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# Effects of Distance Metric in Non-Local Mean Filtering of Ultrasound Images

**Anil A.R.**
*Department of Computer Science & Engineering,*
*Sree Buddha College of Engineering, Alappuzha, Kerala, India.*

**Rajesh Reghunadhan**
*Department of Computer Science, Central University of Kerala,*
*Periya – 671316, Kasaragod, Kerala, India.*

**Abstract:**

Medical ultrasound images contain large quantity of multiplicative noise called speckle noise which degrades the fine image structure required for medical analysis. One of the best performing speckle noise removal method is the non-local mean (NLM) filtering/algorithm when compared to methods like Lee filter, geometric filter, anisotropic diffusion, and median filter. In this paper we study the effects of various distance metrics on NLM algorithm applied to ultrasound images. Various quality measures like root mean square error (RMSE), pixel to noise ratio (PSNR) and Universal image quality index (Q) are used to measure the impact. Experimental results show that the NLM performs better when max-coordinate difference (MaxCD) distance metric is used.

**Keywords:** Euclidean distance, Image quality, non-local mean algorithm, ultrasound image, denoising.

## I. INTRODUCTION

Different types of noises occur in medical images due to the electrical, magnetic, optical interferences in medical equipment's. Medical ultrasonic images are the most commonly used and an economic method in medical imaging which are prone to serve speckle noise. It is practically impossible to completely remove the speckle noise from ultrasound images using the currently available techniques; however, there are algorithms which reasonably well perform on such images. Various methods for speckle noise removal include Lee filter [1], Forst filter [2], Kuan filter [3], median filter [4], anisotropic diffusion (SRAD) [5], wavelet filtering [6], NL-mean algorithm [7][8], etc.

NL-mean filtering algorithm is considered to be one of the best speckle noise removing algorithm. It is an adaptive filtering technique which compares patches from different parts of the image to decide the filtering parameters. To compare these patch windows, NLM algorithm use a distance metric. The default distance metric is Euclidian distance. In this paper, we critically study the impact of replacing this metric with other available distance metrics. The results show that Maximum Coordinate Difference distance (Max-CD) in NLM is better for denoising ultrasound images.

This paper is organized as follows. Section II provides details of the NL-Mean algorithm. Section III provides the experimental setup. Section IV presents the results and discussions. Section V concludes the paper.

## II. NON-LOCAL MEANS (NL MEANS) ALGORITHM

NL Mean algorithm works on the bases of natural redundancy of information (called self similarity) in image [7][8]. Let Xbe a given discrete noisy image, using NLM method the filtered value at a point can be calculated by a weighted average of all the pixels in the image using the formula:

$$NLM(X(a)) = \sum_{\forall b} w(a,b)X(a) \tag{1}$$

$$w(a,b) \in [0,1] \tag{2}$$

$$\sum_{\forall b} w(a,b) = 1 \tag{3}$$

where 'a'$\epsilon$ I is the position to be filtered and 'b' $\epsilon$ I represents other pixels locations in the image.

The similarity w (a, b) is calculated using the equation (4).

$$w(a,b) = \frac{1}{z(a)} e^{-\frac{d(a,b)}{h^2}} \tag{4}$$

$$z(a) = \sum_{\forall b} e^{-\frac{d(a,b)}{h^2}} \tag{5}$$

$$d(a,b) = \left\| X(N_a) - X(N_b) \right\|^2_{R_s} \tag{6}$$

$z(a)$ is the normalization constant, $h$ is the exponential decay control parameter. Neighboring pixels within a radius $R_s$ centered at pixel position a is $N_a$.

## III. EXPERIMENTAL SETUP

In this study, eight different ultrasound images (Bone, Liver1, Abdomen, Baby1, Kidney, Pancreas, Liver2, Baby2) are considered (see Fig. 1 for the images) for comparing the results using various distance measures in NL-means algorithm.

Initially, Lee filter is used to pre-filter the image. Then NL-Mean algorithm is used for de-noising with various distance metrics [14] listed in Tab. 1, where $P_i$ and $P_j$ are pixels of two patches, where $i = \{1,2,\dots,M\}$ and $j = \{1,2,\dots,N\}$.

**Table 1:** Distance Metric

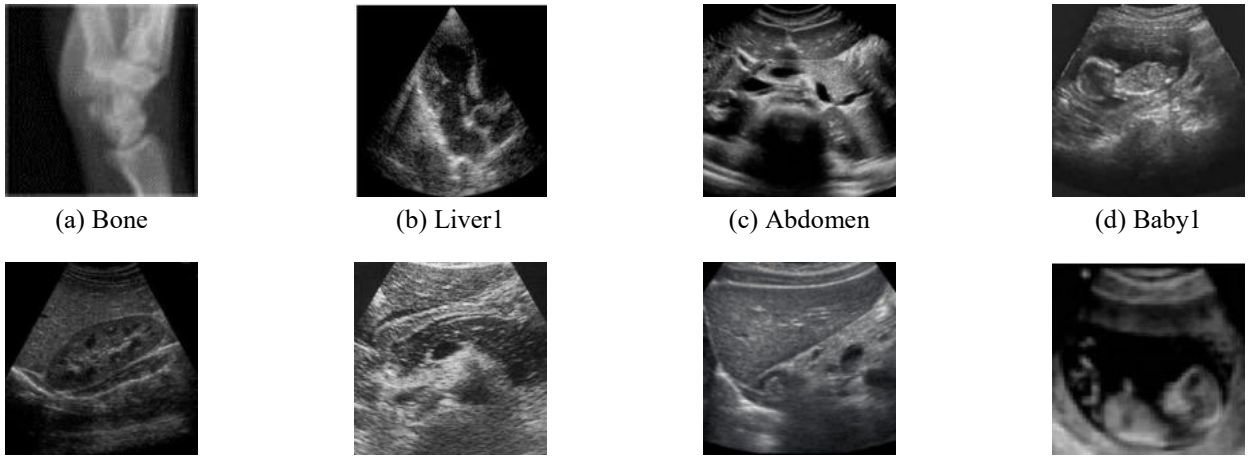
| **Distance Metric** | **Equation** |
|---|---|
| Euclidean Distance (D) | $D = \sum_{i=1}^{M}\sum_{j=1}^{N}(P_i - P_j)^2$ (7) |
| Normalized Euclidean (NE) | $NE = \frac{D}{\sqrt{MN}}$ (8) |
| Weighted Euclidean (WD) with a kernel transformation function | $D = \sum_{i=1}^{M}\sum_{j=1}^{N} Kernal * (P_i - P_j)^2$ (9) |
| Harmonic Mean (HM) | $HM = \left(\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{1}{(P_i - P_j)^2}\right)^{-1}$ (10) |
| City Block (CB) | $CB = \sum_{i=1}^{M}\sum_{j=1}^{N}\lvert P_i - P_j\rvert$ (11) |
| Normalized City Block (NCB) | $NCB = \frac{CB}{MN}$ (12) |
| Canberra Distance (CD) | $CD = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{\lvert P_i - P_j\rvert}{P_i - P_j}$ (13) |
| Bray-Curtis Distance (BCD) | $BCD = \frac{\sum\lvert P_i - P_j\rvert}{\sum P_i - P_j}$ (14) |
| Maximum Coordinate Difference (MaxCD) | $MaxCD = \max\lvert P_i - P_j\rvert$ (15) |
| Minimum Coordinate Difference (MinCD) | $MinCD = \min\lvert P_i - P_j\rvert$ (16) |
| Pearsons absolute dissimilarity (PAD) | $PAD = \sqrt{\frac{MN}{MN-1}\left(NE^2 - \left(\frac{1}{MN}\left(\sum_i x_i - \sum_j y_j\right)\right)^2\right)}$ (17) |
| Hasdroff distance (HD)<br>(d(a, b) is the Euclidean distance) | $HD(A,B) = \max_{a\in B}\{\min_{b\in B}(d(a,b))\}$ (18) |
| Spearman Rank (SR)<br>(D → differences between the ranks of corresponding values of X and Y. N → number of pairs of values (X,Y) ) | $SR = 1 - \frac{6\sum D^2}{N(N^2-1)}$ (19) |

