels have to be removed or new pixels must be added. The process which is used determines the quality of the result.

A lot of research is going on in this field with spline based interpolation methods, as they produce more clear and less jagged images after magnification with minimal detail loss. The capability of increasing the resolution of an image with minimal detail loss helps in a lot of useful applications like better-detailed zooming, conversion of low-resolution digital images and videos to a higher resolution. The higher the resolution of an image, the more will be the number of pixels in the image. More number of pixels produces a higher amount of detail in the image, and results in better and sharper zooming obtaining finer details of the image. The ideal image interpolation algorithm should preserve the qualitative characteristics of the output image since interpolated images suffer from blurring, discontinuities in edges and checkerboard effects.

2. Basic Pixel Interpolation Methods:

Pixels are used to denote the elements of an image. Pixel is a single point in an image, or the smallest addressable screen element in a display device. It is the smallest unit of picture that can be represented or

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controlled. Each pixel has its own address which corresponds to its coordinates. Pixels are normally arranged in a two-dimensional grid, and are often represented using dots or squares. The intensity of each pixel is variable.

The main concept of pixel interpolation is to invent new pixels so that the image quality image does not get affected after altering the size of the image. Some interpolation methods require more memory or longer computation time than others. However, we may need to trade off these resources to achieve the desired smoothness in the result:

- Nearest neighbor interpolation is the fastest method. However, it provides the worst results in terms of smoothness.
- Bilinear interpolation uses more memory than the nearest neighbor method. It also requires slightly more execution time. Unlike nearest neighbor interpolation its results are continuous, but the slope changes at the vertex points.
- Cubic interpolation requires more memory and execution time than either the nearest neighbor or bilinear methods. However, both the interpolated data and its derivative are continuous.

The various Pixel Interpolation methods are:

2.1 Nearest neighbour method:

It assigns the value of the nearest pixel to the pixel in the output visualization. This is the fastest interpolation method but the resulting image may contain jagged edges. When applying nearest-neighbor algorithm into image interpolation, the value of the new pixel is made the same as that of the closest existing pixel. When enlarging an image, this algorithm duplicates pixels; when reducing the size of an image, it deletes pixels.[1][4]

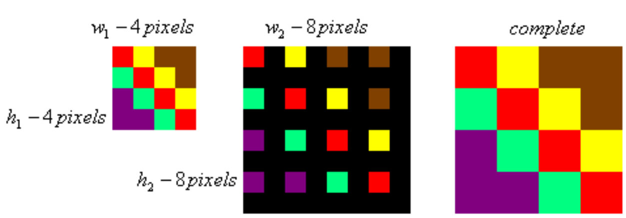

Fig 2.1 Nearest Neighbor Method

2.2 Bilinear Interpolation:

It surveys the 4 closest pixels, creates a weighted average based on the nearness and brightness of the surveyed pixels and assigns that value to the pixel in the output image. Compared to the nearest-neighbor approach, the apparent stair-case effect is significantly reduced and the image looks smoother. This interpolation method appears to work better for image reduction, rather than image enlargement.[1][3][4][5]

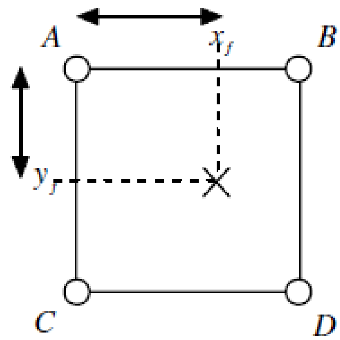

Fig 2.2 Bilinear Interpolation

The formula is given below:[3]

$$I'\left(\begin{bmatrix}x'\\ y'\end{bmatrix}\right) = I\left(f^{-1}\left(\begin{bmatrix}x'\\ y'\end{bmatrix}\right)\right) = I\left(\begin{bmatrix}x\\ y\end{bmatrix}\right)$$

$$= (1-x_f)(1-y_f)A + x_f(1-y_f)B + y_f(1-x_f)C + x_f y_f D$$

where

$$A = I\left(\begin{bmatrix}x_i\\ y_i\end{bmatrix}\right) \qquad B = I\left(\begin{bmatrix}x_i+1\\ y_i\end{bmatrix}\right)$$

$$C = I\left(\begin{bmatrix}x_i\\ y_i+1\end{bmatrix}\right) \qquad D = I\left(\begin{bmatrix}x_i+1\\ y_i+1\end{bmatrix}\right)$$

