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Intelligent & Adaptive Image Denoising Based on Wavelets with Shrinkage Rule

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Abstract

Real time image processing should have high quality results at lesser computational time. A spatial image denoising method using 2D discrete wavelet transform (2D DWT) and Stationary wavelet transform (SWT) is presented in this paper for high quality image results. DWT gives high quality output at low levels of noise at relatively lesser time consumption where as it suffers from translation invariance. SWT overcomes translational invariance by removing the up samplers and down samplers and gives better image quality but consumes more computational time. Considering the advantages of both SWT and DWT, an attempt is made to propose an adaptive and intelligent denoising system which is based on both these wavelet transform methods. The operational schema involves three distinct approaches. The first approach is a buffer unit for approximately clean image. The second approach is based on SWT, and the effects of noise are minimized by soft thresholding at high frequency sub bands. The third approach is based on both SWT and DWT, the noise present in the high frequency sub bands of SWT and DWT are minimized by soft thresholding, and then modified high frequency sub bands of DWT are interpolated with modified high frequency sub bands of SWT using bicubic interpolation technique. The result is a noise free higher order sub bands which are combined with average band of SWT. Finally the resultant bands undergo inverse SWT for denoised output. The experimentation was performed on two different medical images; Peak signal to noise ratio (PSNR) is obtained for various noise variances ranging from 4 to 40 dB. The results shows that the proposed system is more suitable for real time applications where the time constraints are critical while giving high quality image output especially at low to moderate level of noise. In this work an intelligent denoising system is introduced that makes trade-off between the quality of denoised image and the time required for image denoising.

Keywords: 2D Discrete wavelet transform, Stationary wavelet transform, Peak signal to noise ratio, Image quality, Interpolation, Soft threshold.

Introduction

During acquisition or transmission, digital images often get affected by noise. It manifests itself as erroneous intensity fluctuation which steam from imperfection of imaging devices and transmission channel. Noise can seriously affect quality of image. It causes degradation of image spatial resolution, loss of image details and distortion of important image features. Therefore it is essential to correct corrupted pixels before the main processing.

Image and video denoising using adaptive dual-tree discrete wavelet packets (ADDWP) [1], which is extended from the dual tree discrete wavelet transform (DDWT) aim to develop a greedy based selection algorithm to determine the decomposition structure lower in computational complexity than a previously developed optimal basis selection algorithm with only a slight performance loss. Wavelet and Wiener filtering algorithm [2] has been proposed for denoising the image. Image denoising algorithms based on anisotropic diffusion in wavelet domain [3] with adaptive regularized filter size and time step has been proposed. Orthogonal wavelet based [4], incorporating wavelet thresholding method of minimizing effects of noise discussed. This effect of additive random noise was minimized using wavelet denoising technique through deducing the energy of a signal. Image denoising based on Haar wavelet transform [5] modeled where the image with noise is decomposed based on Haar wavelets, and then selects the soft threshold to clean the image noise. Stationary wavelet transforms (SWT) and combining with Prior Distribution Model (PDM) are proposed in [6], through which the threshold function with ideal shrinkage can be deduced, which could be used to improve image denoising in the smooth regions effectively.

A wavelet image denoising algorithm based on local Wiener filtering with directional windows to replace the traditional denoising methods has been described in [7]. A video denoising algorithm based on a spatiotemporal Gaussian scale mixture model in the wavelet transform domain has been proposed in [8].

Noises are removed by soft thresholding the high frequency sub-bands of SWT and DWT [10]. The image with noise is decomposed based on Haar wavelets, and then selects the soft threshold to clean the image noise. Balster in [11] tried to estimate noise level, and Francois in [12] used hardware support to estimate noise.

In this work, we used the estimation method presented in [11] as it had the advantage of consuming less time in estimation and requiring less memory size making it suitable for the targeted real-time applications. We understand that DWT gives high quality output at low levels of noise at relatively lesser time consumption where as it suffers from translation invariance. SWT overcomes translational invariance by removing the up samplers and down samplers and gives better image quality but consumes more computational time.

