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Upscaling Capsule Endoscopic Low Resolution Images

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Abstract-The research through this paper will focus on enhancement of low resolution images taken by the camera of wireless capsule endoscopy. The resolution of this camera is usually 256 by 256, which is usually low and therefore needs enhancement. Image processing for such low resolution digital images is very challenging problems. It is because of the errors due to quantization and sampling. Over the last several years; significant improvements have been made in this area; however, it is still very challenging. Therefore, this research will focus on investigating the effect of interpolation functions on increasing the resolution of endoscopic images. The effects such as aliasing; edge blurring and other artifacts will be investigated.A DWT based algorithm with error feedback is proposed and evaluated. The proposed resolution enhancement technique uses DWT to decompose the input image into different subbands. Then, the high-frequency subband images and the input low-resolution image have been interpolated, followed by combining all these images to generate a new resolution-enhanced image by using inverse DWT. The proposed technique has been tested on endoscopic images. The psnr, mse and maximum error and visual results show the superiority of the proposed technique over the traditional image super-resolution techniques.

Keywords: Sampling, interpolation, PSNR, MSE,ME.

I. INTRODUCTION

This paper focuses on low resolution digital images such as images taken by low resolution camera and capsule endoscopic medical images. The captured images are usually processed by digital image processors which render an image in a two-dimensional grid of pixels; characterized by a discrete horizontal and vertical quantization resolution. This finite resolution, especially for low resolution images, often results in visual artifacts, known as “aliasing” artifacts. These are very common in low resolution images and usually these aliasing artifacts either appear as zigzag edges called jaggies or produce blurring effects. Another type of aliasing artifacts is variation of color of pixels over a small number of pixels (termed pixel region) [1-4]. This type of aliasing artifacts produces noisy or flickering shading. These artifacts can be reduced by increasing the resolution of an image. This can be done using image interpolation, which is generally referred as a process of estimating a set of unknown pixels from a set of known pixels in an image. Image interpolation is in use for last many years, with the key interpolation techniques include nearest neighbor, bilinear, bicubic and lanczos2 interpolation techniques [5].

II. INTRODUCING INTERPOLATION

Interpolation is the method of enlarging or stretching an image from a smaller original image to a larger resultant image.

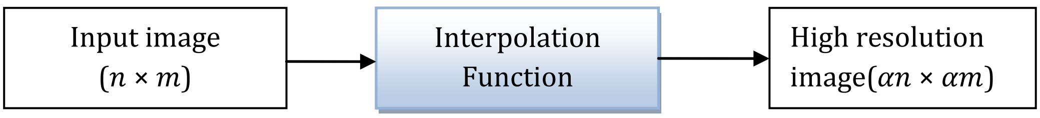

Figure 1: Block diagram for the process of zooming using interpolation functions [3].

Resampling/zooming is the process of transforming a discrete image which is defined at one set of coordinate locations to a new set of coordinate points. Resampling can be divided conceptually into two processes: interpolation of the discrete image to a continuous image and then sampling the interpolated image. An image Interpolation is the method of enlarging the smaller low resolution image to a larger high resolution image which can be defined as Image Scaling. Whereas, approximating the value of continues function by using discrete samples is also defined as an Interpolation .Nowadays, Image interpolation is also available in many image processing tools like Photoshop [1]. Also it has many applications like digital photograph, remote sensing, medical imaging, image decomposition, to correct spatial distortion and many more. We have shown the basic concept of image enlargement using Interpolation. The digital image is a signal which mainly varies in two dimensions. This signal is sampled and quantized to get values. All these values are called the pixels of an image. While increasing the resolution of an image from low to high, it is called up-sampling or up-scaling whereas, the reverse is called down sampling or down scaling [5]. Here, in this paper we have mainly focused on up sampling only.

