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Optimal Nonlocal means algorithm for denoising ultrasound image

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Abstract

We propose a new measure for denoising image by calculating mean distance of all pixels in an image in non-local means (NL-means) algorithm. We compute and analyze the original NL-means algorithm which total all the distance of the patches but, our proposed algorithm calculates the mean value of all distance of all the patches and then than get the sum of all distance. Our proposed algorithm exhibit better result with comparison of the existing NL-means algorithm.

Keywords: NL-means, Patches, Mean Value, Measurement Matrix.

1. Introduction

Non-local means algorithm systematically use all possible self-predictions that an image can be provided [1]. But local filters or frequency domain filters are not avail to do that. Non-Local means (NL-means) approach introduced by Buades et al. to denoise 2D natural images corrupted by an additive white Gaussian noise [2]. NL-means filter normally calculate the total patch distances of the image, computed a weighted average of all the pixels in the image and denoise the image [1][3]. We propose a method that could denoise the image by calculating mean value of all patch distances of the image and denoise the image better than previous filter.

The aim is to recover the original image from a noisy measurement,

$$v(i) = u(i) + n(i) \quad \ldots \quad \ldots\ldots\ldots\ldots(1)$$

where, $v(i)$ is the result value, $u(i)$ is the "original" value and $n(i)$ is the noise perturbation at a pixel i. The best way to model the effect of noise on a digital image is to add some gaussian white noise. In that case, $n(i)$ are i.i.d. Gaussian values with zero mean and variance σ^2 [2].

The denoising methods must not change the original image. But, for the better understanding of an image those method allows to loss data to reduce the noise from the image [4]. Human vision can only understand the better recognition of the intensity of the pixel value of an image [5][6]. That's why, the propose method is allows calculate mean patch distances, avoiding the total patch distances.

Section II. gives the introduction of the NL-means algorithm. Section III. discuses the NL-means algorithm with mean distance calculation of pixel neighborhoods [7]. Section IV. compare the performance of the NL-means algorithm and proposed NL-mean algorithm.

2. Non-Local Means Algorithm

2.1. Non local means

Recently, a new patch-based non local recovery paradigm has been proposed by Buades et al [2]. This new paradigm replaces the local comparison of pixels by the non local comparison of patches. The current pixel does not depend on the distance between neither spatial distances nor in intensity distance. NL-means filter analyzes the patterns around the pixels.

2.2 Algorithm

In the actual *NL-means* algorithm filter the restored intensity $NL(u)(x_i)$ of pixel $x_i \in \Omega^{dim}$, is the weighted average of all the pixel intensities $u(x_i)$ in the image Ω^{dim} (a bounded domain $\Omega^{dim} \subseteq R^{dim}$):

$$NL(u)(x) = \sum_{x_j \in \Omega^{dim}} W(x_i, x_j) u(x_j) \quad \ldots\ldots\ldots\ldots\ldots\ldots(2$$

where the family of weights $\{w(x_i,x_j)\}_j$ depend on the similarity between the pixels x_i and x_j and satisfy the usual conditions $0 \le w(x_i, x_j) \le 1$ and $w(x_i,x_j)=1$. The weight evaluates the similarity between the intensities of the local neighborhoods (patches) N_i and N_j centered on pixels x_i and x_j.

For each pixel x_j in Δ_i, the Gaussian-weighted Euclidean distance $\|.\|^2_{2,a}$ is computed between the two patches $\mathbf{u}(N_j)$ and $\mathbf{u}(N_i)$ of image as explained in [8]. This distance is the traditional L_2-norm convolved with a Gaussian kernel of standard deviation a. The kernel is used to assign spatial weights to the patch elements. The central pixels in the patch contribute more to the distance than the pixels surrounded of the central pixel.

The weights $w(x_i, x_j)$ are then computed as follows:

$$W(x_i, x_j) = \frac{1}{Z_i} \exp - \frac{\|u(N_i) - u(N_j)\|^2_{2,a}}{h^2} \qquad (3)$$

where Z_i is the normalizing constant and h acts as a filtering parameter controlling the decay of the exponential function.

$$Z_i = \sum \exp - \frac{\|u(N_i) - u(N_j)\|^2_{2,a}}{h^2} .. \qquad (4)$$

The NL-means not only compares the gray level in a single point but also compute the geometrical configurations of whole neighborhoods [4]. Fig. 1 showing this fact, the pixel *q*3 has the same gray level value of pixel *p*, but the neighborhoods are much different and therefore the weight *w*(*p*, *q*3) is nearly zero[9][10].