For measuring the impact of various distance measures, the following standard image quality metrics are used.

MSE is a signal fidelity measure [10][11] which is used to measure human perception/quality and is calculated as shown in Eqn. 20. The square root of MSE is the RMSE and is calculated as shown in Eqn. 21. Lower values of MSE and RMSE indicates higher image quality.

$$MSE(p,q) = \frac{1}{N}\sum_{i=1}^{n}(p_i - q_i)^2 \quad (20)$$

$$RMSE = \sqrt{MSE} \quad (21)$$



(a) Bone (b) Liver1 (c) Abdomen (d) Baby1

(e) Kidney (f) Pancreas (g) Liver2 (h) Baby2

**Figure 1:** Test images used for comparing performance of NLM with different distance metrics

PSNR [12] is a metric representing the peak signal to noise ratio, in which a higher value indicates higher image quality. PSNR is calculated as shown in Eqn. 22

$$PSNR = 10\log_{10}\left(\frac{255^2}{MSE(p,q)}\right) \tag{22}$$

MSE, RMSE and PSNR are statistical measures, which may not properly reflect human perception of image quality. Universal Image Quality Index, Q [13] is another image quality metric, which is independent of viewing condition and individual observers, and better captures human perception.

$$Q = \frac{4\sigma_{xy}\bar{x}\ \ \bar{y}}{\left(\sigma_x{}^2 + \sigma_y{}^2\right)\left(\bar{x}^2 + \bar{y}^2\right)} \tag{23}$$

where $\bar{x}$ is the mean of the original image, $\bar{y}$ is the mean of the test image $\sigma_{xy}$ is the covariance between the original and test image.

A new measure is proposed, namely, Visual Equivalent Quality Index (VEQI). VEQI is a measure of the combination of qualities of RMSE, PSNR and Q.

$$VEQI = \frac{Q * PSNR}{RSME} \tag{24}$$

## III. RESULTS AND DISCUSSIONS

We have used all the distance measures discussed in Tab. 1 in NLM to filter 8 different ultrasound images as listed in Fig. 1. Radius of the search window in NLM is chosen as 5 patches and radius of patch size is chosen as 2 pixels. Four image quality metrics discussed in section III, namely, RMSE, Q, PSNR and VEQI are used to measure the denoising quality.

Universal image quality index (Q), PSNR and RSME and VEQI of the filtered ultrasound images using NLM algorithm with various distance measures are given in Tab. 2, 3, 4, 5. MaxCD provides the best average Q, PSNR, and VEQI as shown in Fig. 2, 3, 5. MaxCD also provides the least average RSME as shown in Fig. 4. Noisy image and NL-mean filtered images (with various distance metric) of the images of bone, liver1, abdomen, baby1, kidney, pancreas, liver2, baby2 are shown respectively in Fig. 6, 7, 8, 9, 10, 11, 12, 13

From the experiments we could find that the best distance metric to be used in NLM is Maximum Coordinate Difference (MaxCD). Pearson's absolute dissimilarity (PAD) and NCB comes in second and third position. The worst distance measures for NLM algorithm are SR and HD.

**Table 2:** Universal Image Quality Index (Q) of filtered images using NLM with various distance measures.

| **Test Image →** / **Distance metric ↓** | **Bone** | **Liver1** | **Abdomen** | **Baby1** | **Kidney** | **Pancreas** | **Liver2** | **Average** |
|---|---|---|---|---|---|---|---|---|
| MaxCD | 0.9982 | 0.9955 | 0.9936 | 0.9907 | 0.9866 | 0.9880 | 0.9882 | 0.9915 |
| PAD | 0.9979 | 0.9946 | 0.9938 | 0.9905 | 0.9870 | 0.9880 | 0.9852 | 0.9910 |
| NCB | 0.9977 | 0.9944 | 0.9936 | 0.9898 | 0.9864 | 0.9867 | 0.9848 | 0.9905 |
| CB | 0.9988 | 0.9969 | 0.9859 | 0.9769 | 0.9635 | 0.9786 | 0.9896 | 0.9843 |

