Redundant Wavelet Transform Based Image Super Resolution

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Abstract
The process of Super Resolution (SR) aims at extracting a high resolution image from low resolution image. The proposed technique uses Redundant Wavelet Transform to enhance the resolution of an image using a single low resolution image. The proposed method decomposes the input image into different subbands. Then all subbands are interpolated. Combining all the interpolated subbands using Inverse Redundant Wavelet Transform provides the proposed super resolution image. The algorithm is tested with various wavelet types and their performance is compared. The proposed technique has been tested on Lena, Elaine, Pepper, and Baboon images. The proposed method gives higher quantitative peak signal-to-noise ratio (PSNR) and visual results in comparison to other conventional and state-of-art image Super resolution techniques.

Index Term **—** Image Super Resolution, Interpolation, Discrete Wavelet Transform, Redundant Wavelet Transform.

I. INTRODUCTION

The aim of Super Resolution is to overcome the limitation of the image acquisition device or ill posed acquisition condition [1]. A Super Resolution image is useful for better classification of remote sensing image or to assist radiologist for making diagnosis based on a medical imagery [2].

The most direct approach of obtaining higher-resolution images is to improve the image acquisition device (e.g., digital camera) by reducing the pixel size on the sensor (e.g., charge-coupled device). However, there is a problem in reducing the sensor's pixel size. When the sensor's pixel size becomes too small the captured image quality will be degraded [3]. It produces shot noise that degrades the image quality. Another approach for increasing the super resolution is to increase the chip size, which in turn increase the capacitance. Since large capacitance makes it difficult to speed up charge transfer rate this approach is not effective [4]. A new approach for increasing the resolution which overcomes all these problems is known as Super Resolution. The Super Resolution image processing has grown very rapidly after it was first researched by Tsai and Huang [5] in 1984. They applied Discrete Fourier Transform for Super Resolution. The drawback of this method is that it is insufficient to handle the real-world applications. Many researchers have mentioned the use of wavelet transform for addressing a Super Resolution problem to recover the detailed information (usually the high-frequency information) that is lost or degraded during the image acquisition process [6,7]. The drawback of this method is that they applied multilevel wavelet transform. Ur and Gross introduced Super Resolution through interpolation [8]. The interpolation based Super Resolution approach constructs a high resolution image by projecting all the acquired low-resolution images to the reference image. The information available from each image is then fused together because each low resolution image provides an amount of additional information about the image and finally deblurs the image [9]. The drawback of this method is that the interpolation algorithm cannot do super resolution of single image since it cannot produce those high-frequency components that were lost during the image acquisition process. G. Anbarjafari and H. Demirel proposed a new technique for image Super Resolution by combining both the wavelet transform and interpolation. This technique reduces all the drawbacks of above mentioned techniques. However, applying interpolation in high frequency sub-bands introduces aliasing effects [10, 11].

The proposed technique also combines the wavelet transform and interpolation. This method uses redundant wavelet transform instead of discrete wavelet transform. The proposed method is tested with different types of wavelets & interpolation methods & results are compared.

Rest of the paper is organized as follows: Section 2 presents general description of discrete wavelet transform and redundant wavelet transform. Section 3 describes the interpolation and the various interpolation methods available. Section 4 introduces a discrete wavelet transform based DASR technique for super resolution. Sections 5 elaborates the proposed technique. Section 6 contains the experimental results and comparison. At last, Section 7 concludes the paper.

II. WAVELET TRANFORM

Wavelet is a mathematical tool for hierarchical decomposition of a signal. It allows a function to be described in terms of coarse overall shape along with details that range from broad to narrow [12]. Regardless of whether the function of interest in an image is a curve, or a surface, wavelet offers an elegant technique for representing the levels of detail in the function.

2.1 Discrete Wavelet Transform

The Discrete wavelet transform (DWT) analyzes the signal at different frequency bands with different resolutions by decomposing the signal into coarse approximation and detail information. DWT adopts two sets of function called scaling function and wavelet functions which are associated with low pass and high pass filtering. In other words, decomposition of the image into different frequency bands is simply obtained by successive high pass and low pass filtering and downsampling [13] of the image as shown in Fig.1