An adaptive and intelligent noise reduction technique for additive white Gaussian noise (AWGN) is proposed which aim at suppressing the noise, preserving the edge information at a lesser computational time. This paper is arranged as follows. First in section II the methodology used are defined. Next, in section III the proposed method is described. Section IV details the experimental analysis along with extensive simulations conducted on two medical images under wide range of noise corruptions (up to 40 dB) and their PSNR comparison with well-established state of the art methods for AWGN removal are presented, discussed and concluded.

Methodology

The proposed system for image denoising corrupted by AWGN is built based on discrete wavelet transform, stationary wavelet transform and bicubic interpolation. In this following section the theoretical background of DWT, SWT and bicubic interpolation are introduced.

Discrete Wavelet Transform

Nowadays, wavelets have been used quite frequently in image processing. They have been used for feature extraction, denoising, compression, face recognition, and image super-resolution. The decomposition of images into different frequency ranges permits the isolation of the frequency components introduced by “intrinsic deformations” or “extrinsic factors” into certain sub-bands. This process results in isolating small changes in an image mainly in high frequency sub-band images. Hence, discrete wavelet transform (DWT) is a suitable tool to be used for designing a classification system. The 2 D wavelet decomposition of an image is performed by applying 1 D DWT along the rows of the image first and then, the results are decomposed along the columns. This operation results in four decomposed sub-band images referred to as low–low (LL), low–high (LH), high–low (HL), and high–high (HH). The frequency components of those sub-band images cover the frequency components of the original image as shown in Fig.1.

LL	HL
LH	HH

Figure 1: The result of 2D DWT decomposition

Stationary Wavelet Transform

The SWT was independently developed by several researchers and under different names, e.g. the un-decimated wavelet transform, the invariant wavelet transform and the redundant wavelet transform. The key point is that it gives a better approximation than the discrete wavelet transform (DWT) since, it is redundant, linear and shift invariant.

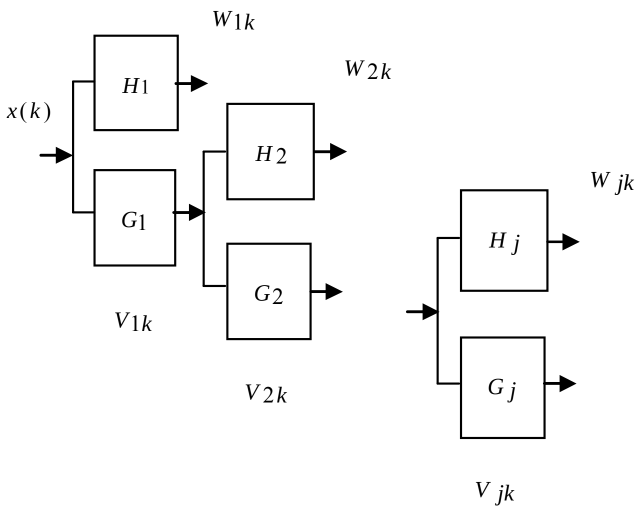

Figure 2: Stationary Wavelet Transform

These properties allow SWT to be realized using a recursive algorithm. Fig.2 shows the computation of the SWT of a signal **x(k)**, where $\mathbf{W_{jk}}$, and $\mathbf{V_{jk}}$ are the detail and the approximation coefficients of the SWT. The filters $\mathbf{H_j}$ and $\mathbf{G_j}$ are the standard low pass and high pass wavelet filters, respectively. In the first step, the filters H_1 and $\mathbf{G_1}$ are obtained by up sampling the filters using the previous step (i.e. $\mathbf{H_{j-1}}$**and** $\mathbf{G_{j-1}}$).

