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RESEARCH ARTICLE

Linear Interpolation Algorithms and their Architectures for Image Scaling – A Survey

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ABSTRACT

Image interpolation is the process of increasing the number of pixels in an image such that the image is enlarged. Interpolation is commonly called as image upscaling, image zooming or image magnification. Linear Interpolation (LI) is fast, cost effective and has low power consumption. It also provides a better image quality. It requires only two pixels to calculate the interpolated pixel value. Applications of LI include computer graphics, medical imaging, remote sensing and multimedia applications (e.g. video teleconferencing). In this survey, various types of LI algorithms and their hardware architectures are analyzed and compared. These algorithms are implemented for different Very Large Scale Integrated Circuit (VLSI) based implementations such as Field Programmable Gate Array (FPGA) and Complementary Metal Oxide Semiconductor (CMOS) technologies. These interpolation algorithms are compared with respect to various parameters like Peak Signal to Noise Ratio (PSNR) and gate count. Based on the evaluation, it is observed that Adder Based Stepwise linear Interpolation (ABSI) method provides better image quality with reduced chip area.

Keywords: Scaling, Linear interpolation, Pixel, Peak signal to noise ratio, Gate count.

1. INTRODUCTION

In interpolation method, the values of a function are determined at positions lying between its samples. Image interpolation is a widely used technique in image processing. The lost signal during sampling can be reconstructed by means of smoothing the data samples using an interpolation function. Quality and complexity vary with different interpolation methods. Interpolation refers to the increase in digital image size. It is also known as upscaling or resolution enhancement. There is no image distortion or complex computation required in a superior interpolation process [1]. The image interpolation algorithm can be adaptive or non-adaptive interpolation [2]. Adaptive methods vary based on the things that they are interpolating (sharp edges vs. smooth texture). They process a dissimilar version of algorithm based on pixel-by-pixel means when an edge is detected. Adaptive techniques consider image features like intensity value, edge information, texture etc. Adaptive interpolation algorithms need more hardware resources which are very expensive [3]. The computational logic of adaptive image interpolation methods depends on the intrinsic image characteristics and concepts. On the contrary, non-adaptive methods treat all the pixels equally. The computational logic of them is constant, however the image characteristics are.

Linear interpolation is a curve fitting technique that uses linear polynomial to develop new data points in the discrete set range of known data points. It is a non-

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adaptive method and it has less complexity when compared with adaptive method. Moreover the quality of image is also improved. An Extended Linear Interpolation (ELI) model provides better image quality and it requires four adders to generate weighting coefficients [4]. Iterative Linear Interpolation (ILI) has better accuracy than cubic spline interpolation, and it also has a better PSNR accuracy with less area [5]. The third Linear Convolution Interpolation (LCI) requires less number of adders and subtractors than the bi-cubic algorithm. It requires reduced chip area and better image quality [6]. LI based on even-odd decomposition generates image with less blurring and jagged edges. The computational cost can be reduced with better visual quality. During the past decade, both FPGA and Application Specific Integrated Circuit (ASIC) technologies were used to develop image interpolators. FPGAs are reconfigurable whereas ASICs are not reconfigurable. FPGAs are used to analyze various VLSI design characteristics such as area, velocity and power of image interpolation circuits.

The remaining part of this paper is structured as follows. Section 2 briefs the different types of LI techniques. Section 3 gives comparative analysis and section 4 concludes with research scopes of LI.

2. DIFFERENT TYPES OF LINEAR INTERPOLATION

This chapter makes an elaborate survey of the characteristics of various image interpolation schemes implemented using linear, bilinear and Piecewise Linear Interpolation (PLI).

2.1. Image scaling using LI

LI is a first order interpolation with low complexity as it requires only two pixels to calculate the interpolated pixel value. [1] has proposed a third order LCI for third order LI. 16 pixels are considered to calculate the interpolated pixel. The architecture has high performance than others and it is implemented on Taiwan Semiconductor Manufacturing Company (TSMC) 0.13μm for real time requirement. It consumes 26303 gate counts in a 447×447μm² chip area. The PSNR value is 39.63dB which is higher than bi-cubic convolution algorithm (31.29dB). The performance of the hardware architecture of third order linear convolution is more efficient than the bi-cubic method [7].