Primarily, there are two main categories for interpolation: Adaptive and Non-Adaptive.In particularly, the process of interpolation refers to finding the information for undefined pixels or missed pixels in an image based on the information provided by given pixels, so that the interpolated image is as close to the actual one as possible [4]. The given information usually includes information related to coordinates, color, gray level or density; with the image having any dimensions. Interpolation is the process by which a small image is made larger. Software tools stretch the size of the image and generate pixels to fill in the blanks. The key interpolation methods include nearest neighbor, bilinear, bicubic and lanczos. A review of these techniques is presented below.

2.1 Nearest Neighbor Interpolation [6]

The nearest-neighbor interpolation function has a rectangular shape in space domain. It can be mathematically expressed as:

$$h(x) = \begin{cases} 1 & |x| < 0.5 \\ 0 & elsewhere \end{cases} \qquad (1)$$

The nearest-neighbor method is usually reported as the most efficient from the computation point of view [7,8]; but, at the cost of poor quality as can be observed from its frequency domain. It is because the Fourier Transform of a square pulse is equivalent to a *sinc* function; with its gain in pass band falls off quickly. In addition, it has prominent side lobes as illustrated in the logarithmical scale. These side-lobes usually result in blurring and aliasing effects in the interpolated image. When applying nearest-1 algorithm for image interpolation, the value of the new pixel is made the same as that of the closest existing pixel.

2.2 Bilinear interpolation [7]

Analytically, bilinear interpolation is an extension of linear interpolation for interpolating functions of two variables (e.g., *x* and *y*) on a regular grid. The bilinear interpolated function uses the term *xy*, which is the bilinear form of *x* and *y*.

$$f_{y1} = f_{11} + \frac{f_{21 - f_{11}}}{x_2 - x_1}(x - x_1)$$
$$f_{y2} = f_{12} + \frac{f_{22 - f_{12}}}{x_2 - x_1}(x - x_1)$$
$$f_{(x,y)} = f_{y1} + \frac{f_{y2 - f_{y1}}}{y_2 - y_1}(y - y_1) \qquad (2)$$

Bilinear interpolation considers the closest 2×2 neighborhood of known pixel values surrounding the unknown pixel. It then takes a weighted average of these 4 pixels to arrive at its final interpolated value. This results in much smoother looking images than nearest neighbor. Weight is determined by assigning weighted value of 4-nearest neighbor pixel to generated output pixel. Each weighing value is proportional to distance from each existing pixel. This method has advantage of simple calculation and output image using bilinear interpolation is usually better than nearest neighbor replication approach. This method has advantage of simple calculation. And output image using bilinear interpolation is better than nearest neighbor replication. However, blurring effect is occurred by averaging surround pixel.

2.3 Bicubic interpolation [8]

Bicubic interpolation is an extension of spline interpolation for interpolating data points on a two dimensional regular grid. This technique uses the information from an original pixel and sixteen of the surrounding pixels to determine the color of the new pixels that are created from the original pixel. Bicubic interpolation is an extension of cubic interpolation for interpolating data points on a two dimensional regular grid. The interpolated surface is smoother than corresponding surfaces obtained by bilinear interpolation or nearest-neighbor interpolation.

Bicubic interpolation works same as bilinear interpolation, except using a cubic function instead of a linear function to estimate pixels between known values. This is a high performance pixel interpolation that gives outstanding results, both in calculation speed and in quality of results.

$$f(x,y) \approx \frac{f(Q_{11})}{(x_2 - x_1)(y_2 - y_1)}(x_2 - x)(y_2 - y) + \frac{f(Q_{21})}{(x_2 - x_1)(y_2 - y_1)}(x - x_1)(y_2 - y) + \frac{f(Q_{12})}{(x_2 - x_1)(y_2 - y_1)}(x_2 - x)(y - y_1) + \frac{f(Q_{22})}{(x_2 - x_1)(y_2 - y_1)}(x - x_1)(y - y_1) +$$

$$= \frac{1}{(x_2 - x_1)(y_2 - y_1)}(f(Q_{11})(x_2 - x)(y_2 - y) + (f(Q_{21})(x - x_1)(y_2 - y) + (f(Q_{12})(x_2 - x)(y - y_1) + (f(Q_{22})(x - x_1)(y - y_1)) \qquad (3)$$

It is usually the best choice when not too radical downsampling operations are involved in geometrical transformations. This form of interpolation has advantages and drawbacks over bilinear interpolation. First, calculating the cubic polynomial in a specific area of the image is more computationally expensive than simple linear fits and also requires a larger neighbor to calculate the curve.