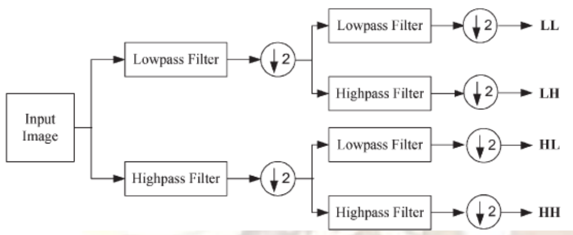


Fig.1 Discrete Wavelet Transform

2.2 Redundant Wavelet Transform

The DWT remove the redundant coefficients which are not necessary to perfectly reconstruct the signal. This makes wavelet compression algorithms more computationally efficient. However, in many image processing applications the redundant wavelet coefficient are useful. This work interpolates missing pixels of an image in the wavelet domain based on the values of the surrounding pixels. As much as possible information is needed to accurately interpolate the missing pixels. Decimation removes potentially valuable information. In cases like this it is beneficial to remove the decimators [14]. This is known as the Redundant Wavelet Transform (RWT) as shown in Fig. 2.

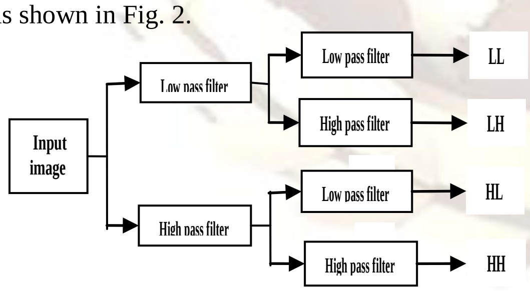


Fig. 2 Redundant Wavelet Transform

III. INTERPOLATION

Interpolation is the process of estimating the values of a continuous function from discrete samples. Interpolation based image processing applications include image magnification or reduction, sub pixel image registration, correction of spatial distortions, image decompression and many more. Many image interpolation techniques are available amongst which nearest neighbor, bilinear and bicubic are the most common [9].

- **Nearest Neighbor Interpolation**

The easiest interpolation from a computational stand point is nearest neighbor. The nearest neighbor algorithm selects the value of nearest point and does not consider the values of neighboring points at all, yielding a piece-wise constant interpolation. This technique is also known as pixel replication.

- **Bilinear Interpolation**

Bilinear interpolation considers the closest 2x2 neighborhood of known pixel values surrounding the unknown pixel and calculates weighted average of these 4 pixels to arrive at its final interpolated value. This results in much smoother images than nearest neighbor interpolation method**.**

- **Bicubic Interpolation**

Bicubic goes one step beyond bilinear interpolation by considering the closest 4x4 neighborhood of known pixels (i.e., total of 16 pixels). Since these pixels are at various distances from the unknown pixel and closer pixels are given a higher weighting in the calculation, bicubic interpolation produces sharper images than the previous two methods.

IV. DASR BASED IMAGE SUPER RESOLUTION (DASR)

The main loss of image after doing super resolution by applying interpolation is on its high frequency components, which results in smoothing of the image Hence, for increasing the quality of interpolated image, edges should be preserved essentially. G. Anbarjafari and H. Demirel proposed a method [10] that preserves the high frequency components of the image. In this technique, Discrete Wavelet Transform (DWT) separates the image into different subband images represented by the LL (low-low subband), LH (low-high subband), HL (high-low subband) and HH (high-high subband). High frequency subband contains the high frequency components of image. All subbands are interpolated by interpolation factor of 2. In order to extract the high frequency component from input low resolution image, difference between the input image and low frequency subband image is added to all high frequency subbands. Input low resolution image and all estimated high frequency subbands are interpolated by the interpolation factor 2. The reconstruction of super resolution image is done by applying Inverse Discrete Wavelet Transform (IDWT) to the interpolated subbands. The block diagram of DASR method is shown in Fig.3

