A Study on Adaptive Image Interpolation Algorithms for Multimedia Applications

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ABSTRACT

Image interpolation enhances the quality of images by introducing new pixels in the given image. The new pixels are created by using old pixels. Non-adaptive and adaptive interpolations are the two major categories of image interpolation which are widely used in multimedia applications. Non-adaptive image interpolation performs the same operation throughout the entire interpolation process. But the adaptive image interpolation performs differently based on the characteristics of the surrounding pixels of the interpolation point. Adaptive image interpolation performs complex operations to improve the quality of image and it provides high-quality interpolation as compared with conventional non-adaptive interpolation. This work evaluates the characteristics of different adaptive image interpolation in terms of their quantitative measures. Both peak signal to noise ratio (PSNR) and structural similarity index measure (SSIM) are considered for this evaluation. Based on the detailed review, it is identified that the adaptive image interpolation using edge-orientation outperforms other adaptive interpolation schemes. Further, it affords that the quality of interpolation can also be improved by using optimized filters and by splitting the edge-regions by higher order.

Keywords: Bi-cubic, Bilinear, Edge-based, Clamp filter, PSNR.

1. INTRODUCTION

Image interpolation is a process which is used to increase number of pixels in an image [1]. It is used when the image is changed from one pixel level to another pixel level [2]. Image interpolation works on the concept of image re-sampling. Re-sampling is a process of converting a discrete image that is represented at one set of coordinate points to a new set of coordinate points. The interpolation process is used to find the information for missed pixels or undefined pixels in a source image based on the information presented by the given pixels. For example, in the Nearest Neighbour (NN) algorithm, a new pixel is generated by using the nearest neighbouring pixel [3]. The given pixel information normally includes information related to density, coordinates colour or grey level [4]. Interpolation is usually performed by convolving an input image with a small kernel of the weighting function [5]. Different kinds of image interpolation algorithms have been developed in the past decade for different applications especially in the field of multimedia.

Interpolation is used in colour filter array (CFA) of digital still colour cameras. Generally, CFA of a single colour image is Bayer array. The Bayer array is necessary to provide red, green and blue (RGB) signals needed for the colour images based on the signals generated by those pixels utilizing a pixel interpolation technique called demosaicing [6]. The Bayer CFA is used to reduce the hardware cost by sensing only one colour component per image pixel and by avoiding the usage of three sensors. In Bayer CFA, only one measure is performed on each pixel in the captured image, and the CFA recovers the full colour image of the input image by performing the interpolation process [7].
Flat panel displays (FPDs) like liquid crystal display (LCD) is the widely used device to replace the existing cathode ray tube (CRT). The FPD panels require higher resolution. Many interpolation techniques are used to improve the resolution of digital image in FPDs [8]. Sub-pixel-based image scaling is used to avoid colour imbalance called a colour-fringing artifact on colour LCDs or organic light-emitting diode (OLED) displays. In LCDs or OLEDs, a single pixel is composed of separately addressable red, green, blue or other colour sub-pixels. By controlling the values of sub-pixels individually, the resolution of the display is improved [9].

Image transfer is a major issue in multimedia communication for modern networks. Video sequences and digital images result in high volume of image data. With high volume of data and less bandwidth of network, the quality of the images transferred through the network is poor due to the occurrence of jitters and flickers. The bandwidth of the network for image transfer is saved and image quality is increased if the low resolution image is afterward converted to high-resolution by using interpolation technology in decoder end [10].

Interpolation is widely used in digital television (TV) industry, due to the use of internet protocol TV (IPTV) system. The IPTV system is used to watch video data on internet by using a digital TV system. In this system, the image interpolation is used to adjust the video resolution to the size of display screen [11].

