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Super Resolution with Interpolation-based Method: A Review

Noor Zaim Fariz Nor Azam
Faculty of Electronic Engineering Technology
Universiti Malaysia Perlis
Arau, Malaysia

Haniza Yazid
Faculty of Electronic Engineering Technology
Universiti Malaysia Perlis
Arau, Malaysia

Saufiah Abdul Rahim
Faculty of Electronic Engineering Technology
Universiti Malaysia Perlis
Arau, Malaysia

Abstract- Image Super Resolution (SR) is a method that was quickly developed and updated nowadays. Image SR can be done different methods such as interpolation-based methods, reconstruction-based methods, and example learning-based methods. Interpolation-based methods in SR is also a great topic of interest in many researchers throughout the world since it can be easily derived from previous work to accommodate any desired outcomes and relatively low computational costs compared to other methods. In this paper, we reviewed 17 different literatures on the developments and the updates of the interpolation-based methods in SR. The reviewed literatures are from journal articles such IEEE Transactions, IEEE Access and conference proceedings such as IEEE INMIC. The performance of these reviewed methods were mostly evaluated by measuring the output HR image quality such as Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index Method (SSIM) values and also the computational costs of the proposed methods such as the run time. Even though many interpolation-based SR methods were proposed throughout the years, there is still the need to further develop this method since there are some improvements can be made in order to produce a good HR image from a LR image such as the edges structure, issues with artifacts, and textural quality of the image.

Keywords – Super Resolution, Image Interpolation, Interpolation Method.

I. Introduction

Super Resolution (SR) is a process to obtain one or more high-resolution images from one or more low resolution observations. The basic idea behind SR is to com-bine the non-redundant information contained in multiple low-resolution frames to produce a high-resolution image. This topic has been discussed in several practical applications such as satellite and aerial imaging [1], [2] medical image processing [3]–[5] facial image analysis, text image analysis[6], [7] sign and number plates reading, and biometrics recognition [8], [9]. Single image SR (SISR) methods are more applicable to achieve this objective such as by using interpolation-based methods, reconstruction-based methods, and example learning-based methods [10]. The example learning-based method is currently a hot topic in SR, but, the algorithm’s performance depends on the reliability of the external database [11].

An image interpolation algorithm is used to convert an image from one resolution (dimension) to another without losing visual detail. There are two types of image interpolation algorithms: non-adaptive and adaptive [12]. An adaptive picture interpolation technique's computational logic is determined by the intrinsic image characteristics and contents of the input image, whereas a non-adaptive image interpolation technique's computational logic is fixed regardless of the input image features. Interpolation-based method usually intuitive and computationally efficient.

In this paper, we discuss the literature and research that were done on image interpolation for SR. The reviewed literatures and research were from journals and conferences.

II. INTERPOLATION METHODS IN IMAGE SUPER RESOLUTION

First In the mathematical field interpolation is one of the methods in estimating new data points based on any given discrete data points [13]. In image processing, interpolation can be used as a method in SR. It estimates the new pixels' intensity values based on the LR image input, where the original LR pixels' intensity value would be the discrete data points. There are several well-known interpolation based methods such as nearest neighbour, bicubic interpolation, bilinear interpolation, basic-splines (B-spline), Lanczos interpolation, Discrete Wavelet Transforms (DWT) and Krigin method [14].

But throughout the years, many new interpolation-based methods in SR have been developed by other researchers furthering the development in the field of image processing. This chapter will discuss the literature on interpolation-based methods in SR presented by researchers throughout the years. Figure 1 shows different types of methods under interpolation-based method.