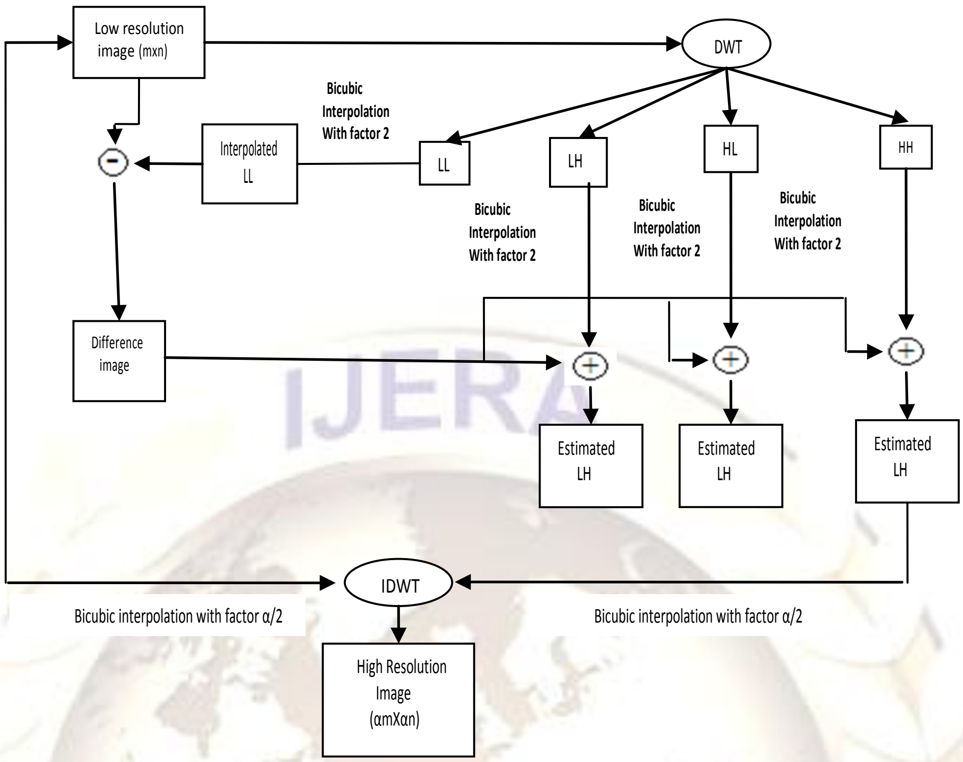


Fig.3. DASR Method of image super resolution

V. PROPOSED SUPER RESOLUTION METHOD

The proposed method is carried out in 4 steps as shown in the block diagram of Fig.4.

Step 1: In the first step, an input low resolution image is generated from original high resolution image through Gaussian down sample function. In this function firstly the original high resolution image is passed through a Gaussian low pass filter, which passes only low frequency component of image. The image is then down sampled row and column wise by a factor of 2. This converts the original high resolution image of size 512×512 into low resolution image of size 128× 128.

Step 2: In the second step, Redundant Wavelet Transform (RWT) is applied to the input low resolution image. The input low resolution image is decomposed through the RWT in four sub bands represented by LL (low-low), LH (low-high), HL (high-low) and HH (high-high).

Step 3: This step is the interpolation step. This technique uses bicubic interpolation which gives sharper image as compared to other interpolation methods. All subbands are interpolated by interpolation factor of 4 and then we achieve interpolated subbands of size 512× 512.

Step 4: The final resolution enhanced image is generated by employing the Inverse Redundant Wavelet Transform (IRWT) to the interpolated subbands. In this technique the required interpolation method is same for all subbands.

I. EXPERIMENTAL RESULTS AND COMPARISION

The performance of the proposed super resolution algorithm is tested on four gray scale images show in Fig. 5, each having a size of 512×512. These test images are first converted to their low resolution version through Gaussian down sample function and then Redundant Wavelet Transform is applied to the low resolution image. The performance of the proposed method is compared by applying wavelets namely Haar, Db8, Db9/7, Sym4 and Sym8. In the next step, bicubic interpolation by factor 4 is applied to LL, LH, HL, HH subbands. Table 1 shows the experimental results in terms of Root Mean Square Error (RMSE) and Peak Signal to Noise Ratio (PSNR $=20\log_{10}255/RMSE$).