Bicubic interpolation

Interpolation is a method of constructing new data points with the range of a discrete set of known data points. 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 can be accomplished using Lagrange's polynomials, Cubic splines or Cubic convolution algorithm. In the proposed scheme using both DWT and SWT bicubic interpolation is chosen instead of bilinear interpolation for the reason that, the later will take only 4 pixels (2x2) into account, while the former will take 16 pixels around it (4x4) while computing average, also images resampled with bicubic interpolation are smoother and has fewer interpolation artifacts. Suppose the function values ***f*** and the derivatives ***f*x**, ***f*y** and ***f*xy** are known at the four corners (0,0),(1,0),(0,1) and (1,1) of the unit square. The interpolated surface can then be deduced by equation (1).

$$p(x,y) = \sum_{i=0}^{3}\sum_{j=0}^{3} a_{ij}x^i y^j \tag{1}$$

Bicubic spline interpolation requires the solution of the linear system described above for each grid cell. An interpolator with similar properties can be obtained by applying a convolution with the following kernel in both dimensions as in equation (2).

$$W(x) = \begin{cases} (a+2)|x|^3 - (a+3)|x|^2 + 1 & \text{for } |x| \leq 1 \\ a|x|^3 - 5a|x|^2 + 8a|x| - 4a & \text{for } 1 < |x| < 2 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

Proposed system

The intelligent image denoising system makes trade-off between the quality and the time consumed for denoising process. Two spatial image denoising techniques (2D DWT & SWT) are used in the proposed system. The 2D DWT gives good quality image consuming less time for denoising. The SWT achieves good quality of image consuming large time for denoising. Thus in the proposed system we have modeled an adaptive and intelligent technique utilizing properties of both the methods according to estimated noise level. The noise in each frame in estimated dynamically and thus choice of denoising technique is opted accordingly. Previous techniques assume that level of noise is known prior to the noise removal process [11, 12]. In this method, estimation process presented in [11] is incorporated as it had the advantage of consuming less time for estimation and requires less memory size making it suitable for targeted real time applications. The schematic of the proposed image denoising framework is presented in the Fig.3. The frame work of proposed system contains three main components, which are discusses below.

Noise estimator

For the spatial noise estimation method, the level of noise in an image frame is deduced from the median value of wavelet co-effiecients in the HH band of 0^{th} scale. The median can effectively estimate the level of noise without being adversely influenced by useful co-efficients because vast majority of useful information in the wavelet domain is confined to HH band [11, 13]. It is worth to denote that, the human visual system appears to have sensitivity threshold. Therefore all frames with noise variance (σ) less than or equal to 5 dB looks equally clean to human eye but once σ value exceeds 20 dB the image frame looks adversely affected. Decision making component is modeled based on above fact. We make use of spatial image discontinuities represented by wavelet co-efficients in order to estimate the level of standard deviation of estimated AWGN in the frame.

Decision making component

In decision making component, the system chooses suitable action towards the input image frames according to the level of noise estimated. It can direct the frames to one of the two image denoising technique in the next step (SWT or DWT with SWT) [9, 10] or it considers a clean frame. The system assumes that image frame having noise level less than 5 dB will be insignificant and unnoticeable to human eye and will not perform denoising, thus minimizing the total time of denoising of the incoming image frames.

One of the two techniques will be applied if the noise level is above 5 dB. The first technique (SWT) will be chosen for low to moderate level of noise (up to 20 dB), as it will produce good denoised frame almost as those produced by the second technique (DWT with SWT), comparatively at a lesser time. The second technique is chosen for noise level (more than 20 dB), as it gives better results when compared to the first technique for higher noise variances.

Denoising component

Three schemas are modeled in the denoising component, schema A, Schema B and Schema C respectively.

Schema A- Modeled for clean frame which act as a buffer, does not undergo denoising.

Schema B [9] - The incoming noisy image frame is transformed with SWT, to obtain 4 sub bands of signals – LL, LH, HL & HH. SWT is applied to the higher order sub bands leaving out average band to produce modified sub bands. From each higher order bands mean absolute difference (MAD) is calculated for deducing the threshold (T) which was used soft thresholding. The obtained noise free higher order sub bands after soft thresholding are interpolated with original average band, Inverse SWT is applied on to the resultant band to obtain denoised image frame.

Schema C [10] - Similar kind of approach is done as like schema-B, where in both DWT and SWT are used, except that, the final stage of noise free modified higher order sub bands of DWT are interpolated with noise free modified higher order sub bands of SWT using bicubic interpolation technique. The resultant bands are made to undergo Inverse SWT for obtaining denoised image frame.