[4] has proposed an ELI model. The interpolation quality is compatible to bi-cubic convolution with high speed architecture. The interpolated pixel and the source image have a different co-ordinate system. It provides a better image quality and it requires 4 adders to generate weighting coefficient. It is implemented by using virtex II FPGA and TSMC 0.13μm. It has an average PSNR value of 35.29dB. The gate count is 25980 with a chip area 450×450μm². ELI is a first order polynomial interpolation with low computation complexity because it decomposes the bi-cubic method as two 1 dimension [7]. ILI method [5] has better accuracy than cubic spline interpolation. On comparison with quadratic and cubic spline method, ILI has a better PSNR accuracy. It consumes less area for an accurate pixel rate. The gradient of the target point can be estimated by using the fuzzy gradient model. The PSNR of 2-D ILI and bi-cubic method are closer. The average value of PSNR is 47.03dB. By using TSMC 0.18μm technology, it requires only 7256 gates. For VLSI implementation, ILI performs better than low cost method [3].

[8] has presented a Linear Interpolation Revitalized (LIR) method. Quality of PLI can be improved by this method. The quality of LI can be further improved by determining the optimal shift. The shifted linear method provides a sharper result than the other methods like cubic interpolations. The theoretical tools used would determine the quality of shifted LI [9]. LI scheme for bi-level image [10] interpolates the scanned signal between the sample intervals. It is based on resampling polynomial function. The performance is found out by assessing their accuracy with the original image. The first-order polynomial image interpolation produces better result than nearest neighbor image interpolation technique.

[11] has implemented linear and cubic interpolation to detect the occurrence of interpolation in an image. This method is applicable to both integer and non-integer factors. The algorithm determines the image produced with low order interpolation. It also determines the fraction of interpolation by detecting the pattern in pixel difference. The overall result of interpolation detection

algorithm lowers when the interpolator order is increased. For an interpolation by two-factor, the phase is preserved. In image processing, linear low pass filters are generally used [12].

Reconstruction of transform coefficients can be done through LI using coefficients from adjacent blocks. [13] LI uses correct block to reconstruct the lost block. To reconstruct the adjacent blocks, algorithms are applied to the affected region. A codebook of size 32 generates reconstructed image that are indistinguishable from the image reconstructed using non-quantized weight. For 512×512 image size, an extra 2560 bytes are transmitted with compressed image and it has an average PSNR of 32.1dB. This method produces a higher quality reconstructed image as it is an extended technique. [14] has implemented LI of biomedical images using adaptive kernel. In this method of interpolation, a continuous domain stochastic model is applied to image data to quantify some statistical properties. The autocorrelation function provides the optimal Minimum Mean Square Error (MMSE) linear estimator for unknown pixel values. For computational efficiency, the symmetric exponential B spline is used. This method has 0.5dB improvement over a polynomial B spline method. [15] has proposed LI of CMOS sensor image data. CMOS is a type of camera sensors that can be used for camera construction. LI for sub pixel object estimation is based on a model of image sensor pixels. Interpolation estimates the shape of object edges by mathematical functions. Within the pixel area, the output signal value linearly increases due to the increase of illuminated pixel area. The resolution of image sensor is 1280×1024 pixels with the pixel size of 5.2×5.2µm. Comparing to CMOS, Charge Coupled Device (CCD) has a drawback that, it requires an external additional electronics.

[16] has proposed a linear image interpolation. By calculating the distance among the image pixels, the space invariant is changed to space variant method. The computational cost is less compared to other nonlinear interpolation operators. Step edges are rare in real images. The interpolation is used to bring back the original image size, and the Mean Square Error (MSE) is evaluated with respect to original data. If the factor is irrational, the coefficient changes at each step. ABSI is proposed [17] to reduce area consumption. LI is frequently used in the reconstruction of signals. Instead of using multiplier and divider, simple operators such as adder and shifter are used that consume less area and power. It achieves a maximum PSNR value of 32.15dB. It is implemented on TSMC 0.18µm and it requires a total area of 552.18µm.

2.2. Algorithms based on bilinear interpolation

Bilinear interpolation defines the intensity from the weighted average of the four closest pixels to the specified input coordinates, and then assigns this value to the output coordinates. Initially, it executes LI in a direction, and then changes to the other direction [18].

