Two Stage Wavelet based Image Denoising

Glincy Abraham, Neethu Mohan, Sreekala S, Neethu Prasannan, K P Soman

Centre for Excellence in Computational Engineering and Networking
Amrita Vishwa Vidyapeetham, Coimbatore, Tamil Nadu, India-641112

ABSTRACT

In this paper we are proposing a 2-stage wavelet based denoising technique. First stage of denoising is performed on the approximation coefficient obtained from the level 1 wavelet decomposition [1] of the noisy image and second stage of denoising is applied on the reconstructed image. The second stage denoising has shown a better result on to the reconstructed image. The detail coefficients are newly estimated from the first level denoised approximation coefficients. For denoising, techniques like Total Variation [3], Split Bregman [4] and NL means [5] are used. The quality of results obtained from different denoising techniques has been measured using various objective matrices such as PSNR, MSE on standard test images.

General Terms

Denoising, Wavelet decomposition

Keywords

Total Variation, Split-Bregman, NL-means, Edge detection

1. INTRODUCTION

Denoising is an important preprocessing technique in image processing, which removes the noise while preserving the image quality [8]. In order to retain the edge information and to maintain the quality of the denoised image, wavelet based decomposition [9] was introduced along with conventional image denoising [2]. For estimating the performance of this technique various wavelets and denoising techniques are applied on the standard images.

Nowadays Wavelet transforms has become a powerful computational tool and plays a significant role in image processing. DWT (Discrete Wavelet Transform) decomposes the input image into approximation and detail coefficients. In this paper, we applied the denoising techniques on these approximation coefficients and these denoised coefficients are used for the estimation of new detail coefficients (horizontal, vertical and diagonal). The denoised approximation and estimated detail coefficients are used for the reconstruction of the image. Amount of noise in this reconstructed image will be considerably less. Second stage denoising helps in further filtering of noises in the image and is shown in section 4. This estimation is done with different wavelets such as 'haar', 'db2', 'bior2.4'.

The techniques used in this paper for denoising include TV denoising [3] Split-Bregman [4] and NL-Means [5]. TV denoising is very effective denoising technique which removes the noise by solving a nonlinear minimization equation. Split Bregman is one of the fastest algorithms for solving through convex optimization. NL-means is another denoising technique based on non-local averaging of pixels. For efficient edge detection Canny [6] method proposed by John F Canny is used, which uses multi-stage algorithm. Canny uses thresholding with hysteresis which requires two thresholds – high and low.

Section 2 gives an over view of various denoising techniques. Section 3 introduces the proposed method. Section 4 discusses the results for various inputs and its quality measurements.

2. DENOISING TECHNIQUES

2.1 Total Variation

Total variation based filtering was introduced by Rudin, Osher, and Fatemi [3]. Total variation denoising is applicable in many digital images processing for reducing the noise. The total variation (TV) of a signal measures how much the signal changes between signal values. Total variation of an N point signal $X(n), 1 \le n \le N$ is defined as

$$TV(x) = \sum_{n=2}^{N} |x(n) - x(n-1)| \qquad (1)$$

For an image $u(x, y)$, then TV to be defined as,

$$TV(u) = \sum_{i=1}^{M-1}\sum_{j=1}^{N-1} |u(i,j) - u(i+1,j)| + |u(i,j) - u(i,j+1)| + \sum_{i=1}^{M-1} |u(i,N) - u(i+1,N)| + \sum_{j=1}^{M-1} |u(M,j) - u(M,j+1)| \qquad (2)$$

The objective function for total variation can be defined as

$$u_t = \frac{\partial}{\partial x}\left[\frac{u_x}{\sqrt{u_x^2 + u_y^2}}\right] + \frac{\partial}{\partial y}\left[\frac{u_y}{\sqrt{u_x^2 + u_y^2}}\right] - \lambda(u - u_0) \qquad (3)$$

Where λ is the regularization parameter, which controls how much smoothing is done. For higher values of λ denoised image is very similar to original noisy image. If it is too small value edge information cannot preserve, so we have to choose an optimum value for λ.