| Test Image → / Distance metric ↓ | Bone | Liver1 | Abdomen | Baby1 | Kidney | Pancreas | Liver2 | Average |
|---|---|---|---|---|---|---|---|---|
| WD | 0.9989 | 0.9972 | 0.9857 | 0.9745 | 0.9612 | 0.9781 | 0.9909 | 0.9838 |
| NE | 0.9882 | 0.9968 | 0.9865 | 0.9763 | 0.9634 | 0.9781 | 0.9906 | 0.9828 |
| D | 0.9989 | 0.9969 | 0.9809 | 0.9665 | 0.9474 | 0.9707 | 0.9896 | 0.9787 |
| HM | 0.9861 | 0.9623 | 0.9345 | 0.9491 | 0.9307 | 0.9168 | 0.9378 | 0.9453 |
| MinCD | 0.9846 | 0.9276 | 0.9377 | 0.9542 | 0.9410 | 0.9287 | 0.9339 | 0.9440 |
| SR | 0.9755 | 0.8349 | 0.8907 | 0.9363 | 0.9755 | 0.8349 | 0.9755 | 0.9176 |
| HD | 0.9275 | 0.7012 | 0.7524 | 0.8123 | 0.7608 | 0.7157 | 0.7705 | 0.7772 |

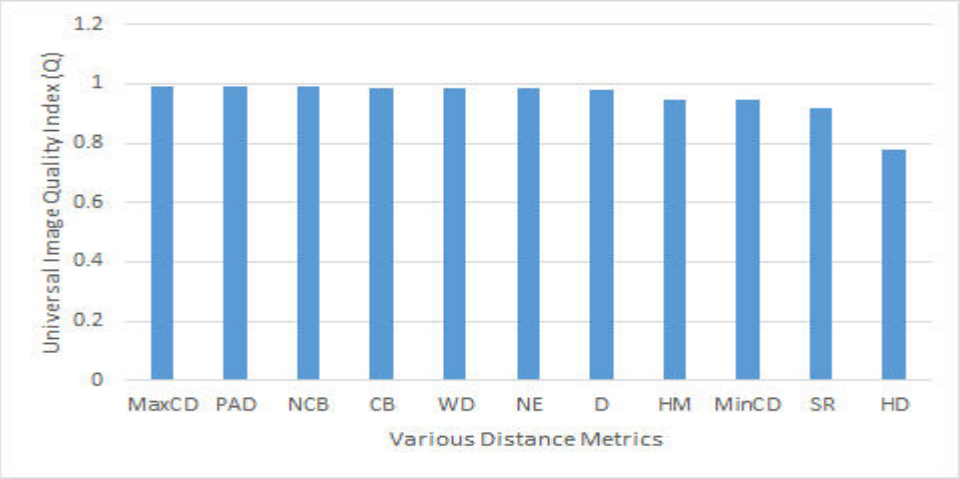



**Figure 2:** Average Q measure for the various distance metrics

**Table 3: PSNR of filtered ultrasound images using NLM algorithm with various distance measures.**

| Test Image → / Distance metric ↓ | Bone | Liver1 | Abdomen | Baby1 | Kidney | Pancreas | Liver2 | Average |
|---|---|---|---|---|---|---|---|---|
| **MaxCD** | 37.4929 | 35.2764 | 33.3648 | 34.3568 | 34.8489 | 32.5429 | 34.0252 | 34.55827 |
| **PAD** | 36.7321 | 34.4917 | 33.6039 | 34.3747 | 35.0656 | 32.5882 | 33.0704 | 34.27523 |
| **NCB** | 36.4409 | 34.3143 | 33.4017 | 34.0190 | 34.8807 | 32.1550 | 32.9353 | 34.02099 |
| **WD** | 39.5379 | 37.3137 | 29.7705 | 29.8172 | 29.9881 | 29.7871 | 35.0458 | 33.03719 |
| **NE** | 39.1907 | 36.7956 | 30.0335 | 30.1833 | 30.2681 | 29.8089 | 34.9269 | 33.02957 |
| **CB** | 39.1540 | 36.8347 | 29.8835 | 30.2696 | 30.2737 | 29.9016 | 34.4900 | 32.97244 |
| **D** | 39.5136 | 36.8779 | 28.4730 | 28.5640 | 28.5641 | 28.4346 | 34.4894 | 32.13094 |
| **MinCD** | 28.0707 | 23.7176 | 23.9826 | 27.7424 | 28.8891 | 25.3953 | 26.8865 | 26.38346 |
| **HM** | 28.5044 | 26.1259 | 23.4805 | 27.1380 | 27.9420 | 24.4282 | 26.9304 | 26.3642 |
| **SR** | 26.2157 | 20.4762 | 21.8141 | 26.4470 | 26.2157 | 20.4762 | 26.2157 | 23.98009 |
| **HD** | 20.9535 | 15.4584 | 16.8111 | 20.2921 | 21.3550 | 18.1668 | 20.6899 | 19.10383 |