2.3 Bicubic Interpolation:

It gives absolutely superb results with negligible artifacts. But it requires an extreme number of complex calculations. It attempts to reconstruct the exact surface between your four initial pixels by extracting sixteen pieces of information based on the values of the samples, the x slopes of those values, the y slopes of those values, and the xy slope cross products of those values. It is often chosen when speed is not an issue.[6][7]

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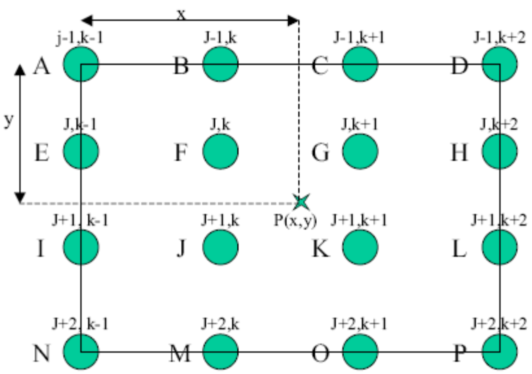

Fig 2.3 Bicubic Interpolation

Bicubic interpolation is a big improvement over the previous two interpolation methods for two reasons:

- Bicubic interpolation uses data from a larger number of pixels.
- Bicubic interpolation uses a Bicubic calculation that is more sophisticated than the calculations of the previous interpolation methods.

The key bicubic equations are:

P(x,y) = a00*x0y0+a01*x0y1+a02*x0y2+a03*x0y3+
a10*x1y0+a11*x1y1+a12*x1y2+a13*x1y3+
a20*x2y0+a21*x2y1+a22*x3y2+a23*x2y3+
a30*x3y0+a31*x3y1+a32*x3y2+a33*x3y3

16 data points are actually used for calculation. Bicubic calculations are often done using matrix techniques [7].

3. Performance Comparison:

There are various types of edges in an image. But step edges are visually more distinct than other types of edges. Therefore, preservation of the sharpness and continuity of the step edges is a key feature. The objective of this method is to evaluate whether the algorithm preserves the original step edges sharp and continuous. In order to evaluate this, a synthetic input image containing only two different area intensities of 225 and 25 is geometrically transformed. In the case of scaling transformation, the image is scaled up and depending on the algorithm used; an unwanted area might arise with a progressive transition from 225 to 25.

Figure 3.1 illustrates the step edge response from 225 to 25.

For bilinear interpolation, a single new spatial area arises, caused by the modest low-pass filter that bilinear interpolation uses. New spatial areas are even more considerable in bicubic interpolation due to the over smoothing in the pass band. In this task, nearest neighbour interpolation presents the best results since it reproduces exactly the interpolated pixels. However, this feature also results in the strong aliasing effects that are associated with the nearest neighbour interpolation [4].

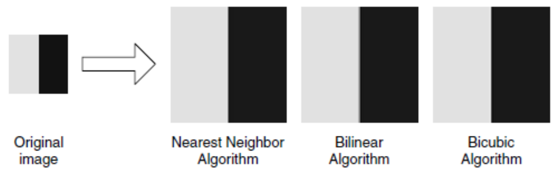

Fig 3.1 (*a*) Scaled images

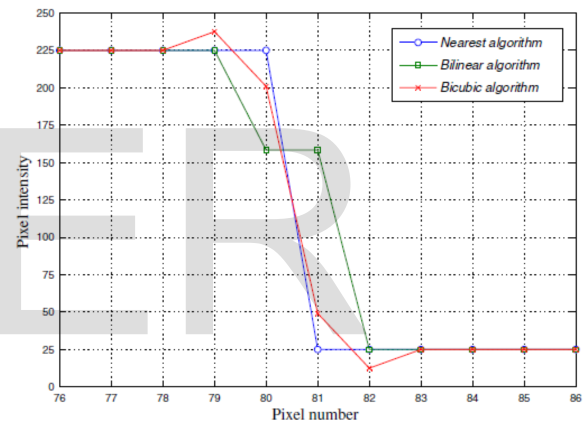

Fig 3.1 (*b*) Performance Diagram.

