RESOLUTION ENHANCEMENT ALGORITHM BASED ON WAVELET AND EDGE EXTRACTION TECHNIQUES IN NOISE PRESENCE

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The images and video sequences registering in optical, radar, medical applications, presented in digital photographs, on HD TV, in electron microscopy, etc. are obtained from electronic devices that use different sensors [1-3]. The visual quality of the images and frames in the video sequences depend on spatial resolution, and because of the physical limitations this suffers of precision needed that can be improved developing better sensors via manufacturing process that seems as a difficult and high cost task. That is why, in many applications of the image/video processing, the additional methods and algorithms are developed where the goal is to restore the resolution degraded in a sensor, permitting better observations of the fine details, edges, etc. [1, 4, 5]. This can be performed using the super resolution (SR) procedures generating a high-resolution (HR) images from one or several low-resolution (LR) images/video frames [1-6]. The goal of the developed algorithm is to provide better resolution than those obtained by other state-of-the-art filter. A number of approaches have been proposed designing the SR algorithms [1-7]. Among them there are: the *nearest neighbor* algorithms, the *bilinear* interpolation, the *bi-cubic* technique, the *fuzzy logic* methods and techniques based on the *spline* technique. Image resolution enhancement using wavelet transform (WT) domain is a relatively new subject, and recently many novel algorithms have been designed [6-9].

A novel resolution enhancement technique presented here uses the interpolation of the high frequency (HF) sub-band images (LH, HL, and HH) in WT domain employing the input LR image. All sub-band images are combined and interpolated with edge information via IDWT performing a final HR-enhanced image. In difference with traditional models in SR WT based frameworks used in literature, a novel model uses the initial LR image that is contaminated by Gaussian noise, so, the additional filtering procedure should be applied before SR procedure. The proposed more realistic model guarantees the robustness of SR process employed when small variations of real data are present.

Below, we justify that the novel algorithm named as *Super Resolution using Wavelet Domain Interpolation with Edge Extraction and Filtered* (SR-WDIEEF) takes real advantages, comparing it with other better SR WT based techniques such as: (WDIRECS) [6]; (DASR) [7]; (IREDSWD) [8]; (DWTSIRE) [9].

Different test images (*Baboon, Cameraman, Peppers, Woman Blonde, Lena, House*) and several RS satellite images (*Sat-1, Sat-2*) with various physical characteristics (fine details, edges, textures, contrasts, smooth, rough background, etc.) are studied applying the designed and better existing SR procedures. To get objective performance of reconstruction the following criteria: PSNR, MAE and SSIM are used where the last metric matches better with human subjectivity [10]. In this paper, the following families of classic wavelet functions are used: *Daubechies* (Db), *Symlet* (Sym), *Coiflet* (Coif) and *biorthogonal* (Bior), as well as novel wavelet atomic functions (WAF) [11]: fup_n, up_n, π_n, and g_n.

A novel framework employs the first level of DWT in an input LR image decomposing it into LL, LH, HL, and HH sub-band images. The LR image without quantization is applied as an input in current proposal during the resolution enhancement process. Therefore, instead of using LF sub-band images, which contains less information than an original input image has, we use this input image applying the interpolation process. Hence, the input LR image is interpolated with the half of the interpolation factor 2, following, this data is used to interpolate the HF sub-bands, as shown in Fig. 1. In order to preserve more edge information, i.e., obtaining a sharper enhanced image, we have proposed an intermediate stage in HF sub-band interpolation process, finding the difference between the LL image and the LR image; this give a better performance using difference in the HF image components. During numerous simulations of the proposed and better existing techniques the objective and subjective performance results are computed for images. Table 1 exposes the criteria results (PSNR, MAE, SSIM) for several test images with different features (fine details, edges, textures, contrasts, etc.) permitting to compare the designed SR-WDIEEF framework and other promising SR algorithms. Because the textures and chromaticity properties of the test images are differ, the performance results confirm the robustness of current proposal. Fig.2 presents the subjective and objective performance where one can see the superiority of developed framework in SR process for the *Sat_1* image. Similar quality results are observed analyzing other test images employing proposed SR framework in the simulation experiments. In all these images according to Table 1, Fig. 1 and Fig.2, the better performance in terms of objective criteria (PSNR, MAE and SSIM) as well as in subjective perception can be viewed when the proposed SR-WDIEEF framework is employed.