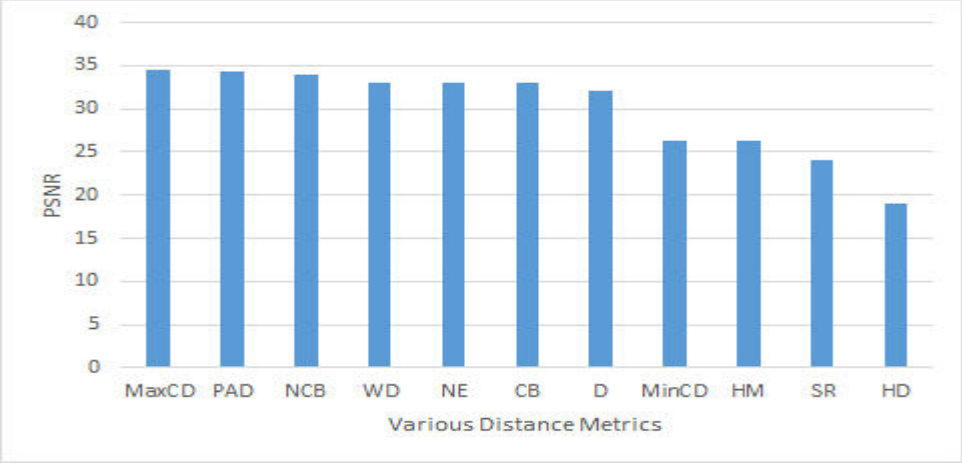



**Figure 3:** Average PSNR for the various distance metrics

**Table 4:** RMSE of filtered ultrasound images using NLM algorithm with various distance measures.

| **Test Image →** / **Distance metric ↓** | Bone | Liver1 | Abdomen | Baby1 | Kidney | Pancreas | Liver2 | Average |
|---|---|---|---|---|---|---|---|---|
| **MaxCD** | 3.4032 | 4.3925 | 5.4738 | 4.8831 | 4.6141 | 6.0171 | 5.0731 | 4.8367 |
| **PAD** | 3.7147 | 4.8078 | 5.3252 | 4.8730 | 4.5004 | 5.9858 | 5.6626 | 4.9814 |
| **NCB** | 3.8414 | 4.9070 | 5.4507 | 5.0767 | 4.5972 | 6.2919 | 5.7513 | 5.1309 |
| **NE** | 2.7990 | 3.6877 | 8.0327 | 7.8953 | 7.8186 | 8.2430 | 4.5729 | 6.1499 |
| **CB** | 2.8108 | 3.6711 | 8.1726 | 7.8173 | 7.8136 | 8.1556 | 4.8088 | 6.1785 |
| **WD** | 2.6893 | 3.4741 | 8.2796 | 8.2352 | 8.0748 | 8.2638 | 4.5107 | 6.2182 |
| **D** | 2.6968 | 3.6529 | 9.6136 | 9.5134 | 9.5133 | 9.6562 | 4.8091 | 7.0650 |
| **HM** | 9.5789 | 12.5963 | 17.0809 | 11.2107 | 10.2197 | 15.3153 | 11.4819 | 12.4977 |
| **MinCD** | 10.0694 | 16.6209 | 16.1215 | 10.3972 | 9.1639 | 13.7017 | 11.5402 | 12.5164 |
| **SR** | 12.481 | 24.1394 | 20.6934 | 12.1390 | 12.481 | 24.1394 | 12.481 | 16.9363 |
| **HD** | 22.8488 | 43.0145 | 36.8115 | 24.6564 | 21.8167 | 31.4916 | 23.5529 | 29.1703 |

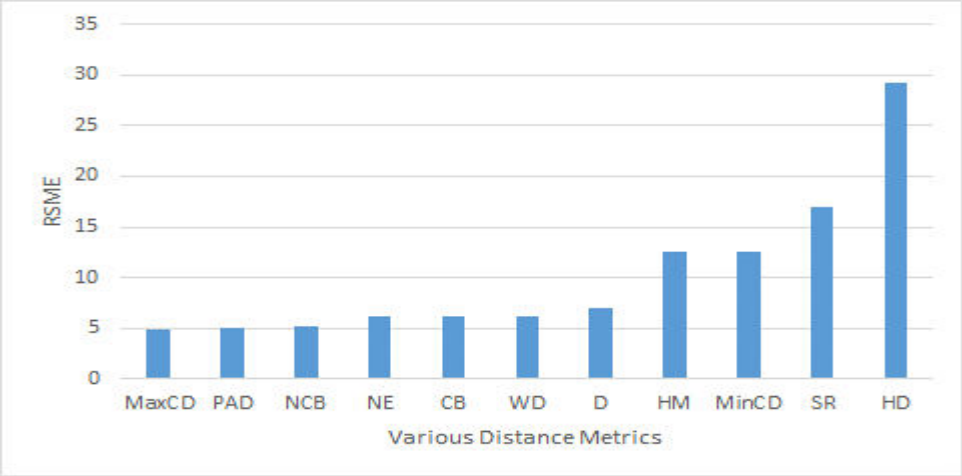



**Figure 4:** Average RSME for the various distance metrics

**Table 5:** Visual Equivalent Quality Index (VEQI) of filtered images

| **Test Image →** / **Distance metric ↓** | Bone | Liver1 | Abdomen | Baby1 | Kidney | Pancreas | Liver2 | Average |
|---|---|---|---|---|---|---|---|---|
| **MaxCD** | 10.99712 | 7.994913 | 6.056353 | 6.970425 | 7.451491 | 5.343502 | 6.627841 | 7.348807 |
| **PAD** | 9.867543 | 7.135373 | 6.27123 | 6.9871 | 7.690371 | 5.37892 | 5.75371 | 7.012035 |
| **NCB** | 9.464541 | 6.953768 | 6.088746 | 6.632656 | 7.484191 | 5.042569 | 5.639539 | 6.758001 |
| **WD** | 13.83646 | 9.945997 | 3.68843 | 3.732341 | 3.729605 | 3.537072 | 7.566006 | 6.576559 |
| **NE** | 13.83646 | 9.945997 | 3.68843 | 3.732341 | 3.729605 | 3.537072 | 7.566006 | 6.576559 |
| **CB** | 13.91313 | 10.00259 | 3.60499 | 3.782684 | 3.733069 | 3.587928 | 7.097676 | 6.531723 |
| **D** | 14.63591 | 10.06422 | 2.905172 | 2.901918 | 2.84461 | 2.858419 | 7.09711 | 6.186766 |
| **MinCD** | 2.744792 | 1.323662 | 1.394937 | 2.546051 | 2.966493 | 1.721291 | 2.175812 | 2.12472 |
| **HM** | 2.934386 | 1.9959 | 1.284624 | 2.297508 | 2.544656 | 1.462314 | 2.199578 | 2.102709 |
| **SR** | 2.048988 | 0.708202 | 0.938938 | 2.039898 | 2.048988 | 0.708202 | 2.048988 | 1.506029 |
| **HD** | 0.850564 | 0.251995 | 0.343607 | 0.668519 | 0.744699 | 0.412871 | 0.676841 | 0.564157 |