2.4 Lanczos interpolation [15]

It is being used for image resampling.it is a mathematical technique to create a newer version of image with a different width and/or height in pixels. Interpolation is a process of determining the values of a function at positions lying between its samples .sampling the interpolated image is equivalent to interpolating the image with a sampled interpolating function.

Lanczos resampling or Lanczos filter is a mathematical formula used to smoothly interpolate the value of a digital signal between its samples. It maps each sample of the given signal to a translated and scaled copy of the Lanczos kernel, which is a sinc function windowed by the central hump of a dilated sinc function. The sum of these translated and scaled kernels is then evaluated at the desired points. Lanczos resampling is typically used to increase the sampling rate of a digital signal, or to shift it by a fraction of the sampling interval. It is often used also for multivariate interpolation, for example to resize or rotate a digital image. It has been considered the "best compromise" among several simple filters for this purpose.

$$L(x) = \begin{cases} sinc(x)sinc\left(\frac{x}{a}\right) & if \quad -a < x < a \\ 0 & otherwise \end{cases} \qquad (4)$$

The effect of each input sample on the interpolated values is defined by the filter's reconstruction kernel $L(x)$, called the Lanczos kernel. It is the normalized sinc function sinc(x), windowed (multiplied) by the Lanczos window, or sinc window, which is the central lobe of a horizontally-stretched sinc function sinc(x/a) for $-a \le x \le a$. The parameter a is a positive integer, typically 2 or 3, which determines the size of the kernel. The Lanczos kernel has $2a - 1$ lobes, a positive one at the center and $a - 1$alternating negative and positive lobes on each side. The theoretically optimal reconstruction filter for band-limited signals is the sinc filter, which has infinite support. The Lanczos filter is one of many practical (finitely supported) approximations of the sinc filter. Each interpolated value is the weighted sum of $2a$ consecutive input samples. Thus, by varying the $2a$ parameter one may trade computation speed for improved frequency response. The parameter also allows one to choose between a smoother interpolation or a preservation of sharp transients in the data. For image processing, the tradeoff is between the reduction of aliasing artifacts and the preservation of sharp edges.

III. COMPARISON OF DIFFERENT INTERPOLATION TECHNIQUES

Table 1: comparison of different interpolation techniques with advantages and disadvantages.

Sr.no.	Technique	Key idea	Advantages	Disadvantages
1	Nearest neighbor	It considers least nearest pixels to the interpolated point.only one pixel is used to compute value of unknown point.	Enhanced speed, least processing time because one pixel is used to find value of interpolated point.	Check board effect, worst quality.
2	Bilinear	2*2 neighborhoods are used to calculate the value of unknown pixel.Total number of pixels is four whose weighted average is compute to find the value of interpolated point. This gives smoothness in resulted image as compare to nearest neighborhood method.	Good quality of images after zooming, smoother images.	Does not suitable for applications where more concentration is given on edges because it creates jagged effects end to end edges. This method produce ringing artifacts, the method may produce blurring effects because of weighted average of neighborhood pixels.
3	Bi-cubic	4*4 neighborhoods are considered for calculating the value of interpolated point. Total number of pixels is 16 and these are at varying distance from interpolated point. The closet pixels to the interpolated point are given higher weights than the farthest pixels.	Sharper images, ideal combination of quality and processing time of zoomed image, standard method for image editing.	Uneven results along edges. Ringing Artifacts , introduce blurriness in image because weighted average method is used.
4	Lanczos 2	It smoothly interpolates the value of a digital signal between its samples.	It is used to increase the sampling rate of signal to avoid	Interpolation with a discrete signal with constant samples does