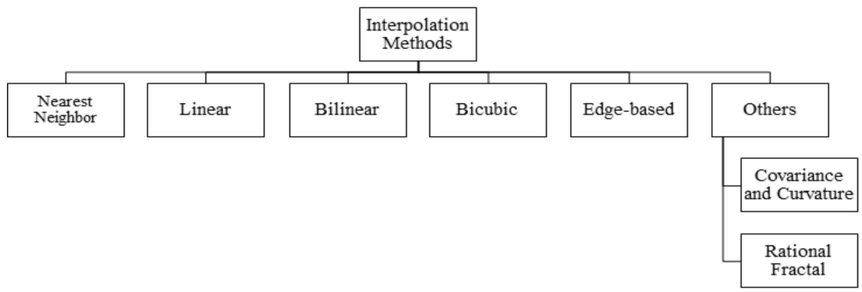

Figure 1. Different types of interpolation methods

2.1. Nearest Neighbour Methods–

In [15], the author presents a method in producing a HR image by using nearest neighbour interpolation method by calculating the estimation of a new pixel value using the nearest pixel. It is stated by the author that apart from conventional nearest neighbour interpolation methods, this research proposed a new method that the estimation of the new pixel value is guided by the nearest pixel value rather than its distance. The author experimented with two interpolation ratios which are 4 and 2. The experiment compared the author's proposed method with other conventional interpolation-based methods (conventional nearest neighbour, bilinear and bicubic methods) and evaluate their performances. The evaluation methods that was done in [15] were Matlab-lines Execution Time (MET) and Peak Signal to Noise Ratio (PSNR). The proposed method has better PSNR values for each experiment compared to the conventional methods but required longer time as stated in the MET values. In conclusion, the proposed method yielded good results as the conventional nearest neighbour interpolation method produce edge jaggedness while this proposed method resolves this issue. Also, when compared to conventional bicubic interpolation, this proposed method shows more image details in image SR.

Nearest neighbour interpolation method was further developed in [16]. In this research, the author used the proposed methods to rescale or resize an image which has the same aspect to SR. Instead of using direct nearest neighbour interpolation to interpolate the LR images, the author used nearest neighbour emulation via logical transform. The proposed methods measure the blocks of pixel data of both input LR images and output HR images and the sum of primary implicants representation of the blocks of data were then derived via logical transform. This research further pro-posed two other methods than the nearest neighbour emulation, also using the same idea which is via logical transform. The results of the proposed nearest neighbour emulation were not presented by the author as the results would be the same as the conventional nearest neighbour interpolation while in the case of interpolation via logical transform, the produced HR image was sharper compared to other conventional interpolation methods. This is important as it paved the way of new interpretation of the conventional ideas. It can be derived, developed, and be 'played with' to achieve any desired outcomes.

The nearest neighbour interpolation method was further developed in [17]. In [17], the author used interpolation to create a super resolved image by using multisurface fitting. A surface is fitted at every LR pixel. The surfaces were constructed using 2-D Taylor series. The purpose of these surfaces are to retain image details such as gradients, curvatures or even higher order dimension. Then, the author estimated the HR pixel value by fusing the multisampling values on these surfaces in the maximum a posteriori fashion. This form of nearest-neighbour method is a new method cultivated by the author by using the idea of the nearest-neighbour method. The main advantage of this method is that it could preserve the image details and structure well than a conventional interpolation method. The author experimented the method by implementing two experiments: simulations and example with real data, and compared them to previous research. The author evaluated the experiments' results by using Mean Square Error (MSE) and Visual Information Fidelity (VIF) for the simulations and Blind Image Quality Index (BIQI) for the example with real data. The author also computed the run time of each method and compared them.

Table -1 Comparison of Nearest Neighbour Interpolation Methods.

Paper	Proposed Method	Year	Evaluation Methods Used
[15]	Estimating the new pixel value is guided by the nearest pixel value rather than its distance.	2012	MET and PSNR
[16]	Used nearest neighbour emulation via logical transform.	2007	MSE
[17]	Using multisurface fitting	2012	MSE, VIF, BIQI, and run time

Table 1 shows the summary comparison of the nearest neighbor interpolation methods throughout the years.

2.2. Linear Interpolation Methods –

In [18], the author used linear interpolation to create a HR image. Despite using linear interpolation directly to the low resolution image, the author used linear interpolation to obtain the relationship between the detail coefficients in the Haar's wavelet sub bands and the set of low resolution images. Using this, the author can approximate the HR images wavelet sub bands by the LR images also using linear interpolation method. Then, the HR image was reconstructed by inverse wavelet transform. In this research too, the author proposed an error correction method to further improve the reconstructed image. These methods are robust to the boundary conditions, hence can work with a wide class of images. These methods also direct, easy to implement and fast but, the author noted that there are also some improvements that could be done. The author noted that the error correction scheme should be iterated more and developing a de-noising technique which should fit better to these methods, especially in more noisy images. Lastly, the author noted the Haar Wavelet may not be optimal and the in order to choose the main wavelet, the choice should be image dependent to yield better results.