Image interpolation is also used in image data compression to reduce or magnify images and correct spatial distortion [12]. A nine-point Winograd Discrete Fourier Transform (WDFT) is used to implement cubic spline interpolation (CSI) for encoding and decoding of image coding [13]. Consumer depth cameras such as Microsoft Kinect sensor and Time-of Flight (TOF) cameras are used in computer vision, graphics, human computer interaction and virtual reality. The limited resolution and the quality of the depth map generated by these cameras are problematic for several applications. The single depth image interpolation using bilateral filter produces high resolution depth textures and sharp edges [14].

This paper compares the characteristics of different adaptive interpolation schemes and the remaining part of this paper is developed as follows. Section 2 gives the details of different adaptive image interpolation algorithms. Section 3 evaluates the different algorithms. Section 4 concludes and affords the future developments.

2. ADAPTIVE IMAGE INTERPOLATION TECHNIQUES

This section briefs the characteristics of different adaptive image interpolation techniques such as Edge-based, Region/Orientation of edge-based, Pre-filter-based, iteratively adaptive and image patches/local structure-based.

An-edge based image interpolation is proposed by Chen et al [10] by partitioning the input image edge area and homogeneous area. The edge pixels are interpolated by utilizing 30 neighbouring pixels and the homogeneous pixels are interpolated by using bilinear algorithm. This technique achieves a highest PSNR value as 31.16 dB for greyscale images, and it also provides a highest PSNR value as 32.32 dB by interpolating colour images for up-scaling from 256 x 256 to 512 x 512. Chen et al [10] also proposed different edge-based bilinear image interpolation techniques for real-time multimedia applications. The fist one is bilinear with pre-filters like clamp and sharpening filters and an edge detection technique [15]. This method provides a highest PSNR as 33.07 dB by scaling-up the image size from 512 x 512 to 1024 x 1024. Moses & Selvathi [16] presented an edge-based bilinear by using combined filter. The combined filter is constructed by using both clamp and sharpening filter with low complexity kernel called I model. This work provides a highest PSNR as 37.02 dB. Another adaptive method is composed by
linear space variant edge detector, sharpening filter and bilinear image interpolation algorithm [17]. This method produces a highest PSNR as 40.37 dB by up-scaling the size of image from 512 x 512 to 1024 x 1024 and it also produces the best SSIM as 0.9955. By comparing with the previous Chen’s method [15] the quality of the interpolated image produced by this method is high. Lee & Park [18] proposed an edge-based interpolation using sharpening filter and Lagrange interpolation. The Lagrange interpolation uses four (4) neighbouring pixels to estimate a new pixel. This interpolation method achieves an average SSIM value as 0.8406 for 2x scaling. Recently, Moses [19] presented an edge-based stepwise linear interpolation for interpolating Kodak colour images. This method uses edge detector, clamp filter and stepwise linear interpolation and it achieves a highest PSNR as 24.38 dB and SSIM as 0.936.