2.2 Split-Bregman

Split-Bregman is a suitable technique for solving total variation minimization problem based on partial differential equations. Optimization problems of the following type can be solved by using Split-Bregman technique

$$\phi : X \to R \quad H : X \to R$$

Constrained function can be defined as

$$\min_{u\in X}\|\phi(u)\|_1 + H(u) \qquad (4)$$

Constrained minimization problem with a subjected to condition can be expressed as,

$$\min_{u\in X, v\in R}\|v\|_1 + H(u) + (\lambda/2)\|d-\phi(u)\|_2^2 \qquad (5)$$

Then the simplified form of Split Bregman can be given as

$$(u^{k+1},d^{k+1}) = \min_{u\in X,d\in R} J(u,d) - J(u^k,d^k) + \lambda\langle b^k,\phi_u - \phi_u{}^k\rangle - \lambda\langle b^k, d-d^k\rangle + \lambda/2\|d-\phi(u)\|_2^2 \quad (6)$$

$$(u^k,d^k) = \min_{u\in X,d\in R} J(u,d) + (\lambda/2)\|d-\phi(u)-b^k\|_2^2 + C_2 \quad (7)$$

Where C_2 is a constant.

Split-Bregman Algorithm [7]

$$Intialize\; k=0\;\; u^0=0\;\; b^0=0$$
$$while \| u^k - u^{k-1}\|_2^2 > tol\; do$$
$$u^{k+1} = \min_u H(u) + \frac{\lambda}{2}\| d^k - \phi(u) - b^k\|_2^2$$
$$d^{k+1} = \min_d |d| + \frac{\lambda}{2}\| d - \phi(u^{k+1}) - b^k\|_2^2$$
$$b^{k+1} = b^k + \|(\phi(u^{k+1}) - b^k\|_2^2$$
$$k = k+1$$
$$end\; while$$

2.3 Non Local Means Algorithms

It is one of the denoising techniques based on non local averaging of all the pixels in the image. Noise contains both high and low frequency components. Earlier techniques focus on removing the high frequency noise at the cost of high frequency fine details of the original image. These techniques take least care in removing the low frequency noises. Non-local means is an algorithm that takes care of the loss of details.

The non local means algorithm considers the extensive amount of self similarity of pixels in an image[10]. Figure 1 [5] explains the self similarity of pixels in an image. Consider the pixel-points p, q_1 and q_2 and their respective neighborhood points. The neighborhoods of pixel p and q_1 are similar but that of q_2 are not similar, which means most pixels in same columns of p will have similar neighborhood as that of p. Pixels with similar neighborhoods can be used to denoised an image. The weighted intensity average of pixels with similar value provides the new denoised value.

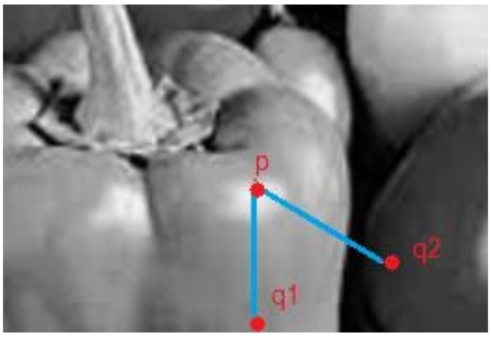


Fig 1. Example of self similarity in an image

The continuous version of NLM can be written as

$$u(x) = \frac{\int_\Omega w(x,y)u_o(y)dy}{\int_\Omega w(x,y)dy} \qquad (8)$$

Where $u_0 : \Omega \to R$ is the given noisy image, $u : \Omega \to R$ is the outcome of the NLM algorithm, function w is defined as

$$w(x,y) = e^{\int_\Omega G_a(z)|u_o(x+z)-u_o(y+z)|^2 dz/h^2}$$, Where

$G_a(z)|u_o(x+z)-u_o(y+z)|^2\,dz$ is the distance between patches located at x, y. h is positive constant which acts as scale parameter. Ga is Gaussian function with standard deviation a.

3. PROPOSED METHOD

Two stage wavelet based denoising approach combines different image processing techniques, wavelet based image decomposition, edge detection, for obtaining the denoised image from the noisy image without compromising the quality of the image. Conventional TV denoising requires large number of iterations for removing the Gaussian noise. And large number of iterations will lead to more blurring of the image. In this paper since two stage denoising is employed, less number of iterations happened. At first, the denoised image is decomposed into approximation and detail coefficients using DWT. The output of the Wavelet decomposition is shown in figure 2. The approximation coefficient contains the low frequency component and detail coefficients contain the high frequency component of the input image. One of the denoising techniques was applied with less number of iterations to the approximation coefficient. In order to get the edge information for retaining the information in the detail coefficients, the horizontal, vertical and diagonal differences of this denoised approximation image are estimated and Canny edge detection technique was used for finding the edges. Coefficients corresponding to these edge locations are retained in the detail coefficients and remaining are equated to zero. Denoised approximate coefficient and estimated detailed coefficients are used for wavelet reconstruction. This reconstructed image contains little amount of noise. Second stage denoising is used for removing this noise. Same denoising technique is used in both the stages. Block diagram for this method is shown in figure 3. Outputs obtained in different stages of this technique are shown in figure 4.