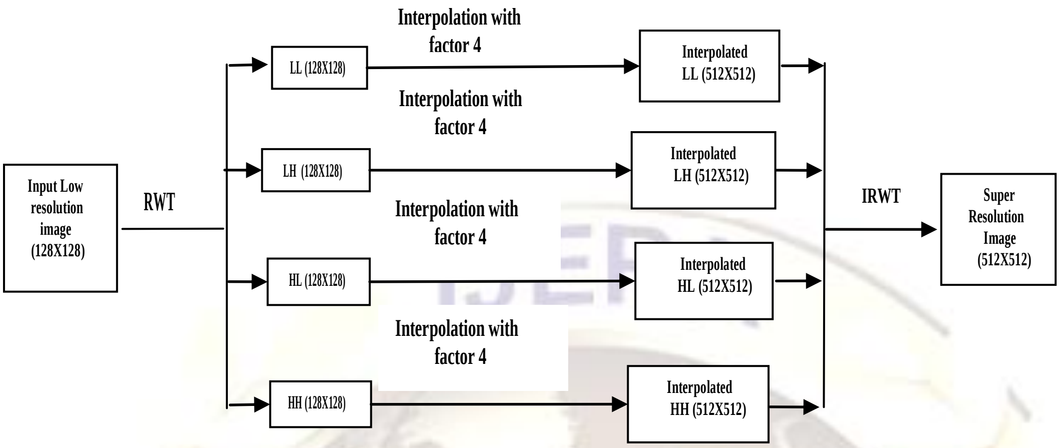
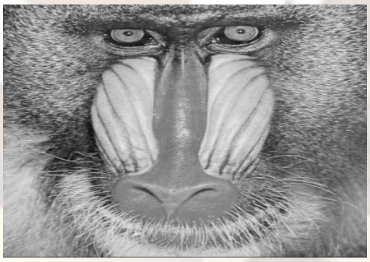


Fig. 4 Proposed Method

Table 2 shows the comparison of super resolution of the proposed method with the interpolation method and DASR method for different wavelets in terms of RMSE and PSNR. It is clear from the comparative table that the PSNR of super resolution image of proposed method is better as compared to interpolation method and DASR method. Qualitative results of Super resolution of Lena, Elaine, Baboon and Peppers images by different methods (Interpolation method, DASR method and proposed method) are shown in the Fig. 6, Fig. 7, Fig. 8 and Fig. 9 respectively.

(a)

(b)



(c)

(d)

Fig. 5 Test image (a) Lena, (b) Elaine, (c) Baboon, (d) Peppers.

Table 1. Numerical results on the test images with different wavelet types.

Wavelet type	Lena		Elaine		Baboon		Peppers	
	RMSE	PSNR	RMSE	PSNR	RMSE	PSNR	RMSE	PSNR
Haar	5.66	33.08	5.94	32.65	8.17	29.33	5.84	32.80
Db8	7.23	30.94	7.84	30.24	9.29	28.77	7.32	30.83
Db9/7	8.29	29.75	9.33	28.73	9.84	28.27	8.49	29.55
Sym4	8.29	29.74	9.34	28.72	9.84	28.27	8.51	29.53
Sym8	9.30	28.76	10.07	28.07	10.18	27.97	9.45	28.62

Table 2. Comparison between the Interpolation super resolution method [9], DASR method [10] and the proposed method in terms of RMSE and PSNR.

Methods / Images	Interpolation method			DASR method			Proposed method		
	Interpolation type	RMSE	PSNR	Wavelet type	RMSE	PSNR	Wavelet Type	RMSE	PSNR
Lena	Nearest neighbor	11.33	27.04	Haar	15.01	24.60	Haar	5.66	33.08
				Db8	14.69	24.79	Db8	7.23	30.94
	Bilinear	10.87	27.40	Db9/7	15.06	24.57	Db9/7	8.29	29.75
	Bicubic	10.60	27.62	Sym4	15.06	24.57	Sym4	8.29	29.74
				Sym8	14.99	24.61	Sym8	9.30	28.76
Elaine	Nearest neighbor	10.34	27.84	Haar	15.95	24.10	Haar	5.94	32.65
				Db8	15.74	24.19	Db8	7.84	30.24
	Bilinear	9.67	28.42	Db9/7	15.92	24.09	Db9/7	9.33	28.73
	Bicubic	9.51	28.56	Sym4	15.92	24.09	Sym4	9.34	28.72
				Sym8	15.95	24.10	Sym8	10.07	28.07
Baboon	Nearest neighbor	21.06	21.66	Haar	15.59	24.27	Haar	8.17	29.33
				Db8	15.47	24.34	Db8	9.29	28.77
	Bilinear	20.89	21.73	Db9/7	15.61	24.26	Db9/7	9.84	28.27
	Bicubic	20.72	21.80	Sym4	15.61	24.26	Sym4	9.84	28.27
				Sym8	15.57	24.28	Sym8	10.18	27.97
Peppers	Nearest neighbor	12.33	26.33	Haar	15.38	24.39	Haar	5.84	32.80
				Db8	15.15	24.52	Db8	7.32	30.83
	Bilinear	11.54	26.88	Db9/7	15.40	24.38	Db9/7	8.49	29.55
	Bicubic	11.37	27.01	Sym4	15.40	24.38	Sym4	8.51	29.53
				Sym8	15.36	24.40	Sym8	9.45	28.62

Fig. 6 (a) *Lena* low resolution image, [b-d] Super resolution methods (b) Interpolation (Bicubic), PSNR=27.62 dB (c) DASR (Db8 + Bicubic), PSNR =24.79 dB, (d) Proposed (Haar + Bicubic), PSNR= 33.08 dB.