3. NL-means algorithm with mean distance calculation

In previous section we discuss about the original algorithm of NL-means. In the equation (2) it estimated value $NL(u)(x_i)$, for a pixel x_i, is computed as a weighted average of all the pixels in the image. In this proposed algorithm of NL-means we determinate the value $NL(u)(x_i)$, for a pixel x_i, is calculate weighted mean distance of all the pixels in the image. The proposed algorithm is only compute the mean distances of the neighborhoods, total all the distances and then it averaged all the weights of neighborhoods.

In NL-means the current pixel does not depend on the distance between neither spatial distances nor in intensity distance. This filter analyzes the patterns around the pixels. The similarity between two pixels x_i and x_j depends on the similarity of the intensity gray level vectors $u(N_i)$ and $u(N_j)$, where N_k denotes a square neighborhood of fixed size and centered at a pixel k [3]. This similarity is determinate as a decreasing function of the weighted Euclidean distance, of equation (3), where a>0 is the standard deviation of the Gaussian kernel. In the distance calculation we compute mean distance of all neighborhoods and then calculate the total of all distances.

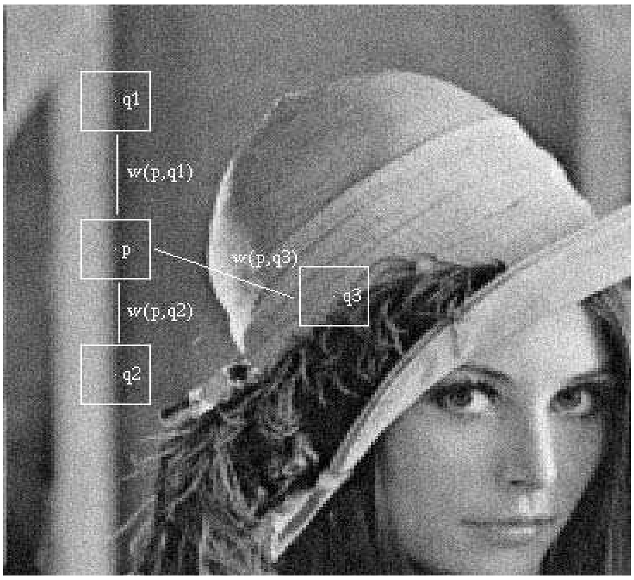

Figure 1: Similar neighborhoods pixels give a large weight, w(p,q1) and w(p,q2), while much different neighborhoods give a small weight w(p,q3).

$$\text{Mean}\left(\|u(N_i)-u(N_j)\|_{2,a}^{2} \right) * \text{size(patch)}$$

After calculating the mean distance of the intensities of the local neighborhoods (patches) N_i and N_j centered on pixels x_i and x_j, it need to multiply with the size of local neighborhood, because it need to have actual distances of all neighborhoods.

From Figure 2. we can read the pixel q4 has the same gray level value of pixel p, but it's neighborhoods make the w(p,q4) is smaller weighted. Here our propose NL-means algorithm turn the q4 pixel intensity less and q3 pixel intensity high [11]. That's why visually the image is more readable and it makes the noise removed.

The original NL-means algorithm donoises an image by smoothing and calculating the total distances of neighborhoods [4]. It improves the visibility of an image than local filters. But the propose algorithm compute the mean distance of all neighborhoods, then calculate the total and makes the image more visible and more easily edge detectable [10].

4. Performance and analysis

In this section we will compare NL-means algorithm and proposed algorithm under three well defined criteria: the noise removing, the visual quality of the restored image and the mean square error, that is, the Euclidean difference between the restored and original images [5][12].

For programming and calculation purposes of the NL-means algorithm, in a larger "search window" of size S×S pixels we restrict the search of similar windows [13]. In all the experimentation we have fixed a similarity square neighborhood N_i of 5×5 pixels and a search window of 11×11 pixels. If N^2 is the number of pixels of the image, then the final complexity of the algorithm is about $25 \times 121 \times N^2$ [3].

Large Euclidean distances lead to nearly zero weights acting as an automatic threshold because the fast decay of the exponential kernel.

These formulas are corroborated by the visual experiments of Figure 3. This figure displays the visual different

between those methods for the standard image Lena(512 x 512). In this figure we can identify the NL-means filter reduce the noise and blur the image and the propose filter reduce the noise [4], blur the image and detected some edges of the image. It makes the image quality increase and more suitable for human eyes.