2.3. Bilinear Interpolation Methods –

In [19], the author presents a traditional four-point bilinear interpolation method to be compared to a new developed scheme which is the three-point bilinear interpolation method to interpolate a digital image. The author presents the common problem in four-point bilinear interpolation method which is the "checkerboard" effects, especially in an unfavourable circumstances. This problem was overcame by using the newly proposed scheme by the author. The experiment shows that the "checker-board" texture effects were reduced significantly when implementing the new bilinear interpolation scheme which is the three-point bilinear interpolation. Even though the three-point bilinear interpolation scheme is simpler to compute, it is slower to process because the decision has to be made. The said decision is as to which three points are to be used as a basis for the interpolation. It is about 4% more costly run in terms of CPU time and to the author's credit, sufficiently cheap to be a better alternative to the four-point bilinear interpolation scheme. This research provides the groundwork of bilinear interpolation of images, hence the works in image SR.

Further works in bilinear interpolation method has been proposed throughout the years, especially in image SR. In [20], the author used bilinear interpolation method to super-resolved an image. The bilinear interpolation method was used to interpolate the smooth area of a LR image and the proposed Edge-Adaptive Interpolation Algorithm (EAIA) was used to interpolate the edge areas in a LR image. The edge areas could be determined by detecting the discontinuity and the sharp changes of the grey values between the edges and the smooth areas. This research proposed a new method of SISR that used bilinear interpolation but yielded a better result than the conventional bilinear interpolation method where the proposed method is edge-adaptive, decrease jaggy-noise and edge blur, strengthen visual effect. Although, there are also more work needed to be done especially with the noise and false edge issues.

Lastly, in [21], the author proposed a new bilinear interpolation method to super-resolve both synthetic and real image sequences. This research aims to provide new methods of a real-time image SR to be implemented into a Field Programmable Gate Array (FPGA) device.

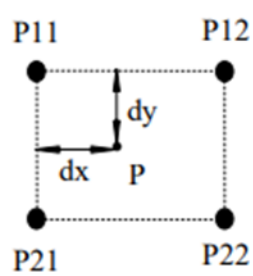

Figure 2. The 4 neighbourhood of a point 'P' in a 2-D image space [21]

$$P = P11(1-dy)(1-dx) + P12(1-dy)dx + P21(1-dx) + P22dxdy \quad (1)$$

Based on the arrangement in Figure 2, the ultimate value of the interpolated pixel value would calculated using the bilinear interpolation method as shown in Eq (1). The bilinear interpolation scheme was then implemented into the proposed method's algorithm to super-resolve an image. The research experimented the proposed bilinear interpolation method on four LR images. The performance in image SR of the proposed bilinear interpolation method was evaluated by measuring the PSNR and Structural Similarity Index (SSIM). The proposed bilinear interpolation method per-formed quite well based on the evaluation in terms of the research objective which is to implement the algorithm into a FPGA device.

Table -2 Comparison of Bilinear Interpolation Methods.

Paper	Proposed Method	Year	Evaluation Methods Used
[19]	Three-point bilinear interpolation	1981	Computational costs
[20]	Edge-Adaptive Interpolation Algorithm (EAIA)	2010	Not mentioned
[21]	Using the neighbourhood of 4 points.	2020	PSNR and SSIM

Table 2 shows the summary comparison of the bilinear interpolation methods throughout the years.

2.4. Bicibic Interpolation Methods –

In [22], the author proposed a bicubic interpolation method for a real-time digital image scaling. This research proposed a Hardware Architecture for Bicubic Interpolation (HABI) where the architecture can work with monochromatic images. A 4x4 pixel mask was applied to the image and every new pixel was calculated using bicubic interpolation method with the use of the center point and horizontal and vertical coefficients. The bicubic interpolation method was then implemented into the architecture and can be used in any FPGA devices for a real-time digital image scaling. The experiment on the proposed method was done on Xilinx Virtex II Pro FPGA and its performance was then evaluated. This research evaluated the performance of the proposed method based on its processing time and computational costs. No image quality evaluation was done.