As wavelet coefficients with larger magnitude are connected with prominent features in the image data, the denoising can be achieved by applying a threshold to the wavelet coefficients followed by reconstruction of the signal to the original image in spatial domain. In the proposed method, soft shrinkage and Median Absolute Difference (MAD) are used, presented in [6]. The scaled MAD noise estimator is calculated by equation (3).

$$MAD = \frac{median(|x|)}{0.6745} \quad (3)$$

Where, |X| is the high frequency sub-band vector. From the Median absolute difference, threshold T is calculated by equation (4)

$$T = MAD * \sqrt{2 \log n} \tag{4}$$

Where, n is the length of the signal. Then the soft thresholding is applied to remove the noise. Finally, the noise free image is obtained by taking inverse SWT.

$$\rho_T(x) = \begin{cases} x - T, & if\ x \geq T \\ x + T, & if\ x \leq -T \\ 0, & if\ |x| < T \end{cases} \tag{5}$$

Experimental results

Table 1 shows the PSNR values, time for denoising by the proposed adaptive and intelligent denoising algorithm based on soft shrinkage rule, compared with the state of the art DWT, SWT technique, also compared with [9,10]. Two images are experimented in this module; Image1 shows coronary angiogram of right coronary artery, showing a discrete tight lesion in the mid segment. Image 2 shows coronary angiogram of left coronary artery, showing a discrete tight lesion in the proximal segment. The images sometimes are difficult to diagnose due to low image quality, minor vessel crossing the major vessel lesion obstructing the view; the exact length of the lesion cannot be predicted. The proposed algorithm works better with visual quality for these images for better diagnosis.

Many interesting facts reveal from the output of the proposed adaptive and intelligent denoising system, when noise variance is low (10 to 20 dB), it opts algorithm based on [9] and when the noise variance is exceeding more than 20 dB it opts for algorithm based on [10], conserving the time at the same time producing good visual quality of the denoised image frame. Simulated results of the same are presented in Fig. 5, 6. The proposed system exhibit 2 dB increase when compared to state of the art DWT & 1 dB increase when compared to state of the art SWT methods for all noise variance; also the time for computation is considerably lesser when compared to well established methods AWGN removal.