Instead of simply checking the characteristics of edge by using conventional edge detectors some researchers presented different algorithm to identify the direction or region of edge pixels and based on the direction, different algorithms are used to enhance the quality of interpolation. Kang et al [20] presented directional adaptive interpolation algorithm for digital zooming system of multimedia devices like tablet, mobile phone cameras, digital camcorder and personal computer (PC). By using filters it first guesses an edge direction and attains weighted smoothing along the projected edge direction. This is pursued by image restoration provided that high quality exaggerated images. The PSNR of this algorithm is measures as 21.87 dB and it achieves SSIM as 0.9098. This method provides higher PSNR value than image interpolation presented. [21]. An adaptive image interpolation algorithm based on isophotes is presented. [22]. This algorithm uses a kernel of local orientation of isophotes and the values of pixels attained through the bilinear interpolation. This algorithm provides a highest PSNR value as 26.37 dB and 26.18 dB by using cubic interpolation and linear interpolation respectively. Lama et al [23] presented an adaptive directional lifting image interpolation algorithm for interpolating a high definition image using directional wavelet transform (DWT). This algorithm proves that DWT-based image interpolation sustains improves the objective and subjective qualities of the up-scaled images over the traditional edge-directed interpolation mentioned in [20] and [22] this algorithm achieves a highest PSNR as 30.69 dB. A higher-order edge-directed (HOED) interpolation is proposed by [24] for image compression system. The PSNR value of this algorithm is 33.31 dB by using eight-order interpolation. A joint scalable video model (JSVM)-based image interpolation is proposed by Li et al [25]. This algorithm provides a highest PSNR as 36.78 dB. It executes the finest in general scale factors, and it maintains superior details around edges. It utilizes two directional auto-regressive (AR) models that are created by pixel’s neighbours. This algorithm presents sparkling sharp edges as well as it does not create aliasing effects. By comparing with the directional lifting interpolation [23], the PSNR of this method is superior. An adaptive edge-directed interpolation proposed by [26] for 4-K display devices. The overall value of edge orientation is divided into regions of angle. If the interpolating pixel belongs to ordered edge set then adaptive edge-directed interpolation is used for up-scaling the image. This algorithm provides a highest PSNR as 38.11 dB and presents 0.9906 SSIM for image interpolation by the factor of 2x in both horizontal and vertical orientation. An edge-oriented area pixel scaling is proposed by [27]. This method uses different equations to interpolate pixels based on their area. This interpolation method provides a highest PSNR as 39.08 dB. Sun et al [28] uses canny edge detection and Gaussian filter to improve the quality of image interpolation. This method uses cubic convolution for interpolation non-edge pixels and uses parallelogram bilinear/bi-cubic algorithm based on region of edge pixels. This algorithm provides a highest PSNR as 42.23 dB. Edge-directed image interpolation for increasing image resolution is presented by [29] by utilizing adaptive gradient scale self-interpolation. In the self-interpolation approach, the displacement field is determined from the gradient scale of the bi-cubic up-scaled image. The determined high-resolution gradient is used as a gradient constriction or an edge
preserving constriction to obtain the high-resolution image. This algorithm decreases the artifacts like blurring and aliasing. This method provides a highest SSIM as 0.899.

Some other interpolation methods also have been proposed by using adaptive pre-filters like Scalable image interpolation [30], adaptive Leung Malik filter bank (ALMFB)-based [31], filter-based bi-cubic [32] and local weighted interpolation [33]. The scalable image interpolation [30] method is computationally scalable and it uses adaptive linear filter. The measured PSNR value is about 33.86 dB and the SSIM value is about 0.8720. ALMFB-based interpolation [31] reduces frustrating artifacts like jagging near the object boundary. This interpolation method produces a highest PSNR as 33.11 dB. An adaptive pre-filter-based bi-cubic image interpolation is presented by [32]. This method includes adaptive sharpening filter and bi-cubic algorithm. It performs well in terms of both visual quality and quantitative evaluation as compared with [34]. The PSNR value of this image interpolation method is about 36.56 dB. Another adaptive filter is used to provide the missing pixels for local weighted interpolation method [33]. This filter increases the accuracy of the interpolated image by 4.08 dB and it also improves the SSIM by 0.096 from the previous algorithm [30], so that measured PSNR and SSIM value of this method of this method is 37.94 dB and 0.968 respectively.

Further, some iteratively adaptive image interpolation algorithms have also been proposed like non-linear iterative [35], Shearlet-based iterative [36] and iterative linear [37]. Battiato et al [35] presented an iterative adaptive image interpolation by using information about the sharp luminance variance while up-scaling the input image. This method is suitable for Bayer data images, red green blue (RGB) images and monochromatic images acquired by digital camera like charge coupled device (CCD)/ complementary metal oxide silicon (CMOS) sensors. The PSNR of this method is about 23.6 dB. Lakshman et al [36] proposed an image interpolation method by utilizing shearlet-based iterative refinement algorithm to exploit spare representation of natural images. This method consists of different steps such as estimating of HR image using filter like FIR, promoting sparsity in a chosen dictionary during the thresholding for receiving an approximation and extracting high-frequency information by approximating the initial estimation. This interpolation scheme provides a highest PSNR as 37.03 dB. An iterative linear interpolation is proposed by [37] by developing fuzzy gradient model and using quadratic iterative linear interpolation (ILI) polynomials. This iterative interpolation schemes provides a highest PSNR as 37.14 dB. This PSNR value is higher than the PSNR values of other iterative interpolations such as non-linear iterative [35], Shearlet-based iterative [36].