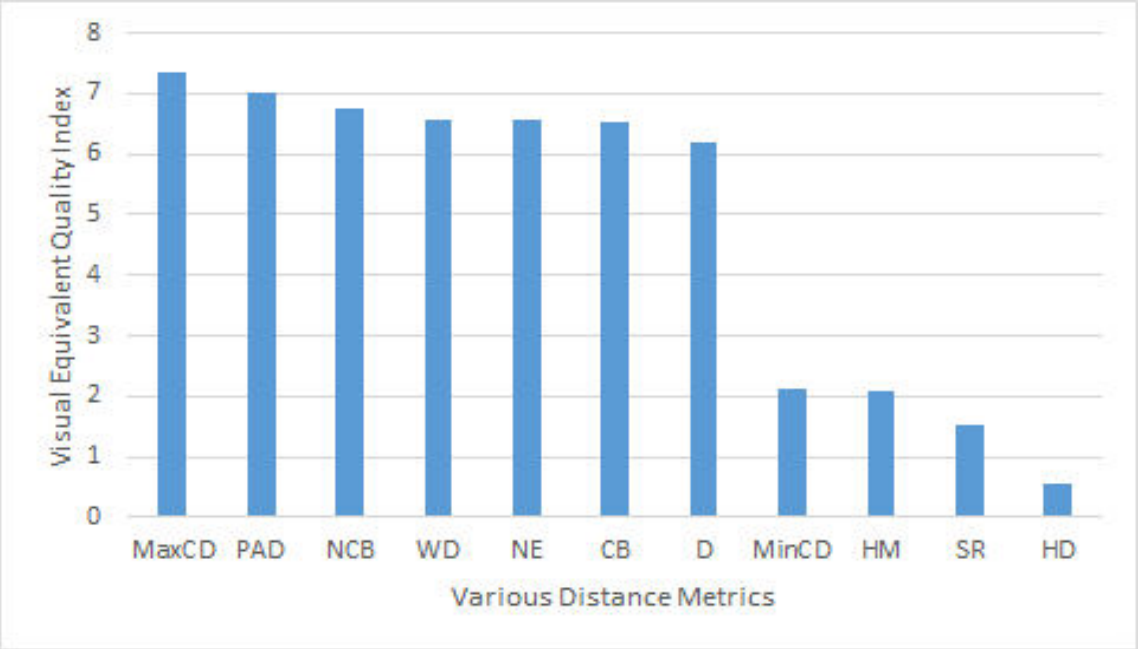
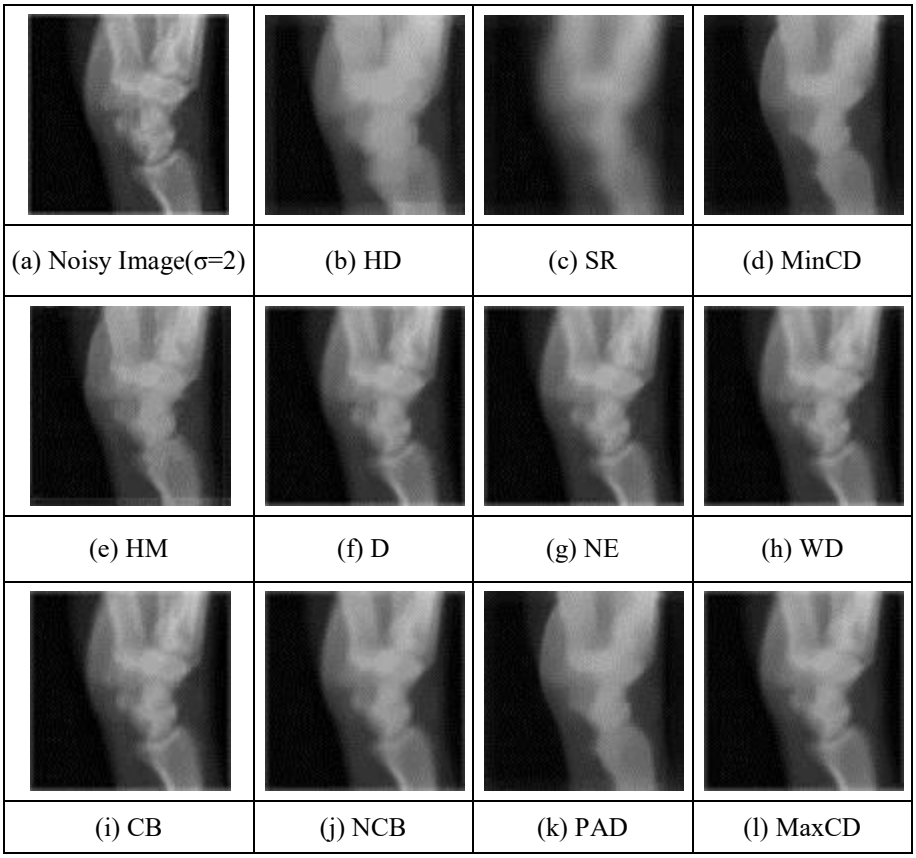
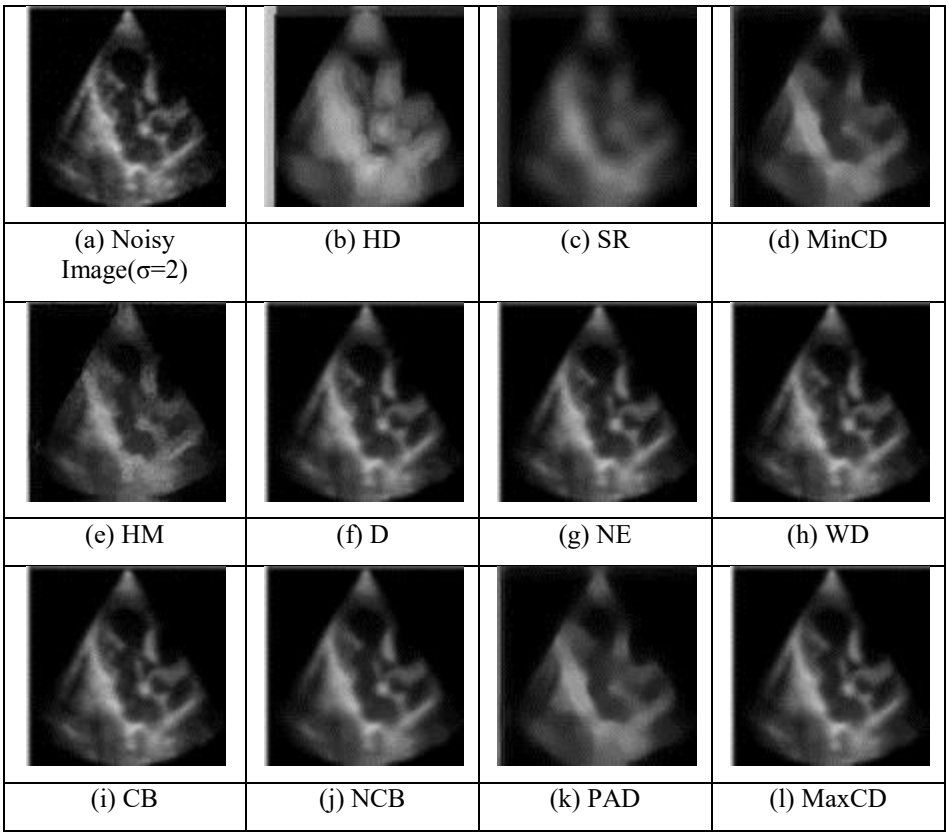