[19] has presented a shape context with bilinear interpolation. Shape context is mentioned to measure the similarity between shapes, mainly in object recognition. Noise affects the similarity in shapes and so bilinear interpolation can be used. It can be used to obtain smooth images. The set of sampled points represents the shapes to determine the similarity. Modified Bilinear Interpolation (MBI) is presented [20] based on bandelet transform. Bilinear interpolation is based on image zoom method and as a result, the information would retain in original image. By using bandelet transform, the quantitative measures such as PSNR and resolution can be improved. Bandelet transform is used to overcome the artifacts of wavelet transform. PSNR of bilinear interpolation is 65.0075dB whereas, the bilinear interpolation based on bandelet transform provides PSNR value of 89.2690dB.

Bilinear interpolation over fuzzified images is used in the original pixels [21] to enlarge an image. The enlarged image may contain blurriness. So the sharpening filters may be used to modify the edge features. Gradient operators are mainly involved in detecting the edges of images. Computation time of bilinear interpolation is 413ms. Interpolation with sharpening process provides better image quality. It also includes image rotation and image reconstruction.

[22] has proposed bilinear interpolation for image fast processing. To improve the calculation, speed graphic processing unit is used along with bilinear interpolation which also improves the image resolution. Wallis transforming is used in

bilinear interpolation blocks. After transformation, the image quality is improved. The processing time of a 512×512 image size is 1.48ms. [23] has presented a novel approach to real time bilinear interpolation. By digital zooming, the quality of the image is improved. A unique caching system has been used to retrieve the pixel values. The remaining pixels can be obtained from the frame buffer memory. By implementing in FPGA, it requires 329 (28%) number of Configurable Logic Blocks (CLB). The distorted image may be due to overlapping of pixel values or undefined pixels. [2] has proposed an adaptive edge enhanced image scalar. The method makes use of edge detector, sharpening filter and bilinear interpolation. The neighboring pixels calculate the characteristics of the interpolated pixel. Bilinear interpolation makes the image smooth; but some edge information is lost. The sharpening filter is used to avoid the loss of edge features. It is implemented on TSMC 0.13µm and it requires a total gate count of 6.67k. It provides a better PSNR value of 42.08dB and the power consumed is 6.9mw at 280MHZ frequency. [24] has presented a low cost high quality image scaling processor. The sharpening and clamp filters are used to overcome blurring. and aliasing artifacts are produced by bilinear interpolation. It has the character of low complexity with high quality. Filters are used to enhance the edge features in an image. It is implemented on TSMC 0.13µm and it requires a total gate count of 6.08k. It provides an average PSNR value of 28.80dB. It consumes 4.68mw power at 280MHZ frequency.

2.3. PLI based image scaling algorithm

PLI requires 16 pixels around an interpolated point of a source image. It has low operation complexity, which lessens the coefficient generation effort and machinery cost. [25] has implemented linearizing thermistor characteristics by PLI. With the help of straight line equations, the unknown points can be determined by interpolating the known data points. The known data points may be separated from the subsequent one. The linearizing thermistor is implemented in real time FPGA. The accuracy of the linearization increases with respect to the increase in data points. Thus FPGA device uses 310 input Look Up Tables (LUTs).

The piecewise weighted LI [26] is based on even-odd decomposition. Even-odd decomposition is an image interpolation method. The input signal is decomposed into even and odd vectors. For each vector, different interpolation methods are used. Comparison is done with cubic convolution in terms of complexity. This method improves the image quality with less complexity. The weighted LI method has an average PSNR value of 38.47dB whereas the cubic convolution has 38.25dB as PSNR value. Linear, bilinear and cubic convolution interpolation is more popular because of less complexity.

[27] has proposed an adaptive LI algorithm using pattern weight. Adaptive linear algorithm considers the patterns near the interpolated value to increase the quality of the interpolated image. Bilinear and bi-cubic interpolations do not consider regional features into account. In adaptive LI, the pixels are sub-sampled and then interpolated to original image size. The method has an average PSNR of 28.30dB. It has 0.5dB which is more than bi-cubic method [3]. LI with edge preserving adaptive weights is based on pixel gray scale modeling [28]. Image interpolation problems such as edge blurring and inaccuracy may be solved using this method. Maximal Eigen value and gray scale value may be used to determine the edges. Euclidean distance and the edge strength between the pixels determine the adaptive weight. Smooth pixels correspond to larger weight. For LI the edge pixels have to be changed. PSNR is used to measure the interpolation performance. This method has an average PSNR value of 28.89dB. Bilinear and bi-cubic interpolation performance can be improved by local gradient information.