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The principal difference of the novel algorithm in comparison with existing methods consists in the mutual interpolation via *Lanczos* and *NNI* techniques for WT HF sub-band images and edge extracting images. Additionally, novel framework applies denoising filtering using the *Non-Local Means* (NLM) for input LR image and for HF sub-bands, in last case, an additional denoising permits to suppress artifacts generated by DWT. Finally, all sub-band images are combined, reconstructing a final HR image via IDWT that appears to demonstrate superiority of designed algorithm in terms of objective criteria and subjective perception in comparison with better existing techniques.

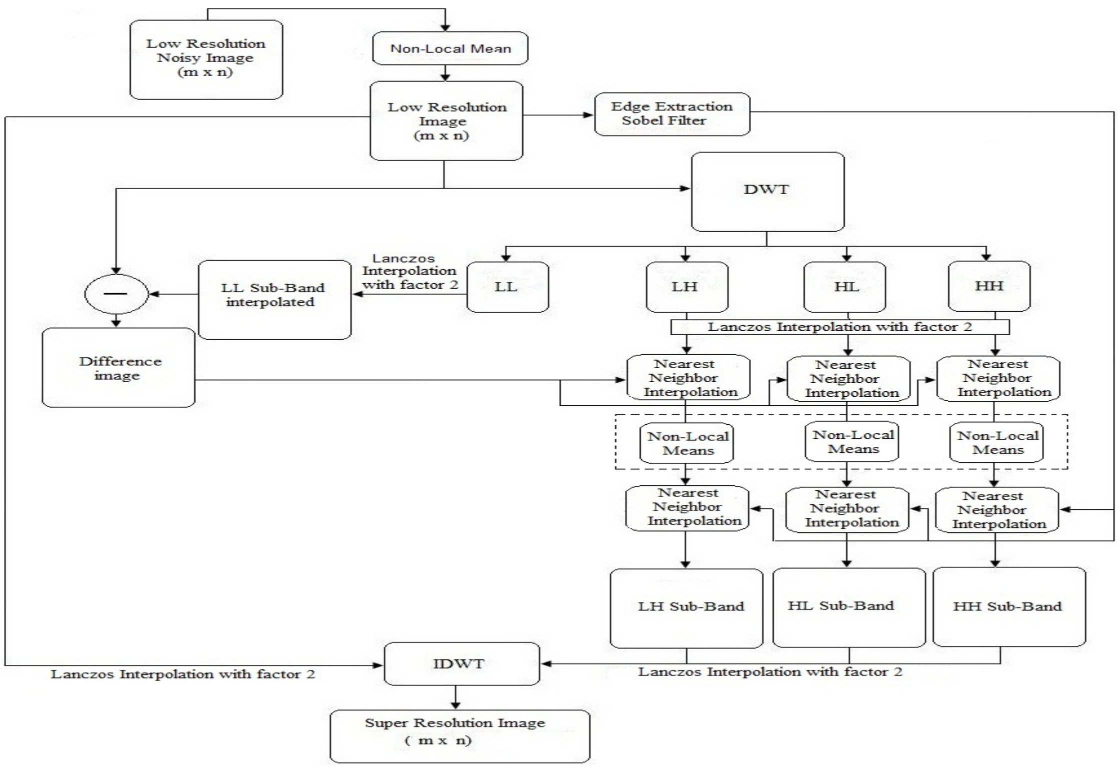

Fig. 1. Block diagram of the designed resolution-enhancement algorithm.

SR Methods		Lena			Peppers			Sat_1			Sat_2		
		MAE	PSNR	SSIM	MAE	PSNR	SSIM	MAE	PSNR	SSIM	MAE	PSNR	SSIM
IREDSWD [8]	Db1	7.31	30.89	0.843	13.84	27.81	0.887	9.46	29.95	0.864	12.56	27.66	0.875
	Sym1	7.30	30.89	0.843	13.84	27.81	0.887	9.86	28.95	0.794	13.46	26.36	0.865
DWTSIRE [9]	Db1	6.71	30.08	0.815	2.62	35.36	0.891	8.92	30.04	0.887	11.76	28.09	0.876
	Sym1	6.71	30.08	0.815	2.62	35.36	0.891	9.92	30.44	0.887	12.10	27.13	0.805
DASR [7]	Db1	6.73	30.07	0.814	2.63	35.37	0.891	8.95	29.42	0.798	12.82	27.58	0.806
	Sym1	6.73	30.07	0.814	2.63	35.37	0.891	9.45	28.12	0.787	12.98	27.23	0.796
WDIRECS [6]	Db1	7.15	29.88	0.806	3.06	35.16	0.882	9.48	28.68	0.810	12.30	27.76	0.816
	Sym1	7.16	29.88	0.806	3.07	35.16	0.882	9.45	28.12	0.791	12.59	27.55	0.811
PROPOSED SRWDIEEF	Db1	6.12	30.66	0.852	1.38	36.54	0.911	8.42	30.54	0.895	12.02	28.16	0.893
	Sym1	6.12	30.65	0.852	1.38	36.54	0.921	8.92	29.54	0.877	12.08	28.13	0.883
	up_9	2.54	34.59	0.851	4.18	32.91	0.926	8.92	30.14	0.877	11.76	28.10	0.887
	π_2	5.80	32.84	0.787	2.52	35.07	0.926	8.95	28.72	0.875	12.10	27.13	0.825
	g_2	6.04	32.80	0.782	1.69	36.76	0.914	8.42	30.14	0.875	12.06	28.11	0.886