**Figure 5:** Average VEQI for the various distance metrics



| | | | |
|---|---|---|---|
| (a) Noisy Image(σ=2) | (b) HD | (c) SR | (d) MinCD |
| (e) HM | (f) D | (g) NE | (h) WD |
| (i) CB | (j) NCB | (k) PAD | (l) MaxCD |

**Figure 6:** Noisy image and NL-mean filtered images of bone with various distance metric



| | | | |
|---|---|---|---|
| (a) Noisy Image(σ=2) | (b) HD | (c) SR | (d) MinCD |
| (e) HM | (f) D | (g) NE | (h) WD |
| (i) CB | (j) NCB | (k) PAD | (l) MaxCD |

**Figure 7:** Noisy image and NL-mean filtered images of Liver1 with various distance metric

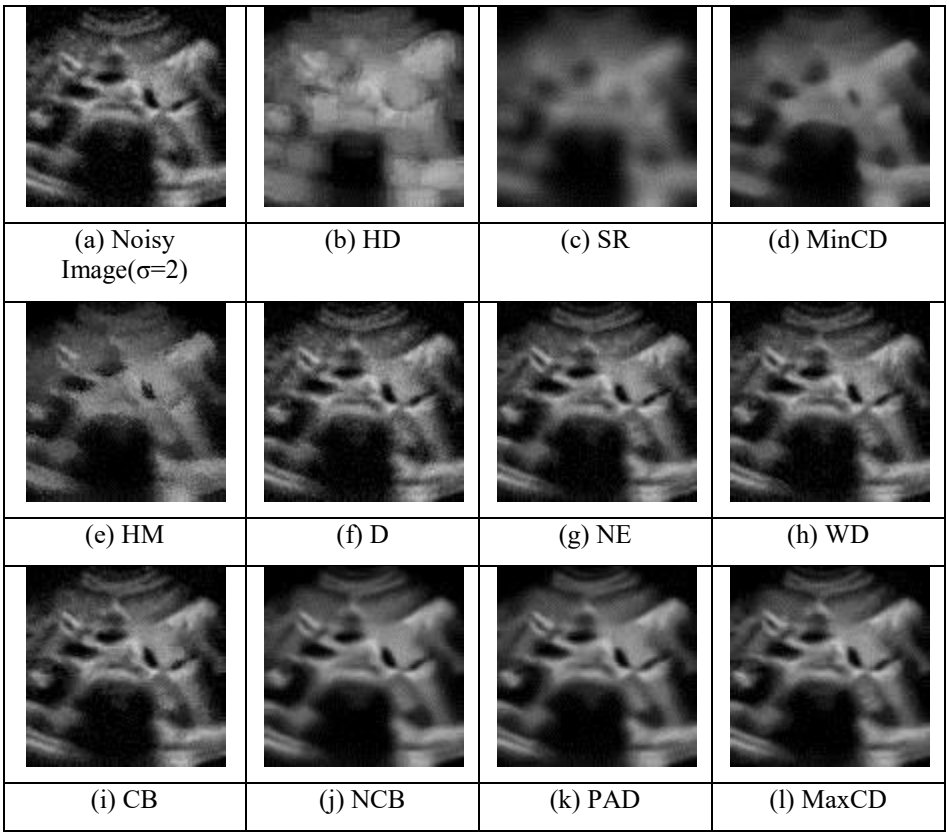



**Figure 8:** Noisy image and NL-mean filtered images of Abdomen with various distance metric

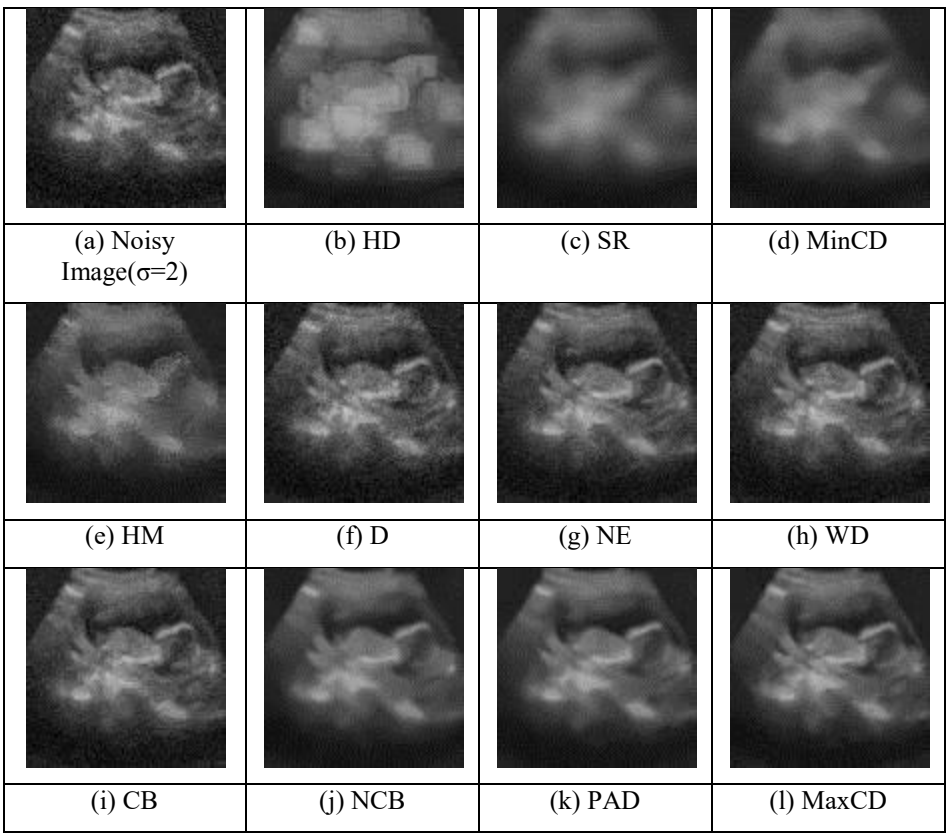