3. COMPARATIVE ANALYSIS

The performance of the scaling algorithm is evaluated by using both quantitative measure of quality and performance measure like area and speed. Quality measure specifies the accuracy of the algorithm based on metrics such as MSE and PSNR. Performance measure specifies the computational complexity of image interpolation algorithms. Quality measure is the figure of merit used for the evaluation of image processing technique [29]. Table 1 illustrates the PSNR comparison of TSMC based image interpolation such as LCI, ELI, ILI, adaptive edge-enhanced and ABSI.

Table 1.Comparison of TSMC-based algorithm

Method	PSNR (dB)	Technology	No. of gates
LCI [1]	39.63	TSMC 0.13µm	26303
ELI [4]	35.29	TSMC 0.13µm	25980
ILI [5]	47.03	TSMC 0.18µm	7256
Adaptive edge-enhanced image [2]	42.08	TSMC 0.13µm	7256
Image scaling [20]	28.80	TSMC 0.13µm	6.08k
ABSI [14]	32.15	TSMC 0.18µm	552.18

From table 1, it is observed that ILI produces higher PSNR as 47.03dB. ILI reaches accuracy that is compared with bilinear interpolation. The complexity associated with ILI is even lower [5]. ILI is implemented with TSMC 0.13µm CMOS standard cell library and consumes 7256 gates. Table 2 gives the comparison of PSNR of different software based image interpolation algorithms such as Bandlet transform based image interpolation, image reconstruction, interpolation using adaptive weight, interpolation using pattern weight and interpolation using linearizing thermistor.

Based on table 2, Bandelet transform method of bilinear interpolation has the largest PSNR value of 89.269dB. The Bandelet transform reduces the effect of jagged edges, and improves the visual effect [30]. Bandelet transform is more complex and computationally intensive.

Table 2.Comparison of software-based algorithm

Method	PSNR (dB)
Bandelet transform method [16]	89.269
Image reconstruction [10]	32.1
Adaptive weight [24]	28.89
Pattern weight [23]	28.30
Linearising thermistor [21]	38.47

The novel approach to bilinear interpolation method is implemented using FPGA and it consumes 329 CLBs. The piecewise even odd decomposition method is implemented using FPGA and it consumes 310 LUTs. Area efficiency can be analyzed by the number of LUTs on FPGA-based interpolation methods and in terms of number of gate count consumed.

Figure 1 demonstrates the comparison of gate count on different TSMC based image interpolation algorithms such as third-order linear [1], extended linear [4], ILI [5] and ABSI [17].

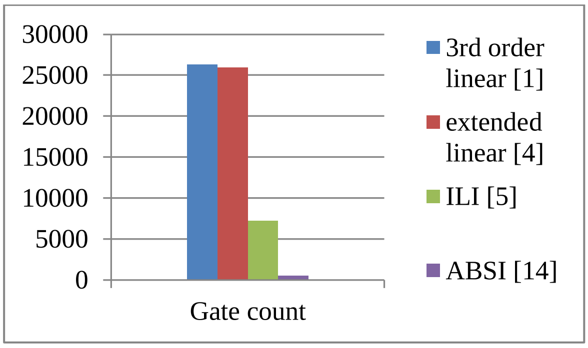

Figure 1.Comparison of gate counts of LI methods

From figure 1, it is observed that ABSI method requires only 552.18 gates and it is has very less count when compared with the other LI methods. ABSI uses simple operators such as adder and shifter and they require low power and less area consumption [31]. The ILI method provides a better image quality with PSNR value of 47.03dB [32]. The bilinear interpolation based on bandelet transforms provides a higher PSNR value of 89.26dB. Further it is observed that ABSI method provides moderate image quality with less area consumption.

4. CONCLUSION

This work explains the quantitative measures (PSNR) and VLSI characteristics of various LI methods. From the survey, it is observed that ABSI produces a required image quality with PSNR value of 32.15dB with less computational complexity. By implementing in TSMC 0.18µm ABSI method requires only 552.18 gate counts. Thus the area consumption is lesser for ABSI method than the other LI methods. The quality of image increases for increasing PSNR values. Furthermore, the PSNR of ABSI can be improved by using adaptive filter based technology. Also, the computational complexity of other interpolation techniques like ILI can be reduced by using simple arithmetic operations and by reducing the number of operations.

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