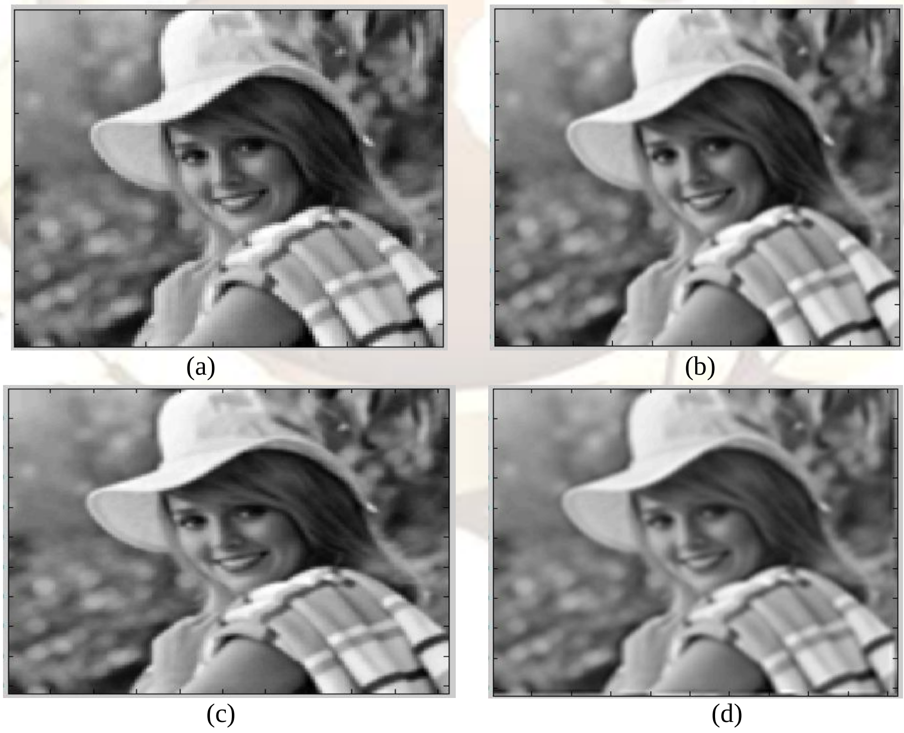


Fig. 7 (a) *Elaine* low resolution image, [b-d] Super resolution methods (b) Interpolation (Bicubic) PSNR= 28.56dB, (c) DASR (Db8 + Bicubic), PSNR = 24.19 dB, (d) Proposed method (Haar + Bicubic), PSNR= 32.65 dB.