			aliasing.	not yield a constant function

IV. SYSTEM MODEL

High-frequency components (i.e. the edges) are main loss of an image after being super-resolved by applying interpolation. This loss occurs due to the smoothing caused by interpolation. To increase quality of the super-resolved image, preserving the edges is essential. Therefore, Gholamreza Anbarjafari and Hasan Demirel proposed a super-resolution technique based on interpolation of the high-frequency sub-band images obtained by discrete wavelet transform (DWT) of the input image, as shown in Figure 4. This technique uses DWT to decompose an image into different subband images; namely, low-low (LL), low-high (LH), high-low (HL), and high-high (HH). These subband images contain the high-frequency components of the input image. In this technique, the interpolation is applied to high-frequency subband images as well as the input image. Finally, the IDWT of the interpolated subband images and the input image produce the final high-resolution output image. In this technique, the employed interpolation method is same for all subband and input images. In this technique, the interpolation and wavelet functions are the two important factors in determining quality of the super-resolved images. The benefit in this scheme is that this super-resolution process considers the higher and lower frequency components into considerations; which is not taken into account in direct interpolation. Also it is known that in the wavelet domain, lowpass filtering of the high resolution image produce the low resolution image. In other words, low frequency subband is the low resolution of the original image. Therefore, instead of using low frequency subband, which contains less information than the original high resolution image, Hasan Demirel and Gholamreza Anbarjafari used the input image for the interpolation of low frequency subband image. The quality of the super resolved image increases using input image instead of low frequency subband. However, even this approach is reported to give jaggies and blurriness in the super resolved images. Therefore, the research proposed in this paper focuses to use an error routine to reduce the artifacts produced in images when zoomed using wavelet based techniques. This is discussed below.

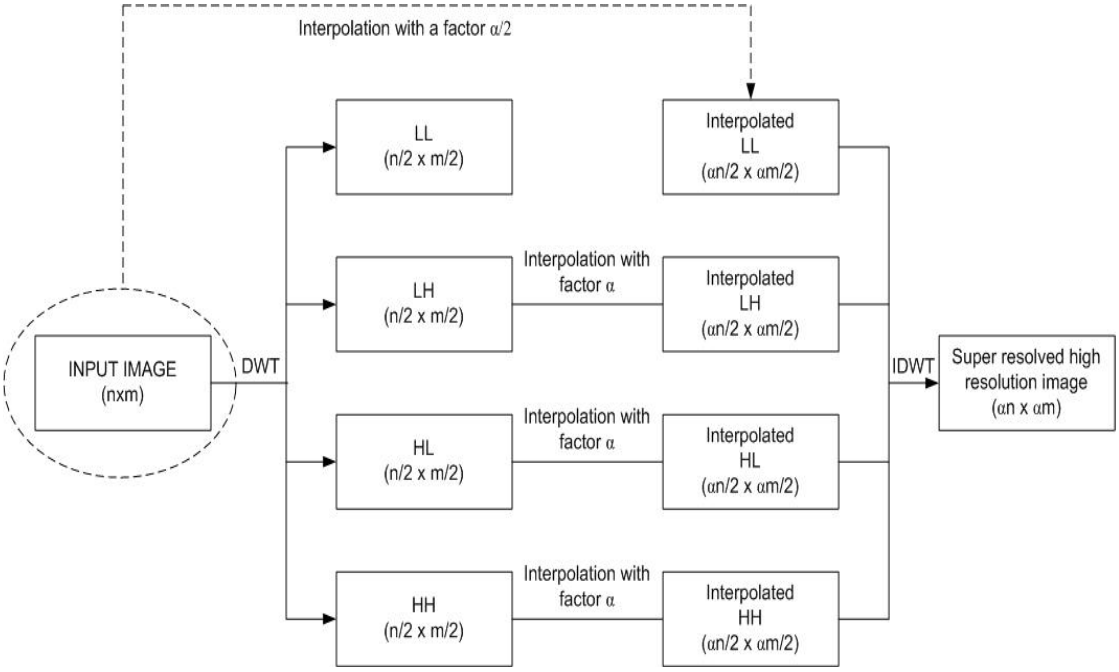

Figure 2: Block diagram of DWT-SR method.