Fig 2: Approximation and detailed coefficient obtained by using DWT.

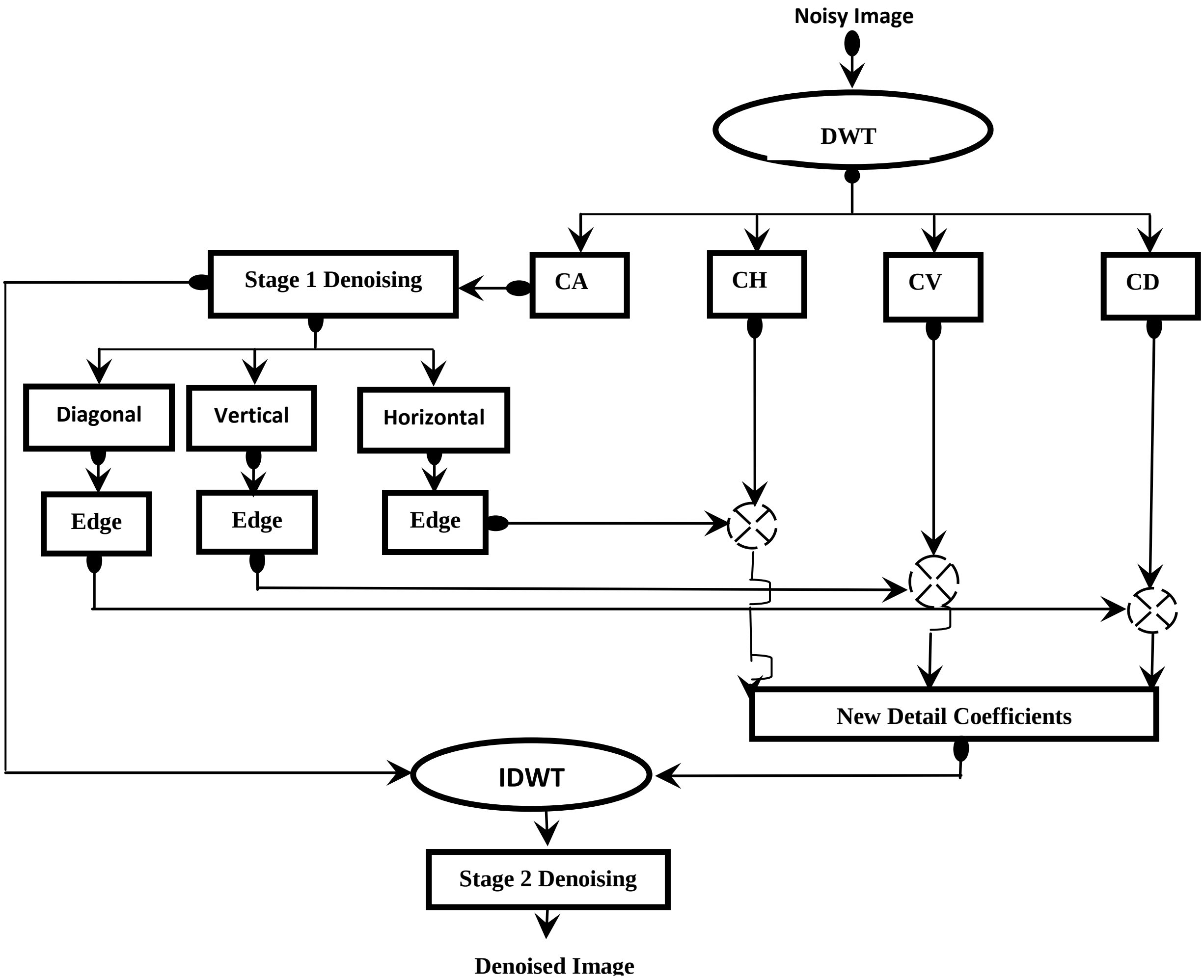


Fig 3: Block diagram of the proposed method

(a) (b) (c) (d)