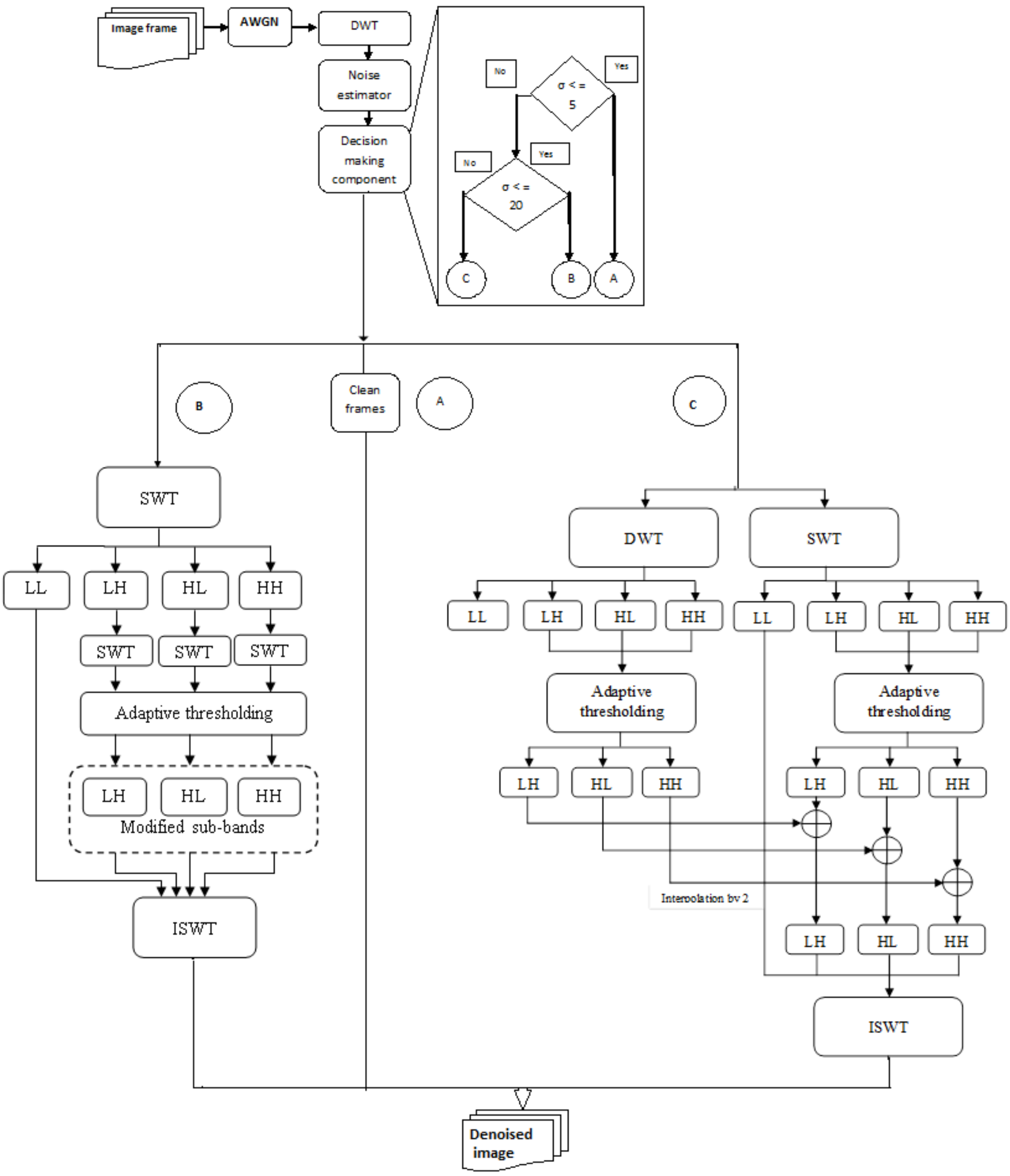

Figure 3: Proposed adaptive and intelligent image denoising system based on wavelets and shrinkage rule