In medical images, the accuracy and sharpness of edges is very essential. For example, in endoscopic images, it is highly desirable to gain information about the disorders/diseases in track through which the wireless endoscopic capsule passes. These disorders/diseases usually have similar color as that of the normal track; however, have sharp edges. Therefore, it is desirable to have a zooming operation; which maintains the sharpness of the edges. Thus in the proposed methodology, a feedback error routine is developed.In the developed methodology, the image is super-resolved over an interval of zoom factor of 2. At each stage, the error is computed with respect to the original bicubic interpolated image and the obtained error is added back to the DWT super resolved image at each stage. The idea of error routine is that when the interpolation operation is performed on high frequency components obtained using the DWT transform, then the interpolation will smooth out these components. Although, the results obtained using the DWT based super-resolution techniques is better than the traditional techniques; yet, it can be further enhanced. For this reason, the interpolation is performed in steps of 2; and at each stage the error is calculated with respect to the original super-resolved image using interpolation (Bicubic Interpolation in this paper). This error is then added to the input image of the next stage. In this way, the error can be reduced and a better quality image can be obtained. However, this method has a drawback of time consuming and the zooming/super-resolution factor should be a multiple of order of 2.

V. RESULTS

A low resolution endoscopic image of 256X256 is taken as input image. MATlab is used for showing the comparison between different Interpolation methods. Peak Signal to Noise Ratio (PSNR) and mean square error (MSE) and maximum error (ME) are the basic parameters for comparison of all algorithms. Visual quality is the most important parameter for the effectiveness. First of all the input image is downsampled by factor of 2 and then enlarged or interpolated by different techniques such as Nearest Neighbor, Bilinear, Bicubic ,Lanczos-2 and proposed algorithm. Results are shown in Table 2. The table 2 clearly reflects that the PSNR value of the proposed method is the highest among the nearest-neighbor, Bilinear, Bicubic ,lanczos2 and proposed algorithm and MSE of the proposed algorithm is lowest among nearest –neighbor, bilinear , bicubic ,lanczos 2 and proposed algorithm.

Original image

Downsampled image

Nearest neighbor

Bilinear

Bicubic

Lanczos 2

Proposed algorithm

Fig. 3 A capsule endoscopy image is reduced to 50% of its original size and then zoomed back to its original size using nearest neighbor, bilinear, bicubic , lanczos2 and proposed algorithm.

Table 2: PSNR, MSE and Maximum error of images zoomed using nearest neighbor, bilinear, bicubic , lanczos2 and proposed algorithm

Test image	Nearest neighbour	Bilinear	Bicubic	Lanczos2	proposed algorithm
PSNR	29.2169	30.8021	30.5422	30.5181	46.489
MSE	77.8735	54.0588	54.3846	57.7121	1.4594
ME	160	134	147	147	90

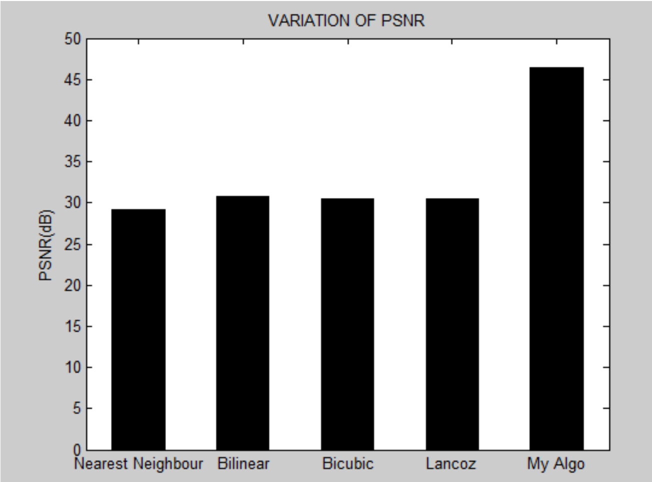

Fig. 4 PSNR comparison of capsule endoscopy image zoomed using nearest neighbor, bilinear, bicubic , lanczos2 and proposed algorithm using 2 dimensional functions.