Fig 4. The performance of the proposed algorithm for lena image with SNR of 25 dB a)original image b) noisy image c)first stage denoised image d)second stage denoised image. Bregaman denoising and bior2.4 wavelet is used

4. RESULTS AND DISCUSSION

For doing experiment Matlab 2009 is been used. Proposed method uses three different wavelets such as ‘haar’, ‘db2’, ‘bior2.4’ and different standard images (clean images) such as ‘lena’, ‘cortex’, and ‘pepper’. The clean images used are shown in figure. Additive white gaussian noise are added to these clean images with varying SNR (Signal to Noise Ratio) levels such as 10dB, 15dB, 20dB, 25dB, 30dB and 35dB. The result obtained by using Total variation, NL- means and Split Bregman are shown below with the help of figures, tables. The metrics used to evaluate the method are PSNR (Peak-Signal-to-Noise ratio) and MSE (Mean Square Error). The SNR level for the figure is 25dB. The four images in each figure represents original image, noise added image, first stage denoised image and second stage denoised image.

(a) (b) (c) (d)

Fig 5: Result of TV method

(a) (b) (c) (d)

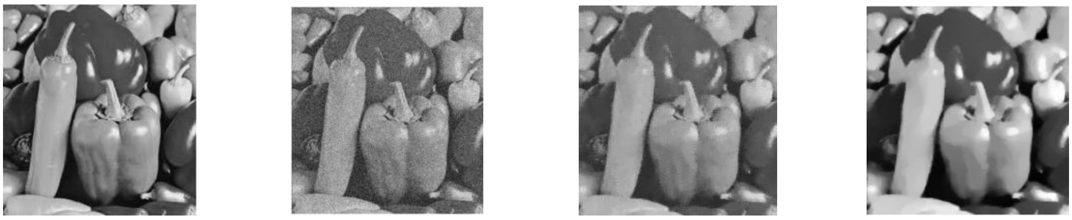
Fig 6: Result of Split Bregman method

(a) (b) (c) (d)

Fig 7: Result of NLmeans method

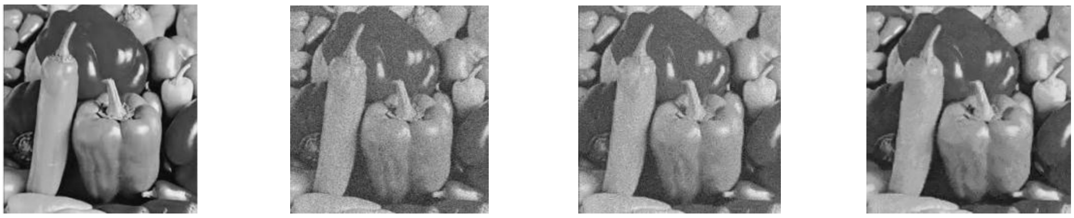
(a) (b) (c) (d)

Fig 8: Result of TV method



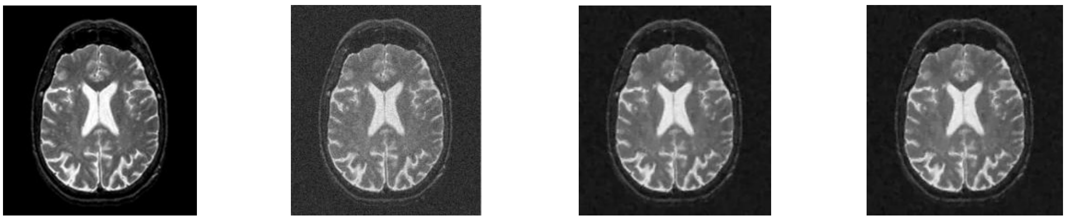
(a) (b) (c) (d)

Fig9: Result of Split Bregman method



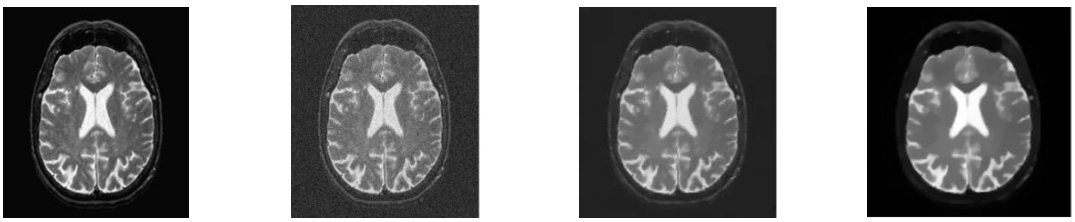
(a) (b) (c) (d)