In [23], the author proposed a method on which to solve the common problem in bicubic interpolation which is blurry or smooth edges. The proposed method intended to preserve the edges structures of a super resolved image. The edges of the LR image needed to be detected first. The method will first compute two orthogonal directional gradients using the known pixels in the HR image neighbourhood. Then, the edge direction was estimated using the ratio of the two orthogonal directional gradients. In this step, the author can separate between strong and weak edges. For a strong edge, the missing pixel is estimated using the bicubic convolution interpolation along the detected edge direction, otherwise adaptively combining the two orthogonal directional bicubic convolution interpolation results. The experiments on this research are super-resolving four LR images by a factor of four. The performance of the pro-posed method was then evaluated and compared with other research on SR using conventional bicubic convolution interpolation methods. The proposed method shows the highest PSNR values for each experiment than the other conventional bicubic convolution interpolation methods.

Lastly, an overlapping bicubic interpolation method for SISR was proposed in [24]. This method was proposed to tackle the common issue with bicubic interpolation methods by previous research which is the blur at the edges and the corners of the reconstructed images. SR via sparse representation from previous research also was mentioned in this literature as a way to solve this issue but this method takes more time to process. Hence, in this research, the author proposed a method to overcome this issues as well as to implement this method into a hardware system. This method successfully super-resolved a set of LR images by a factor of two and the performance of this method was evaluated by measuring its PSNR, SSIM and computational time. These evaluations were than compared with previous research that use a conventional bicubic interpolation method and sparse representation. It was concluded that this proposed method performs very well in the comparisons and can be use in real-time application for many small camera systems with limited processing capabilities as the proposed algorithm is simple yet efficient.

Table -3 Comparison of Bicubic Interpolation Methods.

Paper	Proposed Method	Year	Evaluation Methods Used
[22]	Hardware Architecture for Bicubic Interpolation (HABI)	2005	Processing time and computational costs
[23]	Edge-directed bicubic interpolation algorithm	2010	PSNR
[24]	Overlapping bicubic interpolation method	2017	PSNR, SSIM and computational time

Table 3 shows the summary comparison of the bicubic interpolation methods throughout the years.

2.5. Edge-based Interpolation Methods –

Edge-based methods were proposed to solve the common issues in image interpolations and SR. which is the blurring effect or the zigzagging effect of the edges and the corners of the reconstructed images especially in bilinear and bicubic interpolation methods. Researchers through the years come up with edge-based methods to solve these issues and create a better result in terms of image quality in SR.

In [25] for example, the author proposed an updated edge-based method for SR. It was proposed to produce a fast edge-oriented algorithm for SR. The main concept of this proposed method can be part into two parts. The first part is to detect the homogenous areas or the non-edge areas of the LR image and interpolate it using bilinear interpolation for a fast computational time with good image quality result. The second part is to interpolate separately of the previously non-interpolated areas as they are the edge areas. The interpolation of the edges were done by measuring the minimum differences of the neighbouring pixels of four directions and interpolate the pixel values in the direction of which direction that has the minimum differences in value. This research experimented with this proposed method by super-resolving a set of both grey level images and colour images and also compared them with other previously proposed methods by other researchers. This research experiments by up-sampling these sets of images from 128x128 pixels to 512x512 pixels and also from 256x256 pixels to 512x512 pixels. In conclusion, the proposed method performs very well compared to the other previous research in terms of average PSNR values and computational time and can be implemented for a real-time use.

A further work in edge-based was proposed in [26]. According the author, a problem posed in previous research on edge-based is that if the estimated edge direction is wrong in the previous edge-based research, it could pose a severe effect to the image quality. This could very well happen, according to the author in [26], if there is insufficient data provided by the LR image and could lead to the difficulty in determining the edge direction. The author proposed a method to solve this problem by making a partition in the neighbourhood of each would-be-interpolated pixel into two oriented subsets in orthogonal directions. An estimate of the missing pixel in the HR image would be yielded by each of the oriented subset. More interestingly, this research make the use of the Linear Minimum Mean Square-Error estimation (LMMSE) principle in order to combine the two directional estimates and make the final interpolation of said missing pixel. This research operates on the assumption of that a LR image is a directly down-sampled from an associated HR image. The LMMSE-based interpolation in this research was presented with two types of interpolation used which are the bicubic convolution interpolator and linear convolution interpolator. The proposed poses a big drawback which is that it is highly costly to process. Hence, this research provided a simplified version of the LMMSE-based interpolation which apply the optimal weighing technique. This simplified version was also presented with two types of interpolation used which are the bicubic convolution interpolator and linear convolution interpolator. This research experiments the proposed methods with six image samples and compared them with other previous research which included the conventional bicubic and bilinear interpolation. The performance of these experiments were then evaluated by measuring the PSNR values. The LMMSE-based interpolation yielded better results in image SR than other methods while the simplified version of the LMMSE-based interpolation reduces the computational costs of the proposed method.