Image patches and local structure are also considered for improving the quality of image interpolation. Some image patch-based and local structure of pixel based interpolation techniques have been proposed in the recent years. Sun et al [34] proposed an adaptive image interpolation by using bi-cubic interpolation and non-local patches of images. The input image is interpolated by using bi-cubic and then the interpolated image is subdivided into number of non-local patches. After that, based on the characteristics of the derived non-local patches, different algorithms are used to measure the coefficients for the required spatial interpolation. This interpolation method provides a highest PSNR as 35.08 dB and SSIM as 9.660. Zhu et al [38] proposed an image interpolation algorithm to provide high-resolution image from a single low-resolution image. This method uses some similar image patches selected according to the non-local geometric similarity. This interpolation scheme achieves highest PSNR as 35.21 dB and SSIM as 0.980. Choi & Kim [39] proposed an edge-orientation-based pre-learned kernel to provide super interpolation. It performs direct super-resolution and up-scaling without utilizing any transitional interpolation. The low-resolution image patches are clustered by utilizing the information of edge-orientation. This image interpolation method provides a highest PSNR as 38.36 dB with SSIM as 0.948. By preserving the distances of edge pixels Wang et al [40] proposed an image interpolation for providing
high-resolution images. This method produces a highest SSIM as 0.871. A local structure constrained image interpolation is proposed by [41]. The major contributions of this technique are estimating high-resolution gradient map and reconstructing the structure of texture area in display systems. This method provides a highest PSNR as 37.28 dB and the SSIM as 0.997. Recently, Varatharajan et al [42] proposed an adaptive decision-based kriging interpolation scheme to remove salt and pepper noise in an image. This scheme will be used in multimedia devices like camera sensors. Kriging interpolation is based on linear statistical method reduces the variation error. This method achieves highest PSNR as 44.48 dB and highest SSIM as 0.991.

3. COMPARATIVE ANALYSIS

This section provides performance comparison of different adaptive image interpolation algorithms based on their quantitative measures such as PSNR and SSIM. Figures B1 to B5 show the comparison of PSNR of different interpolation category of adaptive image interpolation algorithms. Further, Table I shows the overall comparison of both PSNR and SSIM of different adaptive image interpolation algorithms.

Figure B1 shows the PSNR values of various edge-based adaptive image interpolation algorithms such as Edge-based Bilinear (EBBL) [10] and [15], Edge-based Bilinear with Combined Filter (EBBLCMF) [16], Edge-based Bilinear with Sharpening Filter (EBBLSF) [17] and Edge-based Stepwise Linear (EBSL) [19].

Based on Figure B 1, it is demonstrated that all bilinear interpolation algorithms outperform the stepwise linear interpolation [19]. Among the various bilinear image interpolation algorithms, the edge-based bilinear with space variant edge-detector and sharpening filter [17] performs well by producing highest PSNR as 40.37. By comparing remaining bilinear interpolation, the edge-based bilinear with combined filter [16] outperforms by providing highest PSNR as 37.02 dB. Figure B 2 gives the comparison of PSR of different region/orientation of edge-based image interpolation algorithms such as Directional Adaptive Interpolation (DAI) [20], Isophotes-based Interpolation (IBI) [22], Directional Wavelet Transform-based Interpolation (DWTI) [23], Higher-order Edge-directed (HOED) [24], Joint-scalable Video Model-based (JSVM) [25], Edge-directed Interpolation (EDI) [26], Area Pixel Scaling (APS) [27] and Parallelogram Bilinear/Bi-cubic (PBLBC) [28].