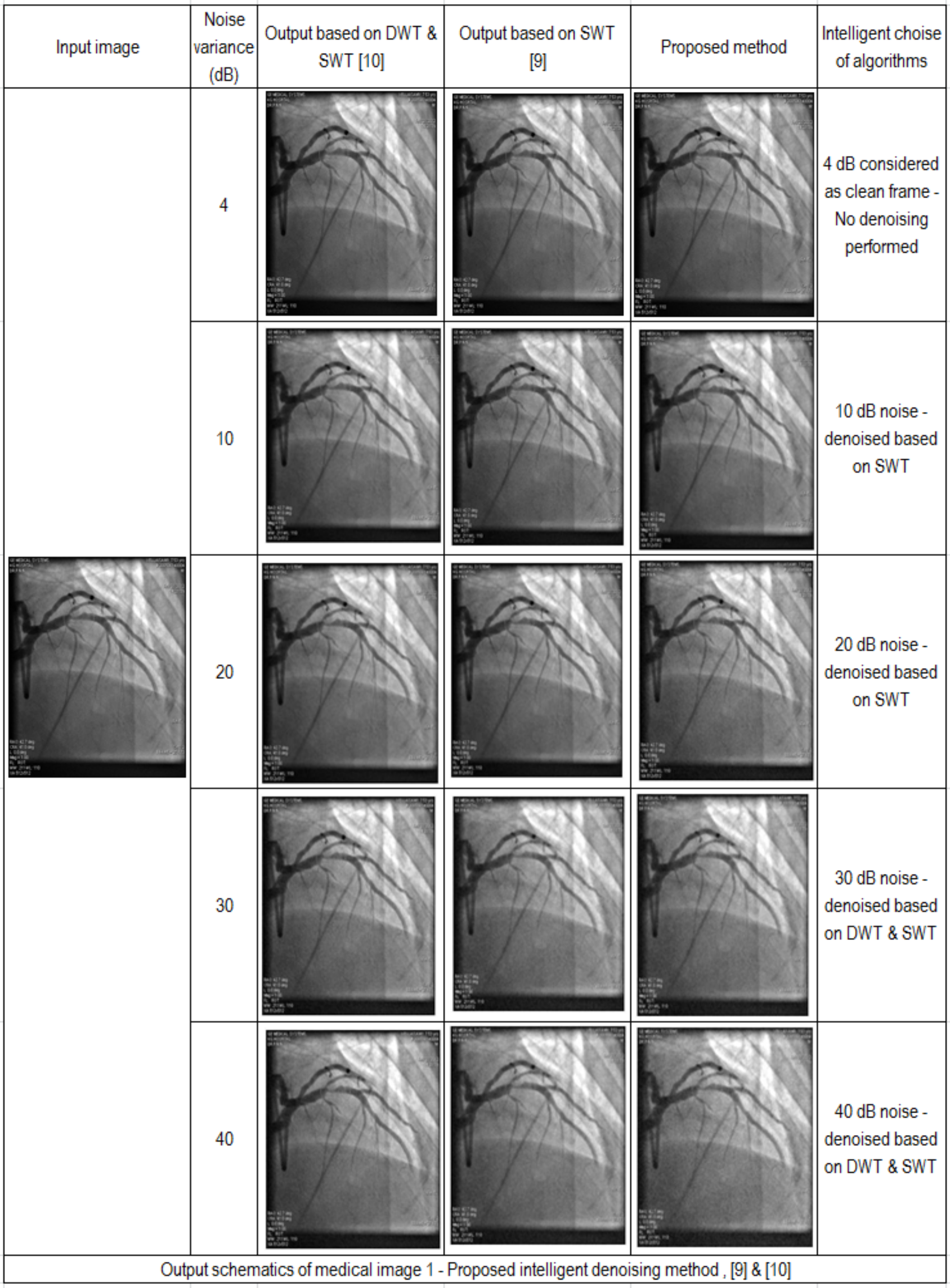

Figure 4: Output schematics of medical image 1 – proposed intelligent denoising method, [9] & [10].