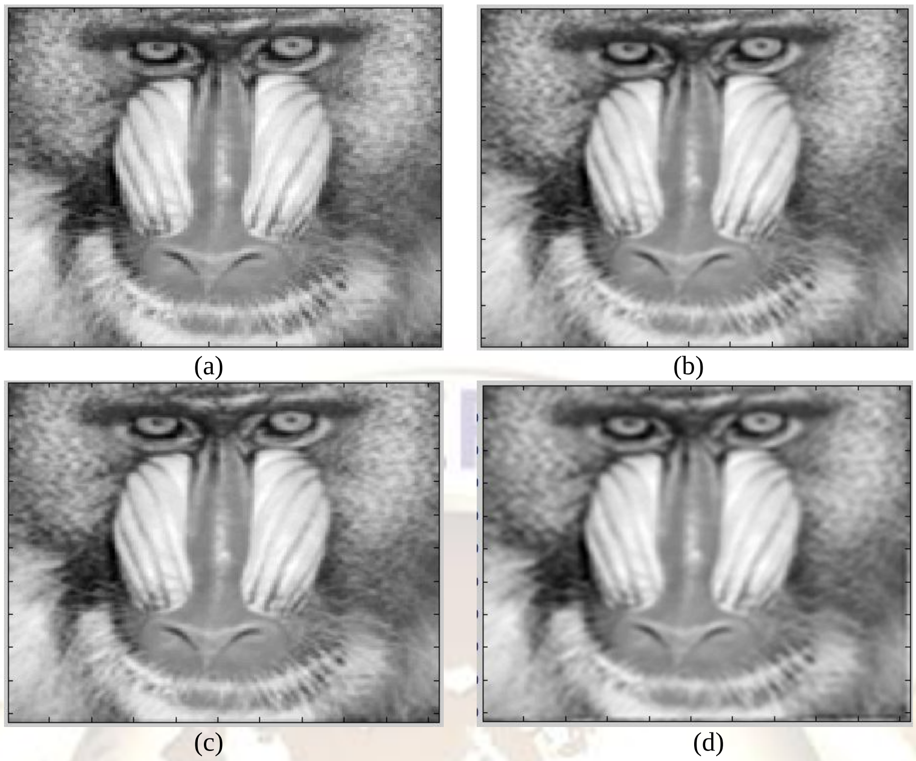


Fig. 8 (a) *Baboon* low resolution image, [b-d] Super resolution method (b) Interpolation (Bicubic), PSNR= 21.80 dB, (c) DASR (Db8 + Bicubic), PSNR = 24.34dB, (d) Proposed (Haar + Bicubic), PSNR= 29.33dB.

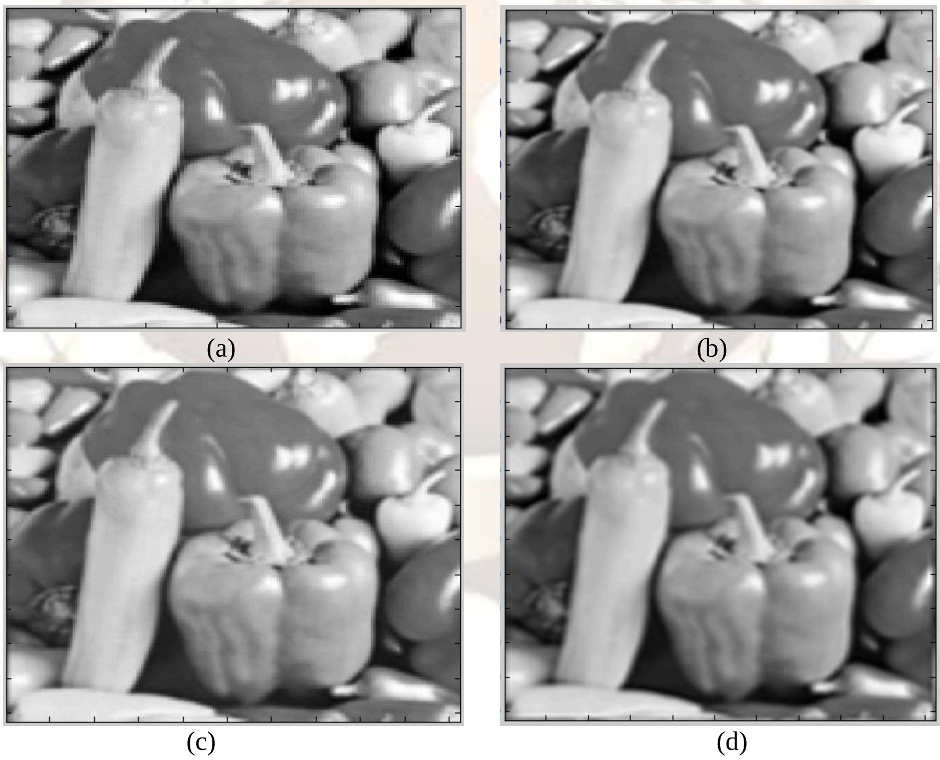


Fig. 9 (a) *Peppers* low resolution image, [b-d] super resolution methods (b) Interpolation (Bicubic), PSNR= 27.01 dB, (c) DASR, (Db8 + Bicubic), PSNR= 24.52 dB, (d) Proposed (Haar + Bicubic), PSNR= 32.80 dB.

II. CONCLUSION

This paper proposes a new super resolution technique that uses RWT instead of DWT. RWT reduces aliasing effect as it does not down sample the image. This technique uses RWT to decompose an input image to different subband images. The subbands are then interpolated by factor 4. Afterwards, these entire images are combined using IRWT to generate super resolution image. The experiment is repeated for various wavelets and interpolation methods. The best result is obtained by combining Haar wavelet with bicubic interpolation. The proposed method has been tested on the well known benchmark images, where their PSNR and visual quality show the superiority of the proposed technique over the conventional and state of art image resolution enhancement techniques.

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