Based on Figure B 2, [28] provides high quality image interpolation by using either parallelogram bilinear or parallelogram bi-cubic based on the angle of edge pixel. This method outperforms the other region/orientation of edge-based image interpolation by providing higher PSNR as 42.23 dB. Figure B 3 shows the quality comparison of different pre-filter-based adaptive image interpolation algorithms in terms of PSNR. The different algorithms are Linear filter-based Interpolation (IFI) [30], Leung Malik Filter Bank-based Interpolation (LMFBI) [31], Sharpening Filter-based Interpolation (SFL) [32] and Adaptive Filter-based Interpolation (AFL) [33].

Based on Figure B 3, AFL [33] provides highest PSNR among the various filter-based adaptive interpolation algorithms by using modified filter and local weighted coefficients. Figure B 4 shows the comparison of different iteratively adaptive interpolation algorithms such as Non-linear Iterative Interpolation (NLII) [35], Shearlet-based Iterative Interpolation (SBII) [36] and Iterative Linear Interpolation (ILI) [37].

Based on Figure B 4, both ILI [37] and SBII [36] outperform the NLII [35] in terms of PSNR. The ILI [37] provides higher PSNR as 37.14 dB. Figure B 5 shows the PSNR comparison of various image interpolation algorithms which are developed based on image patches or local stricter of image pixel. The various patch or local structure-based image interpolation techniques are Non-local Patches-based bi-cubic (NLPBC) [34], Non-local Geometric Similarity-based Interpolation (NLGSI) [38], Patch
Clustering-based Interpolation (PCBI) [39], Local Structure Constrained Interpolation (LSCI) [41] and Decision-based Kriging Interpolation (DKI) [42].

From Figure B 5, it is proved that recently developed DKI [42] provides higher PSNR as 44.48 dB by using local structure-based decision to perform Kriging interpolation. Further, the clustering of patch [39] also provides better interpolation quality by providing highest PSNR as 38.86 dB.

Table A 1 summarizes the characteristics of different adaptive image interpolation algorithms in terms of PSNR and SSIM. From Table 1, it is identified that edge-based bilinear interpolation [17] provides a good PSNR as 40.37 and SSIM as 0.9955. But the edge-directed Parallelogram Bilinear/B-cubic proves that the interpolation based on the direction or region of edge pixels is superior to ordinary edge-based interpolation techniques. Further, the results of recently developed Decision-based Kriging interpolation [42] show that the quality of interpolation would also be improved by taking decision based on the local structure of pixels. This method provides higher PSNR among the different adaptive image interpolation technique. However, the SSIM value of this interpolation is little bit lower than the SSIM of edge-enhanced Bilinear [17].

Figure B 6 shows the overall performance by comparison of different categories of adaptive image interpolation schemes such as edge-based, edge-oriented, pre-filter-based, Iteratively-based and local structure-based. From Figure B 6, it is identified that all categories of adaptive image interpolation algorithms perform equally in terms of their quantitative measure PSNR. However, the local structure-based and edge-oriented categories are superior to other interpolation categories slightly.

4. CONCLUSION

This work analyses the characteristics of various adaptive image interpolation algorithms used for multimedia applications. This study concentrates on the quality of interpolated image based on PSNR and SSIM. From the detailed review, it is understood that various researches have been performed to optimize the interpolation process adaptively. Among the various algorithms, adaptive interpolations using the orientation of edges are superior to other interpolation techniques in terms of quality. Also, the recently developed algorithms utilize other adaptive techniques such as edge-based and iterative-based algorithms. Further, this review suggests that the quality of image interpolation can be improved by utilizing optimized filters and by splitting the group of edge pixels to more numbers. Therefore, any kind of adaptive interpolation technique can be selected to improve the quality of images based on the requirements.