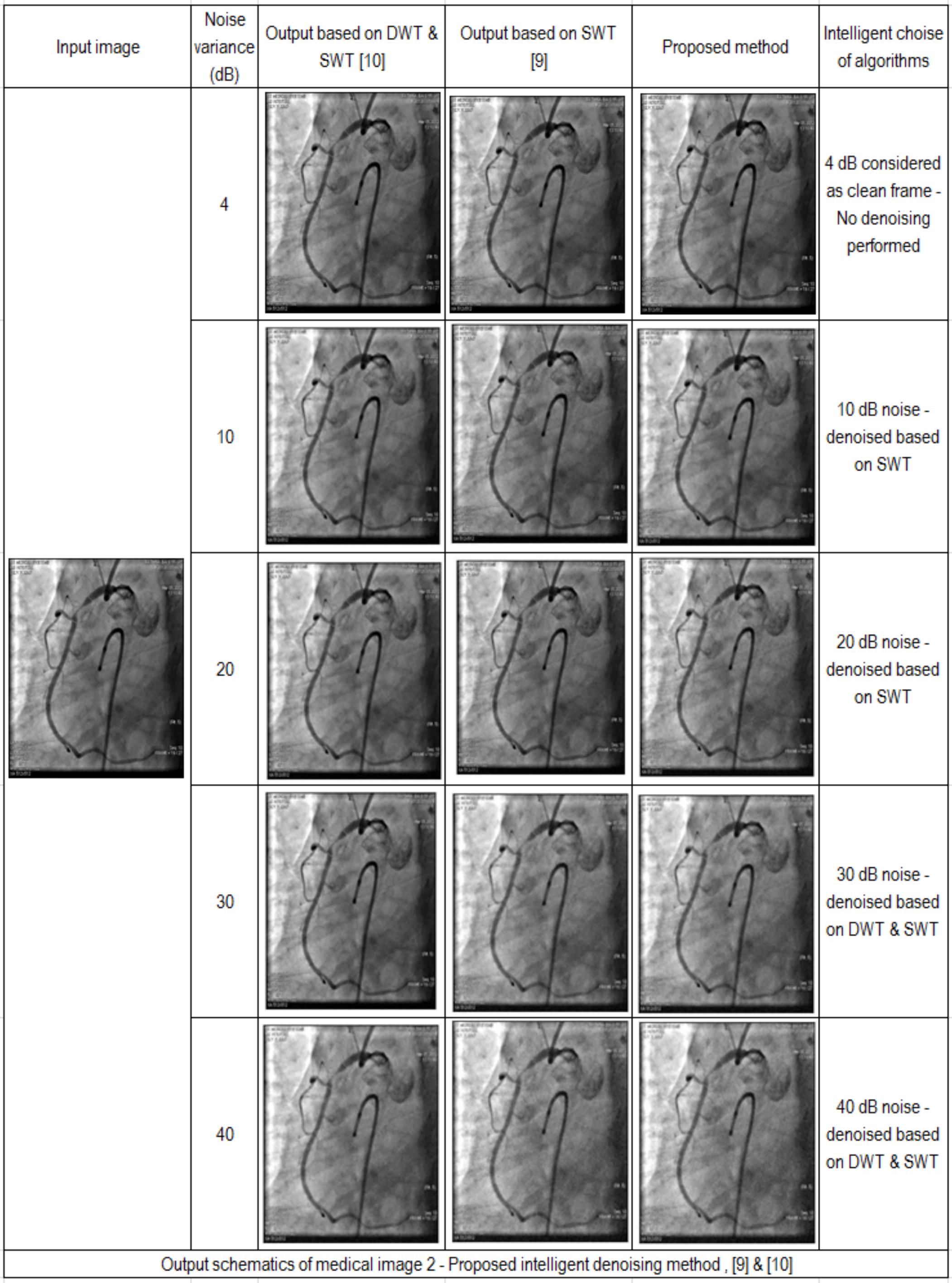

Figure 5: Output schematics of medical image 2– proposed intelligent denoising method, [9] & [10].

Table 1: PSNR, Time computation for proposed adaptive and intelligent image denoising algorithm based on wavelets.

Input image	PSNR (dB)			Proposed algorithm based on SWT [9]		Proposed algorithm based on DWT & SWT [10]		Proposed Intelligent denoising algorithm based wavelets & soft shrinkage rule	
	Estimated noise variance	DWT	SWT	Time (Sec)	PSNR(dB)	Time (Sec)	PSNR(dB)	Time (Sec)	PSNR(dB)
	10	30.89	32.34	26.39	32.81	24.75	32.34	26.58	32.81
	20	26.56	27.31	20.74	27.78	18.65	27.28	20.91	27.78
	30	23.56	23.53	20.52	24.01	14.71	24.02	14.79	24.02
	40	21.29	21.11	19.19	21.58	9.67	21.63	9.71	21.63
	10	30.36	32.26	24.18	32.73	24.78	32.05	24.28	32.73
	20	26.31	27.19	21.85	27.76	18.06	27.18	21.93	27.76
	30	23.42	23.54	20.91	24.01	11.66	23.99	11.81	23.99
	40	21.24	21.15	16.3	21.64	10.13	21.67	10.47	21.67

Conclusion

We proposed an adaptive and intelligent denoising technique based on DWT, SWT, and Soft thresholding for image corrupted by AWGN. The proposed system makes trade-off between quality of output and time for denoising. High frequency information in images is effectively extracted by using Discrete and stationary wavelet transform. The adaptive thresholding is used to denoise the image. The noise estimation is done by using median absolute difference method. Experimental results are compared with DWT, SWT and [9, 10]; it shows that the proposed denoising algorithm is very robust for medical images that are polluted by AWGN. The results produced by this system emphasis its ability to fulfill the real time application requirements in terms of producing high quality image in appropriate time for proper diagnosis and implementation in scanners. There are a number of potential improvements and extensions that may be done in future. Both algorithmic and software optimizations are needed to accelerate this algorithm by viewing certain advanced models in describing the statistical motion properties of natural video signals [14], that may be employed to impose stronger statistical prior in a Bayesian framework and in turn improve denoising performance.

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