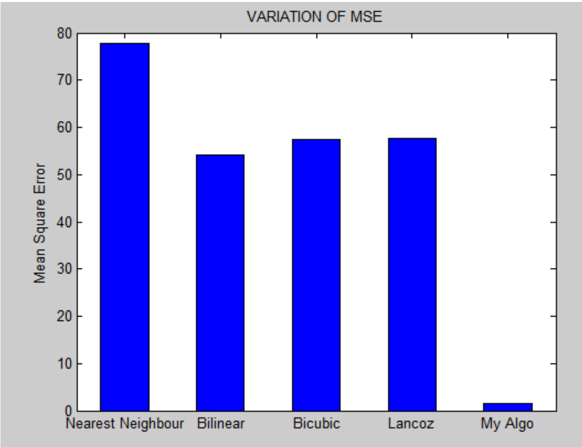

Fig. 5 MSE comparison of image of head zoomed using nearest neighbor, bilinear, bicubic , lanczos 2 and proposed algorithm using 2dimensional functions.

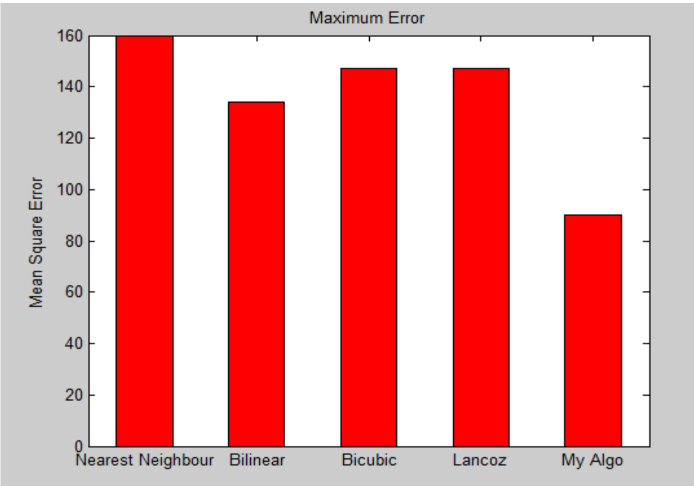

Fig. 6 Maximum error comparison of capsule endoscopy image zoomed using nearest neighbor, bilinear, bicubic lanczos2 and proposed algorithm using 2 dimensional functions.

VI. CONCLUSION

This paper presented the results obtained on applying the DWT and error routine based proposed algorithm on low resolution endoscopic images. Each interpolation technique has its own advantages and disadvantages, some are inferior in quality while some are weal with the time that occurs to get the enlarged image as an output are suitable for edge enhancement applications. The techniques that consider more number of pixels while computing the value of unknown points in zoomed image produce better results than the methods that consider less number of pixels. Higher order methods give better results than other methods but in much cases computational complexity increases. The results obtained are evaluated both visually and analytically in terms of PSNR, MSE and maximum error. It is observed that the visual results of proposed algorithm are better as compared to nearest neighbor, bilinear, bicubic and Lancoz interpolation functions. A minimum 10% increase in PSNR is obtained for the images zoomed using the proposed algorithm as compared to nearest neighbor, bilinear, bicubic and Lancoz interpolation functions. Whereas, a minimum 10% decrease in the value of MSE and a minimum 20% decrease in maximum error is noticed for the proposed function. the proposed algorithm preserves the sharpness of edges in zoomed images and is more suitable for zooming endoscopic images compared to traditional nearest neighbor, bilinear, bicubic and Lancoz interpolation functions.

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