**Figure 9:** Noisy image and NL-mean filtered images of Baby1 with various distance metric

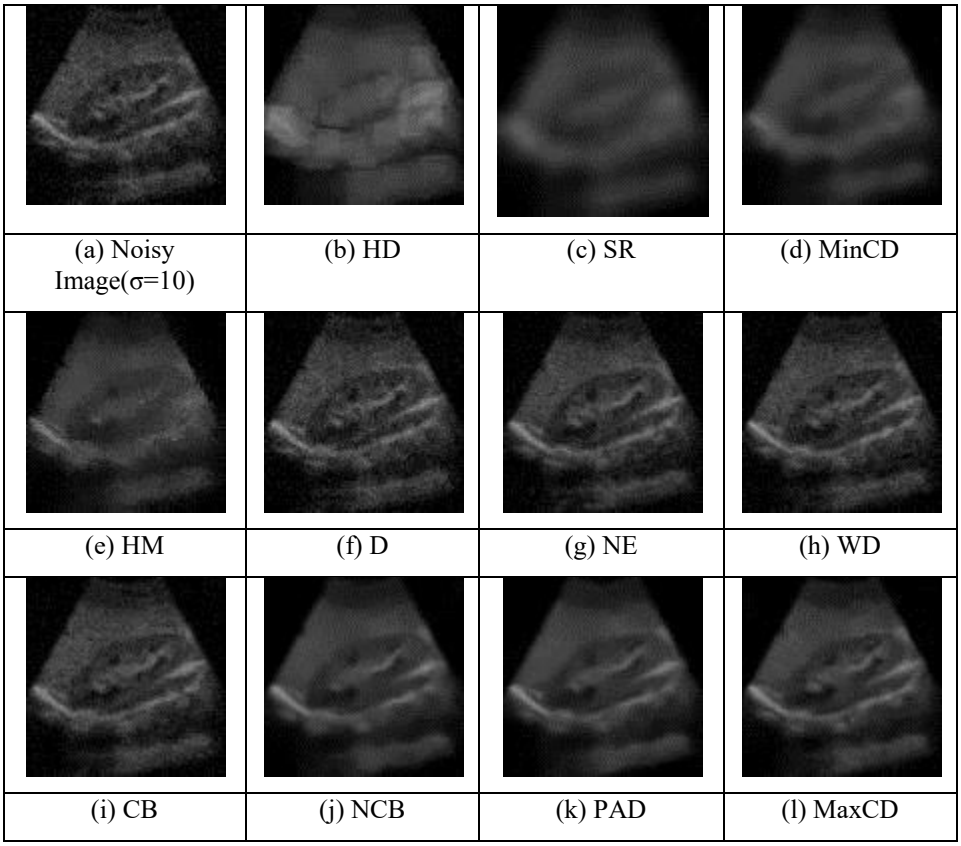



**Figure 10:** Noisy image and NL-mean filtered images of Kidney with various distance metric

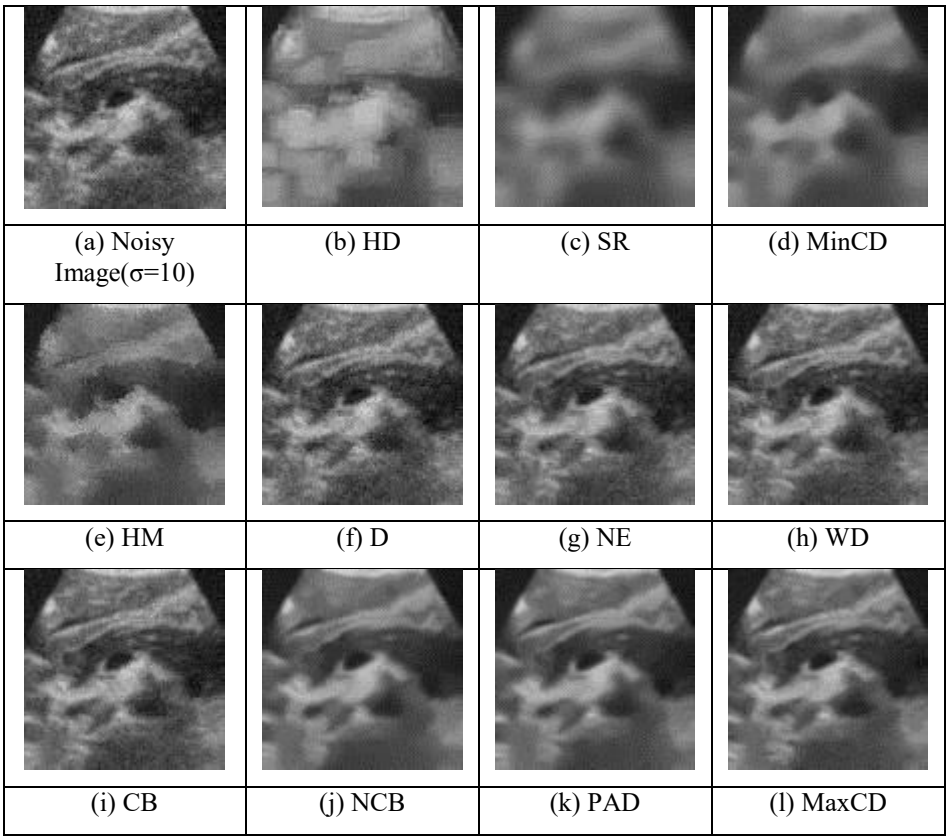
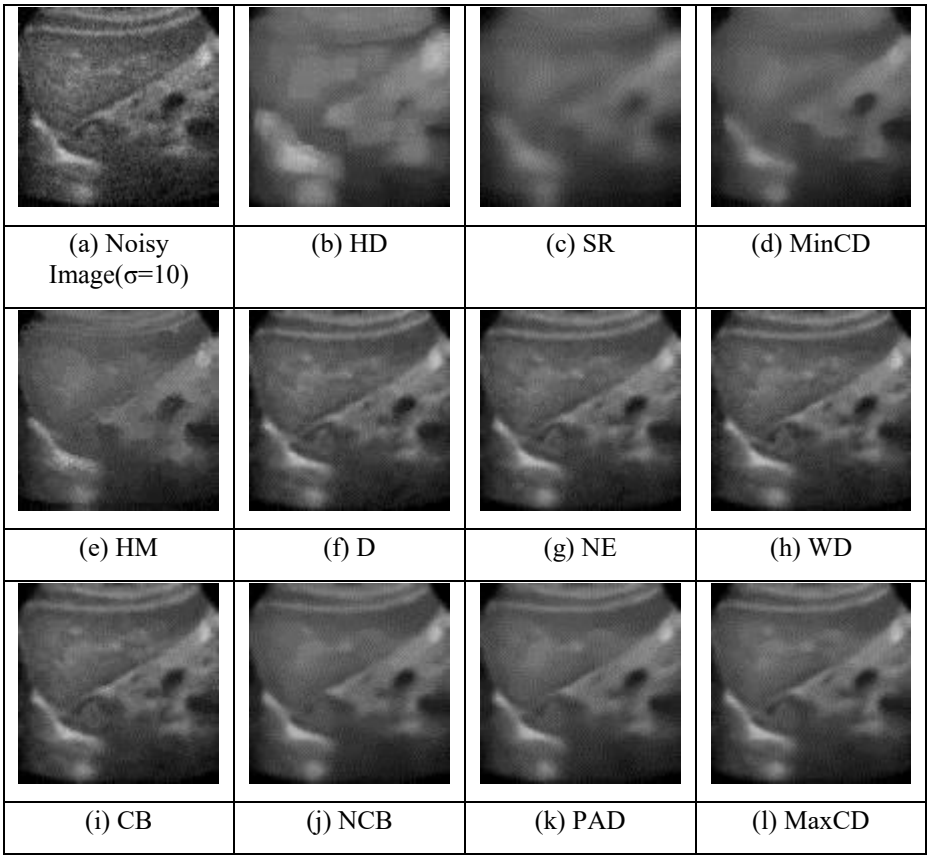
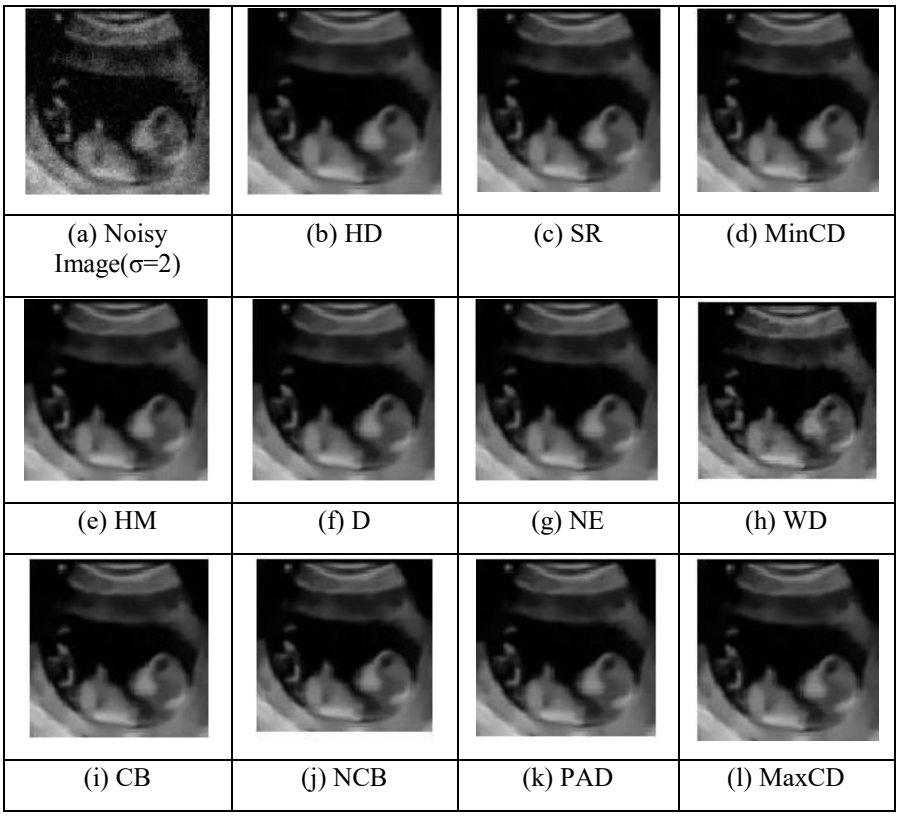



**Figure 11:** Noisy image and NL-mean filtered images of Pancreas with various distance metric



| | | | |
|---|---|---|---|
| (a) Noisy Image(σ=10) | (b) HD | (c) SR | (d) MinCD |
| (e) HM | (f) D | (g) NE | (h) WD |
| (i) CB | (j) NCB | (k) PAD | (l) MaxCD |

**Figure 12:** Noisy image and NL-mean filtered images of Liver2 with various distance metric



| | | | |
|---|---|---|---|
| (a) Noisy Image(σ=2) | (b) HD | (c) SR | (d) MinCD |
| (e) HM | (f) D | (g) NE | (h) WD |
| (i) CB | (j) NCB | (k) PAD | (l) MaxCD |

**Figure 13:** Noisy image and NL-mean filtered images of Baby2 with various distance metric

## V. CONCLUSION

The effect of using various distance metrics in NL-Mean algorithm for ultrasound images is studied in this paper. The results reveal that Maximum Coordinate Difference (MaxCD) is the best distance metric in the NL-Mean filtering for the denoising of ultrasound images. Other two near best distance metrics are PAD and NCB. It can also be observed from the results that HD and SR are the worst distance metrics and not to be used in NLM for denoising ultrasound images.

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