The edge-based method was further developed in [27] by using adaptive gradient magnitude self-interpolation. In this research, a sharp HR gradient field was first estimated by an adaptive self-interpolation algorithm. Within the self-interpolation algorithm, the calculation of the displacement field was done from the gradient magnitude of the bicubic up-sampled image. This displacement field was also being used to interpolate the bicubic up-sampled image as an initialization. The estimated HR gradient was used as a gradient constraint or a constraint to preserve the edges to recover the HR image. The motivation behind adding the edge-constraint is that, in traditional reconstruction-based methods, its algorithms often bring undesired artifacts in HR image, especially along salient edges. The proposed method was then experimented on several colour images by super-resolving those images by factors of two, three and four. The results were then compared with other edge-based methods by previous research. The performance of these experiments were measured by measuring its root mean square (RMS), ERMS and SSIM values. Based on the evaluation, the proposed methods performed better than other methods especially previously proposed edge-based methods. The drawback of this method is the computing time which takes longer than several other methods that were compared to.

Finally, in a recent work in [28] proposed a new edge-based interpolation method to reduce the computational cost of the process against the previous state-of-the-art edge-based methods and also resolving the issues with artifacts and blurring of the edges of the low complexity of other conventional interpolation methods. The proposed method used Extended Edge Slope Tracing (EEST). EEST was used to predict the present slope change by using the adjacent slope information. Slope-based interpolation was then used to interpolate the image by using the slope value obtain by the EEST. This technique is proposed to provide a simple, yet efficient interpolation technique to reduce the computational cost of the proposed algorithm since the un-desired artifacts at the edges are still needed to be removed later on. To resolve the issues with undesired artifacts, two correction techniques were applied at the end of the algorithm which are: two-way interpolation and thin edge correction. The pro-posed method was then experimented with several greyscale images that were up scaled by the factors of two and four and also several colour images that were up scaled by the factor of two. These experiments were than compared to one conventional interpolation method and several state-of-the-art edge-based methods. According to the PSNR values, the proposed method performs quite well with most of the experiments yielded the best SR image quality compared to the other methods while the computational time is very low and comparable to a low-complexity interpolation method such as a traditional or conventional interpolation method. These evaluations meant that the proposed method yielded high quality of HR images comparable to the state-of-the-art edge-based methods but has low computational cost which could further the development in SR technology.

Table -4 Comparison of Edge-based Interpolation Methods.

Paper	Proposed Method	Year	Evaluation Methods Used
[25]	A fast edge-oriented algorithm	2005	PSNR and computational time
[26]	An edge-guided image interpolation algorithm via directional filtering and data fusion	2006	PSNR
[27]	Edge-directed single-image super-resolution via adaptive gradient magnitude self-interpolation	2013	RMS, ERMS, and SSIM
[28]	Efficient edge-based image interpolation method using neighboring slope information	2019	PSNR and computational time

Table 4 shows the summary comparison of the edge-based interpolation methods throughout the years.