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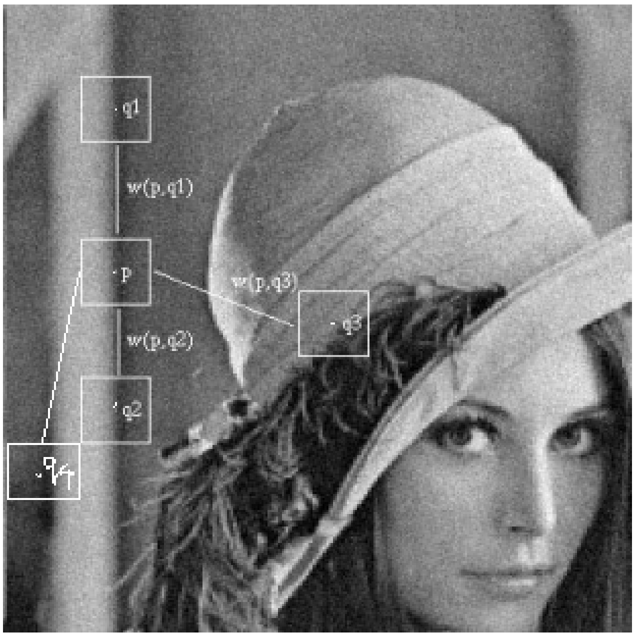


Figure 2: Similar neighborhoods pixels w(p,q1) and w(p,q2) give a large weights, while much different neighborhoods w(p,q3) and w(p,q4) give a small weight.

Table 1. displaying the improvement of the signal-to-noise ratio (SNR), root mean square errors (RMSE) and peak signal to noise ratio (PSNR) of two ultrasound noisy images.

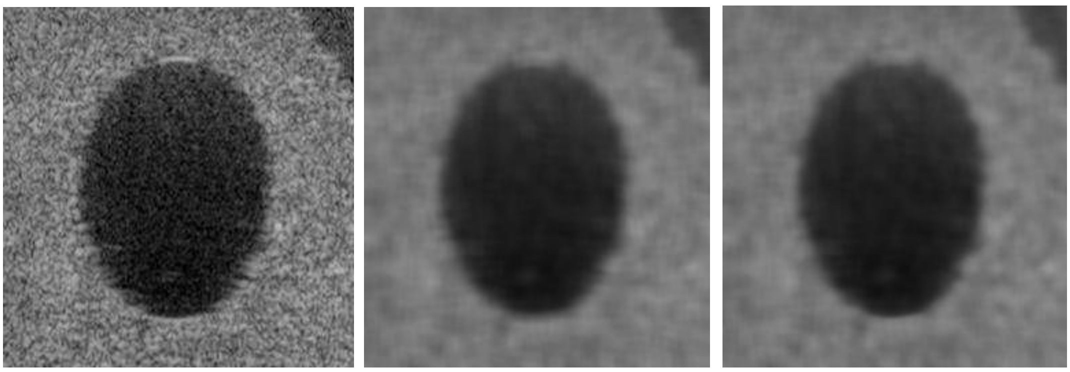
Signal to Noise Ratio (SNR) compares the level of desired signal to the level of background noise. The higher the ratio the less obtrusive the background noise is.

Let, see the improvement of ultra sound phantom image (256×256) and a normal ultrasound image.

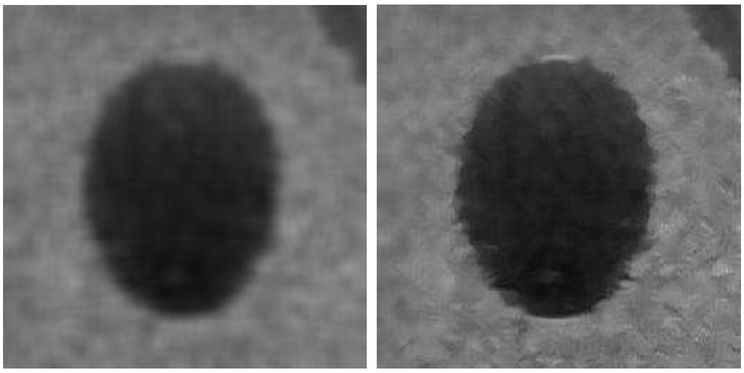
a)The speckle noisy image(512×512) , b) Original NL-means filtered image in left and Proposed filtered image in right(h=10)

c) Original NL-means filtered image in left and Proposed filtered image in right(h=2.5)