REFERENCES


APPENDIX A

Table A1: PSNR and SSIM comparison of different Adaptive Image Interpolation Algorithms

<table>
<thead>
<tr>
<th>Interpolation method</th>
<th>PSNR (dB)</th>
<th>SSIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge-directed Super Resolution [20]</td>
<td>21.87</td>
<td>0.7006</td>
</tr>
<tr>
<td>Non-linear Iterative [35]</td>
<td>23.6</td>
<td>NA</td>
</tr>
<tr>
<td>Edge-based stepwise linear [19]</td>
<td>24.38</td>
<td>0.936</td>
</tr>
<tr>
<td>Isophotes-based Bilinear/Bi-cubic [22]</td>
<td>26.37</td>
<td>0.679</td>
</tr>
<tr>
<td>Adaptive Directional Wavelet Transform [23]</td>
<td>30.69</td>
<td>NA</td>
</tr>
<tr>
<td>Edge-based Bilinear [10]</td>
<td>32.32</td>
<td>0.679</td>
</tr>
<tr>
<td>Edge-based Area Pixel Scaling [27]</td>
<td>32.73</td>
<td>NA</td>
</tr>
<tr>
<td>Adaptive Bilinear [15]</td>
<td>33.07</td>
<td>NA</td>
</tr>
<tr>
<td>Edge-based with Leung Malik Filter [31]</td>
<td>33.11</td>
<td>NA</td>
</tr>
<tr>
<td>Higher Order Edge-directed [24]</td>
<td>33.31</td>
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</tr>
<tr>
<td>Linear Filter-based [30]</td>
<td>33.86</td>
<td>0.8720</td>
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<tr>
<td>Bi-cubic with non-local patches [34]</td>
<td>35.08</td>
<td>9.660</td>
</tr>
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<td>Non-local geometrical Similarity-based [38]</td>
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<td>0.980</td>
</tr>
<tr>
<td>Adaptive Bi-cubic [32]</td>
<td>36.56</td>
<td>NA</td>
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<tr>
<td>Directional Auto Regressive Model-based [25]</td>
<td>36.78</td>
<td>NA</td>
</tr>
<tr>
<td>Edge-based Bilinear using combined filter [16]</td>
<td>37.02</td>
<td>NA</td>
</tr>
<tr>
<td>Shearlet-based [36]</td>
<td>37.03</td>
<td>NA</td>
</tr>
<tr>
<td>Iterative Linear [37]</td>
<td>37.14</td>
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<tr>
<td>Edge-based Local Structure Constrained [41]</td>
<td>37.28</td>
<td>0.997</td>
</tr>
<tr>
<td>Deinterlacing of Closeness &amp; Similarity-based [33]</td>
<td>37.94</td>
<td>0.968</td>
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<td>Edge-directed Bi-cubic [26]</td>
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<td>Edge-based Super Interpolation [39]</td>
<td>38.36</td>
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<td>Adaptive Edge-enhanced Bilinear [17]</td>
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<td>Edge-directed Parallelogram Bilinear/Bi-cubic [28]</td>
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<tr>
<td>Decision-based Kriging [42]</td>
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<tr>
<td>Edge-based Lagrange [18]</td>
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<tr>
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<tr>
<td>Edge-directed Super Resolution [29]</td>
<td>NA</td>
<td>0.899</td>
</tr>
</tbody>
</table>
APPENDIX B

Figure B1: PSNR comparison of different edge-based image interpolation systems.

Figure B2: Comparison of PSNR of different region/orientation of edge-based image interpolations.

Figure B3: Quality comparison of various filter-based adaptive interpolation schemes.
Figure B4: PSNR comparison of different iteratively adaptive image interpolation methods.

Figure B5: PSNR comparison of different patch/local structure-based image interpolation methods.

Figure B6: Overall comparison of Adaptive Image Interpolation schemes.