2.6. Other Methods –

1) *Covariance and Curvature based Method*

In [29], a fast, hybrid interpolation method was proposed in which it make the use of covariance and curvature based interpolations. These two interpolation methods will be used to interpolate the edges and the smooth areas. The algorithm of this proposed method will switch in order to interpolate appropriately whether the edges or the smooth areas. First, the algorithm needs to differentiate between the edges and the smooth areas. The algorithm will carefully analyse the neighbouring pixels of a pixel horizontally, vertically and diagonally and then the minimum and the maximum difference of all four pixel values will be compared to a pre-defined threshold value and, subsequently, can be identified as edges or smooth areas. The covariance based interpolation will be used to interpolate the edges. The local covariance coefficients of the LR image were estimated first. These covariance coefficients will be used to determine the covariance coefficients of the HR image. Curvature based interpolation will be used to interpolate the smooth areas. Firstly, it will perform bilinear interpolation along the direction where second derivative is lower. Then, the interpolated point will be refined iteratively to follow the isophote curve. In the case of diagonals, the difference of intensity levels between diagonals at opposite direction will be determined. Bilinear interpolation will be performed where the difference is less. The proposed method experimented with a LR image and the result was then compared to another hybrid approach and other conventional interpolation methods by previous research. The evaluation of these results was done by measuring the PSNR values. The performance of this proposed method performed better in the comparison and also provided a low computational cost technique than others.

2) Rational Fractal based Methods

In [30], a new type of bivariate rational fractal interpolation model was proposed. Apart from current interpolation schemes, this model can be employed to describe image features better since this model has different forms of expression with various values of the scaling factors and shape parameters. Furthermore, this model com-bines the advantages of rational interpolation and fractal interpolation. The developed algorithm of this method will first divide the input LR image into texture and non-texture regions and then those regions will be interpolated accordingly. In the texture region, the primary focus of this research, the scaling factors will be calculated accurately using local fractal analysis since the scaling factors are crucial in preserving the texture. According to the proposed algorithm, the LR image will be divided into many 5x5 patches and then the texture for each patch will be detected using the isoline method. Every 5x5 patch image will then be interpolated into 17x17 HR image patch by using bivariate rational fractal interpolation model. In order to interpolate using bivariate rational fractal interpolation model, the scaling factor must be calculated first. It is important that the scaling factor was calculated accurately since, as previously mentioned, scaling factors are crucial in preserving the texture. Finally, a HR output image will be produced by traversing each patch in the LR image. The proposed method was experimented on a several images that were up scaled by the factors of two, three and four and was compared to other state-of-the-art interpolation methods. The evaluation of the experimental results was done by measuring the PSNR, SSIM and Feature Similarity Indexing Method (FSIM) values. According to the evaluation, the proposed method performed much better than other state-of-the-art interpolation methods and has several advantages which are; it is stable, adaptable and can control interpolation error.

Finally, a recent work on rational fractal interpolation method was done in [31]. This research also claims to tackle with the issue of poor texture retention in other SR methods. In the proposed method, the LR image was first divided into overlapping 3x3 size patches. The local fractal dimension of every patch was then calculated. Then, the patches were segmented into different categories adaptively by analysing the distribution of local fractal dimension. The rational fractal interpolation function for each region was then determined through local fractal analysis. Finally, based on the assumption that the fractal dimension is invariance in the process of up-sampling, the optimization process was done. Experiments were done using the proposed method and other state-of-the-art SR methods by super-resolving several LR images by the factors of two, three and four. These experiments were then evaluated by measuring the PSNR, SSIM, and FSIM values and on average, the performance of the proposed method is better than other state-of-the-art methods.

Table -5 Comparison of Rational Fractal Interpolation Methods.

Paper	Proposed Method	Year	Evaluation Methods Used
[30]	Single-image super-resolution based on rational fractal interpolation	2018	PSNR, SSIM and FSIM
[31]	Adaptive rational fractal interpolation function for image super-resolution via local fractal analysis	2019	PSNR, SSIM and FSIM

Table 5 shows the summary comparison of the rational fractal interpolation methods throughout the years.

III. CONCLUSION

Most of the literatures reviewed in this paper make the use of measuring the PSNR and SSIM values and also its computational costs to evaluate the performance of the proposed methods. These literatures proposed new methods in order to improve the previously proposed interpolation-based methods in image SR especially in the later works where the authors provide new ways of producing a HR image within the image interpolation and able to do so. The most promising interpolation-based method is the edge-based method since the common problem in image interpolation is the blurring and artifacts at the edges. In edge-based methods, most of the proposed methods able to distinguish between the edges and the non-edges areas in an image. By distinguishing them, the authors can then proposed the best interpolation methods for each area in order to preserve the image’s structural integrity and texture while also reducing the blurring and artifacts especially at the edges and producing a high quality HR image.

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