Fig10: Result of NLmeans method



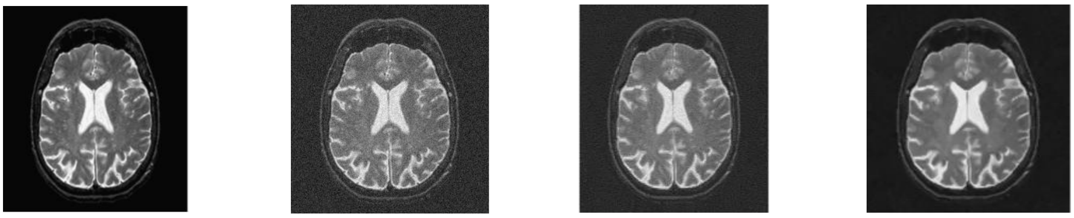
(a) (b) (c) (d)

Fig11: Result of TV method



(a) (b) (c) (d)

Fig12: Result of Split Bregman method



(a) (b) (c) (d)

Fig13: Result of NLmeans method

Outputs obtained by applying three denoising techniques in different images with SNR 25db and Bior2.4 wavelet. a) Original image b)Noisy image c)First Level Denoised Image d) Second Level Denoised Image

Table1: PSNR and MSE values for various SNR , denoising technique and wavelets applied on different images

IMAGES	WAVELETS	SNR	TV		SPLIT-BREGMAN		NL-MEANS	
			MSE	PSNR	MSE	PSNR	MSE	PSNR
		10	469.6815	21.4128	192.7240	25.2814	414.0674	21.9601
		15	307.8095	23.2480	184.3603	25.4741	269.3889	23.8270
		20	229.4304	24.5243	180.6849	25.5616	208.9667	24.9300
		25	190.0711	25.3416	183.4872	25.4947	167.4253	25.8926
	Haar	30	166.3524	25.9205	180.0933	25.5758	146.0011	26.4872
		35	149.5035	26.3843	180.2803	25.5713	133.4379	26.8780
		10	482.4780	21.2960	171.8085	25.7804	476.3154	21.3519
		15	306.2128	23.2706	158.4206	26.1327	291.7184	23.4812
		20	225.1808	24.6055	151.7401	26.3198	210.5647	24.8969
		25	175.1624	25.6964	150.7249	26.3490	164.7860	25.9616
	Bior2.4	30	148.2276	26.4215	154.5793	26.2393	141.2835	26.6299
		35	125.4892	27.1447	153.1577	26.2794	119.9662	27.3402
LENA		10	437.5258	21.7208	175.5789	25.6861	418.5901	21.9129
		15	275.8331	23.7243	165.9563	25.9309	258.7878	24.0014
		20	200.2419	25.1153	163.5259	25.9949	187.2144	25.0474
		25	163.0329	26.0081	165.9373	25.9314	145.6871	26.4966
	Db2	30	138.5293	26.7154	165.8690	25.9323	127.3375	27.0812
		35	121.6648	27.2792	164.2709	25.9752	111.3845	27.6626
		10	375.4918	22.3848	177.5720	25.6371	330.7893	22.9353
		15	244.6736	24.2449	171.4216	25.7901	220.9676	24.6875
		20	192.3557	25.2898	167.9459	25.8791	173.5558	25.7364