Figure 3. (a) .02 speckle noise is add to the lean image, (b) NL-means filtered image using degree of filter, h =10, (c) Proposed filtered image using degree of filter, h =2.5

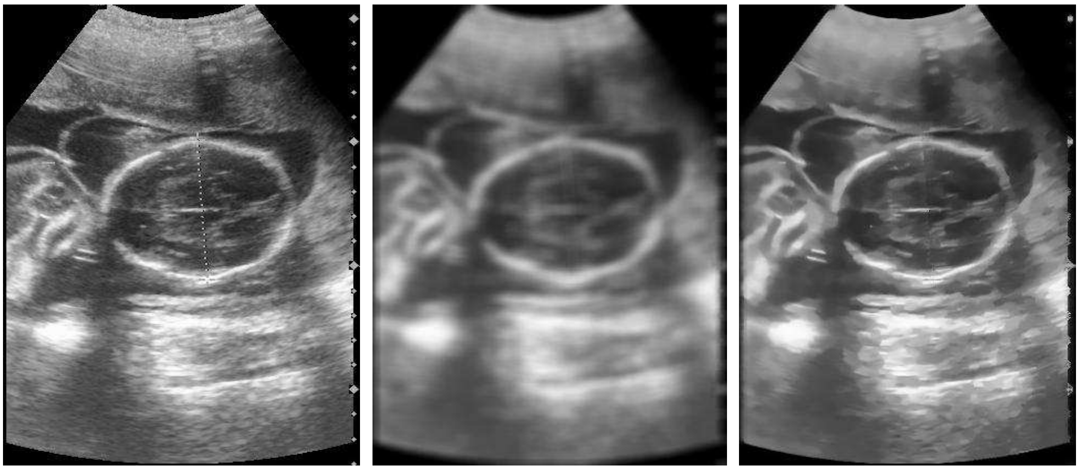


a)The ultrasound phantom image(256×256), b)Original NL-means filtered image in left and Proposed filtered image in right(h=10)



c) Original NL-means filtered image in left and Proposed filtered image in right(h=1)

Figure 4. (a) ultrasound phantom image (b) NL-means filtered image using degree of filter, h =10 (c)Proposed filtered image using degree of filter, h =1



(a) (b)

(c)

Figure 5. (a) Normal ultrasound image (b)NL-means filtered image using degree of filter, h =10 (c) Proposed filtered image using degree of filter, h =1

$$SNR = 10.\log_{10} \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(x_{i,j}^{2} + y_{i,j}^{2})}{\sum_{i=1}^{M}\sum_{j=1}^{N}(x_{i,j} - y_{i,j})^{2}}. \quad \ldots\ldots\ldots\ldots\ldots(5)$$

where M and N are the width and height of the image. The larger SNR values correspond to good quality image.

The Root Mean square error (RMSE), is given by

$$RMSE = \sqrt{\left(\frac{1}{MN} \cdot \sum_{i=1}^{M} \sum_{j=1}^{N} (x_{i,j} - y_{i,j})^2\right)} \quad \text{.......................(6)}$$

Peak Signal to Noise Ratio (PSNR) is computed using

$$PSNR = 20.\log_{10}(g^2 \max / RMSE) \quad \text{……....……...(7)}$$

where g^2 is the maximum intensity in the unfiltered images. The PSNR is higher for a better transformed image.

Table 1: Measurement Matrix

Image name	Degree of filter	Filter	SNR	RMSE	PSNR
Phantom (Figure 4)	10	NL-means	8.31	15.74	24.23
		Proposed	8.55	15.35	24.44
	1	NL-means	8.35	15.67	24.26
		Proposed	**9.64**	**13.58**	**25.51**
Normal Ultra sound (Figure 5)	10	NL-means	9.91	19.61	22.32
		Proposed	11.16	17.24	23.43
	1	NL-means	10.37	18.71	22.73
		Proposed	**13.30**	**14.00**	**25.24**

Since, we can measure from Figure4. and Figure 5. it does not rely on any visual interpretation this numerical Measurement is the most objective one. A small root mean square error does not assure a high visual quality, the high SNR assure high visual quality of image. From the above discussion it can measure that the NL-means calculation with mean distance is better method to denoise image.

5. Conclusions

Human vision is very sensitive to high-frequency information. Image details (e.g., corners and lines) have high frequency contents and carry very important information for visual perception. Accordingly, the purpose of this study was to determine the preference of filter of NL-means algorithm and for image enhancement in a clinical soft-copy display setting and to establish a promising set of algorithm for use with various ultrasound image.

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