4. Spline based Interpolation:

B-spline based interpolation methods produce more clear and less jagged images after magnification with minimal loss in the image detail.

Munetoshi Numada, Takashi Nomura, Kazuhide Kamiya, Hiroyasu Koshimizu and Hatsuzo Tashiro [8] demonstrated in their paper that one of the causes of the decreased sharpness of the reconstructed image by Computed Tomography (CT), is associated with the linear interpolation during the back projection process and replaced the linear interpolation by cubic interpolation using the B-Spline. They achieved the reduction of unsharpness to 1/2 that of the conventional method and the reduction of processing time to a level equivalent to that of the conventional method in their experiment.

Natale, Desoli, Giusto and Vernazza [9] in their paper presented an algorithm which uses a least-squares approach by means of a spline-like scheme. This approach guarantees reduction in the tile effect, lower computational complexity and robustness against noise when compared to standard interpolation algorithms. By comparing the results obtained by the Least-Squares Bilinear Interpolation (LSBI) with those yielded by other interpolations that do not take into account the pixel values inside blocks, they noticed that the LSBI scheme achieves a marked increase in the visual quality of the reconstruction, in both ***SNR*** and subjective terms. The edges were better defined.

Meijering [10] compared different interpolation methods and concluded that the Spline interpolation constitutes the best trade-off between accuracy and computational cost. Therefore it is preferred over all other methods in Medical imaging.

Seong Won Lee and Joon Ki Paik [11] proposed an adaptive zero order interpolation and adaptive four directional moving average interpolation algorithm in their paper. It was an adaptive version of a B-Spline interpolation algorithm. Adaptivity was used in two different phases; (i) adaptive zero order interpolation was realized by considering directional edge information and (ii) adaptive length of moving average filter in four directions was obtained by computing the local image statistics. Simplicity both in computation and implementation and better interpolated images was its major advantage over conventional algorithms.

Nebot, Albiol and Bachiller [12] suggested a modification in the traditional B-Spline interpolation method for improved sharpness of the resulting images with a small additional computational cost based on the combination of conventional interpolation with an enhancement algorithm. The enhancement algorithm was based on a non linear partial differential equation and takes advantage of properties of B-Spline Functions. The increase in the sharpness of the B-Spline interpolated sequence is based on the PDE

$$\partial f(x,t)/\partial t = -\left|\partial f(x,t)/\partial x\right| F(\partial^2 f(x,t)/\partial x^2)$$

where F(.) is a function such that $xF(x) \geq 0$ [12].

Conclusion:

This paper focuses on the various methods for image interpolation. From the above analysis, the following conclusions have been drawn:

1). The image interpolated by nearest-neighbor method exhibits jaggedness while linear interpolation causes the image to be blurred.
2). B-spline interpolations are considered as a solution due to many attractive properties such as compact support, sufficient regularity, smooth behavior and easy implementation.
3). By replacing linear interpolation with cubic interpolation using the B-spline and by calculating the control points of B-spline by Fourier transform, both the reduction of noise and decrease of unsharpness are achieved and processing time required to calculate the control points of the B-spline is negligible.
4). The enhancement algorithm using non-linear partial differential equation and properties of B-Splines, improves the sharpness of the resulting image with small additional computational cost.
5). Least-squares approach by means of a spline-like scheme reduces tile effect, lowers computational complexity and provides robustness against noise.

Future Work:

The results of implementation of various interpolation schemes depict that a lot of advancement need to be done to get highly refined images after scaling. A spline based method needs to be implemented which results in decreased jaggedness and less computational time and cost and is easy to understand.

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