PEPPER	**Haar**	25	157.3129	26.1632	166.3207	25.9213	146.7435	26.4652
		30	140.4432	26.6558	167.3562	25.8944	130.7190	26.9674
		35	128.8912	27.0286	165.4439	25.9443	121.6589	27.2794
	Bior2.4	10	357.5616	22.5973	146.2815	26.4789	361.8132	22.5460
		15	220.0797	24.7050	137.0415	26.7623	219.8704	24.7091
		20	161.1183	26.0594	129.8188	26.9974	156.9398	26.1735
		25	126.8048	27.0994	131.9146	26.9279	125.2639	27.1525
		30	106.5310	27.8560	130.1494	26.9864	109.3381	27.7431
		35	94.4527	28.3787	130.5413	26.9733	96.3602	28.2918
	Db2	10	329.8899	22.9471	153.3561	26.2738	319.2815	23.0891
		15	205.4821	25.0031	148.6414	26.4094	194.5471	25.2406
		20	151.1988	26.3353	142.5305	26.5917	143.5987	26.5593
		25	122.8566	27.2368	141.7675	26.6150	119.6524	27.3516
		30	105.1201	27.9139	143.8016	26.5532	103.5709	27.9784
		35	93.5434	28.4207	141.4719	26.6241	92.9523	28.4482
CORTEX	**Haar**	10	173.4387	25.7393	192.8844	25.2778	171.4136	25.7904
		15	133.0572	26.8904	192.7704	25.2804	133.3394	26.8812
		20	117.0054	27.4487	194.0108	25.2525	122.7949	27.2390
		25	106.4295	27.8602	191.7412	25.3036	114.7209	27.5344
		30	101.8293	28.0521	192.4496	25.2876	111.4165	27.6613
		35	96.9273	28.2663	191.6156	25.3065	107.9106	27.8002
	Bior2.4	10	147.0779	26.4553	151.4136	26.3292	157.2083	26.1660
		15	99.9823	28.1316	151.6972	26.3210	107.4039	27.8206
		20	80.6164	29.0965	151.9697	26.3132	91.4771	28.5177
		25	69.7430	29.6958	152.6894	26.2927	82.1508	28.9847
		30	64.9670	30.0039	152.8228	26.2889	77.4640	29.2398
		35	58.6304	30.4496	152.46	26.2992	72.8118	29.5088
	Db2	10	137.1325	26.7594	169.1666	25.8477	143.4448	26.5640
		15	95.6656	28.3232	167.9859	25.8781	101.1889	28.0795
		20	80.5492	29.0702	170.2718	25.8194	89.9937	28.5887
		25	73.5569	29.4646	166.6787	25.9120	83.3093	28.9239

		30	67.1340	29.8614	169.1139	25.8490	79.2112	29.1429
		35	64.7134	30.0209	168.5356	25.8639	77.3656	29.2453

5. CONCLUSION

In this paper, a two stage wavelet based denoising method is presented. Experiments are conducted on 3 different images with different SNR values and the results for various denoising techniques are compared. The proposed method gives good results for different SNR values as seen in the table. Db2 and Bior2.4 wavelet gives better results compared with Haar. Here in denoising, only the detailed coefficients obtained from the dwt are retained, keeping the rest of the coefficients as zero. In future, denoised versions of these coefficients could also be utilized to provide better result.

6. REFERENCES

[1] Stephane G Mallat "A theory for multiresolution signal decomposition:The wavelet representation"IEEE Transactions On Pattern Analysis And Machine Intelligence,Vol 11, No. 7. July 1989

[2] Nilamani Bhoi, Dr. Sukadev Meher" Total Variation based Wavelet Domain Filter for Image Denoising" First International Conference on Emerging Trends in Engineering and Technology

[3] L. Rudin, S. Osher, and E. Fatemi. Nonlinear total variation based noise removal algorithms. PhysicaD, 60:259–268, 1992

[4] Jacqueline Bush "Bregman Algorithms" Senior Thesis. University of California, Santa Barbara, June 10, 2011

[5] A.Buades, B.Coll, and J Morel "A non-local algorithm for image denoising", IEEE International Conference on Computer vision and Pattern Recognition,2005

[6] John Canny, member, IEEE, "A Computational Approach to Edge Detection", IEEE Transactions on Pattern Analysis and Machine Intelligence, VOL. PAMI-8, NO. 6, November 1986

[7] Bregman Algorithms Author: JacquelineBush Supervisor Dr.CarlosGarc´ıa-Cervera June 10, 2011

[8] R C.Gonzalez and R.E Woods,Digital Image Processing, Addison Wesley Longman Inc.,2000.

[9] Kossi Edoh and John Paul Roop "A Fast Wavelet Multilevel Approach to Total Variation Image Denoising", International Journal of Signal Processing, Image Processing and Pattern Recognition Vol. 2, No.3,September 2009.

[10] Dr. K.P.Soman, R.Ramanathan "Chapter 25, Digital Signal and Image Processing- The Sparse Way" 2012 by Isa Publishers.