Table 1. Objective criteria results with for resolution enhancement from 128x128 to 512x512 (LR image is contaminated by Gaussian noise with deviation of 0.02).

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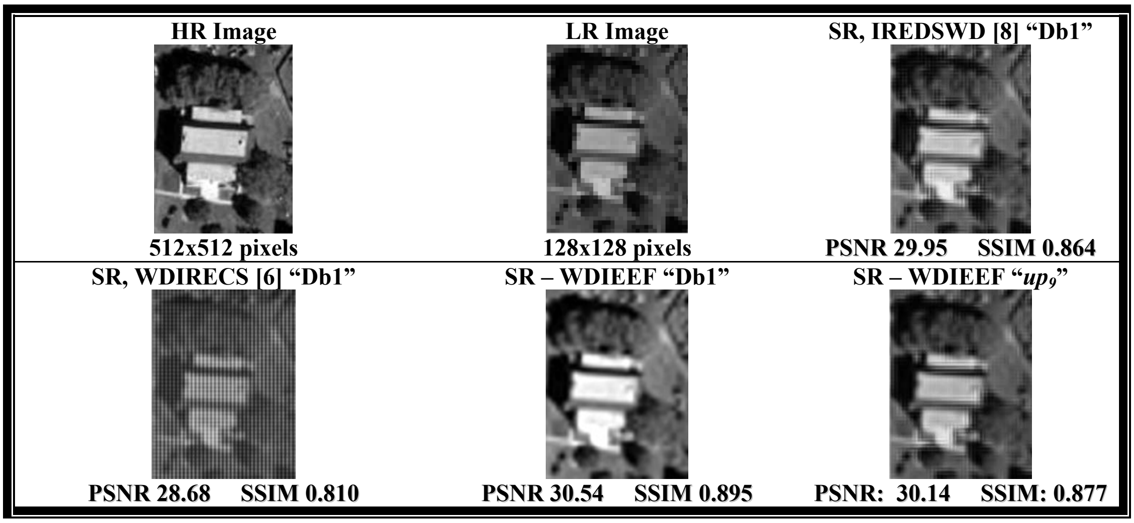

Fig. 2. Visual perception results for *Sat_1* image contaminated by Gaussian noise with deviation of 0.02.

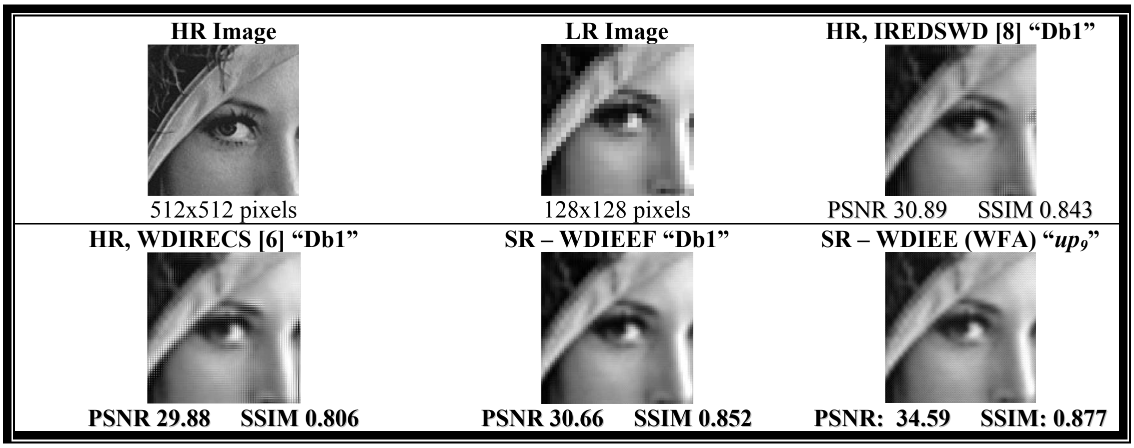

Fig. 3. Visual perception results for *Lena* image contaminated by Gaussian noise with deviation of 0.02.

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