Ultrasound speckle reduction using adaptive wavelet thresholding

— Optimization for Computer Vision —

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Outline

Context

Medical ultrasonography:

- Relies on the principle of acoustic impedance
  - Sending high frequency acoustic waves that interact with organs and tissues producing echoes
  - Echo patterns are harnessed to compute a detailed 2-D image of the body tissue

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- Relies on the principle of acoustic impedance
  - Sending high frequency acoustic waves that interact with organs and tissues producing echoes
  - Echo patterns are harnessed to compute a detailed 2-D image of the body tissue
- Non invasive, rapid and accessible results
- Contraints: speckle, acoustic shadows, artifacts, etc.

Article presentation

- **Ultrasound speckle reduction using adaptative wavelet thresholding**
- Authors: Anterpreet Kaur Bedi and Ramesh Kumar Sunkaria
- Released in 2022, in Multidimensional Systems and Signal Processing

Objectives

Speckle:

- Granular multiplicative noise that degrades texture information and obscures details ex: lines, edges, and boundaries
- Encapsules texture information depending on anatomical tissues
- **Despecking:** crucial pre-processing step consisting in removing speckle while preserving essential features of image.

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- Granular multiplicative noise that degrades texture information and obscures details ex: lines, edges, and boundaries
- Encapsules texture information depending on anatomical tissues
- **Despecking:** crucial pre-processing step consisting in removing speckle while preserving essential features of image.

The authors introduce a novel technique to despeckle ultrasound images based on wavelet thresholding.

Methods: Previous work

Two main approaches:

- **Single scale:**
  - Direct application of filters
  - ex: Weiner filter, linear filters (e.g., median filter), and non-linear filters (e.g., statistic filters, low-pass filters)

Methods: Previous work

Two main approaches:

- **Single scale:**
  - Direct application of filters
  - ex: Weiner filter, linear filters (e.g., median filter), and non-linear filters (e.g., statistic filters, low-pass filters)
- **Multi-scale:**
  - Operate on a set of sub-images derived from an original image.
  - Step 1: acquiring sub-image sets, e.g.: wavelets, curvelets, ridgelets, etc.
  - Step 2: despeckling
  - Paper's focus: multi-scale approach based on a thresholding function applied on wavelet coefficients.

Methods: 6-step algorithm

Algorithm Image despeckle

Step 1: Log transformation of the image
Step 2: Wavelet decomposition
Step 3: Choice of threshold
Step 4: Thresholding function implementation
Step 5: Inverse wavelet transformation
Step 6: Exponential transformation

Methods: Steps 1 & 2

Step 1: Log transformation

Turn multiplicative noise into additive

$\longrightarrow$ consider log transformation of the image: L(f(x,y))

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Step 2: Wavelet decomposition (2 level)

Breaking down the ultrasonic image into a set of sub-images

$\longrightarrow$ Multi-resolution analysis: approximate component (A) & detailed components: (H, V, D)

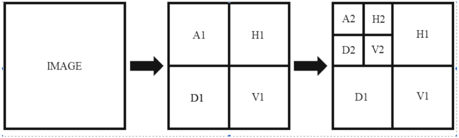

Figure: 2 level decomposition

- First level: $[A_1, H_1, V_1, D_1] = DWT(L(f(x, y)))$
- Second level: $[A_2, H_2, V_2, D_2] = DWT(A_1)$

Thresholding techniques

Thresholding methods to address despeckling consist in modifying wavelet coefficients with values below a given threshold

- **Soft thresholding:** wavelet coefficients below a given threshold to zero, and values above the threshold are reduced towards zero

$$\widehat{w} = \begin{cases} 0 & \text{if } |w| < t \\ sign(w)(|w| - t) & \text{if } |w| \geq t \end{cases} \tag{1}$$

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- **Hard thresholding:** set to zero wavelet coefficients below the threshold, leaving other coefficients unchanged

$$\widehat{w} = \begin{cases} 0 & \text{if } |w| < t \\ w & \text{if } |w| \geq t \end{cases} \tag{2}$$

Methods: Steps 3 & 4

Step 3: Choice of threshold

The authors introduce a global thresholding function based on diagonal sub-bands at at several decomposition levels to apply on detailed components: H, V, D.

$$\tau = 2\beta[\frac{|(\sigma_i^2 - \sigma_D^2)|}{\sigma_i}] \ , \ \beta = \sqrt{2Log(L)}$$

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Step 4: Thresholding function

They introduced an adaptative thresholding function merging soft and hard techniques: scaling down gradually to zero wavelet coefficients with values below threshold without altering other coefficients.

$$X_T(w) = \begin{cases} w.e^{n_l(|w|-t)} & \text{if } |w| < \tau \\ w & \text{if } |w| \geq \tau \end{cases}$$

Methods: Steps 5 & 6

Major asumption: speckle predominantly manifests in low-valued wavelet coefficients.

Step 5: inverse wavelet transformation
Captures the denoising modifications and returns the denoised version of the log of the image.

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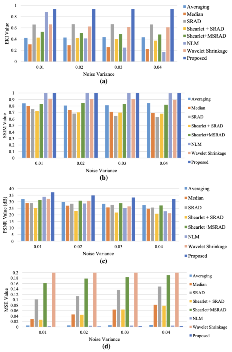
Step 6: Exponential transformation
To bring back the image to its original domain $f' = e^{Lf'}$

Paper results



a- Comparison of average performance measures for test images

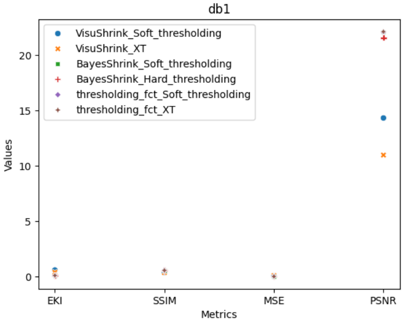
Performance measures	Average filtering	Median filtering	SRAD	Shearlet with SRAD	Shearlet with MSRAD	NLM filtering	Wavelet shrinkage method	Proposed method
EKI	0.342303	0.326886	0.41669	0.76203	0.459838	0.64107	0.6386	0.838143
SSIM	0.698353	0.798411	0.663866	0.74334	0.65550	0.99929	0.9097	0.999517
PSNR (dB)	30.62895	27.13495	25.1017	23.1511	31.32304	34.56615	32.5661	36.92762
MSE	0.012599	0.01234	0.110242	0.005602	0.178275	0.003700	0.2282	0.001829

b- Paper results

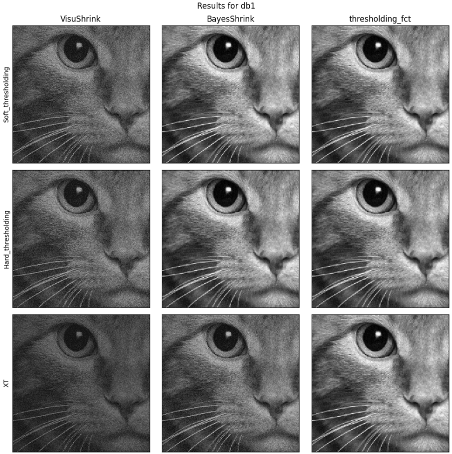
Results: Implementation Challenges

- Contradiction regarding threshold computation:
  Global threshold $\neq$ Threshold for each detailed component
  Nomenclature problem?
- Lack of specificity: computation of noise variance of noisy image σ_i
- Computation time
  $\longrightarrow$ significant size reduction of the ultrasound images dataset

Results: Synthetic noisy image



a- Filter's performance on a synthetic noisy image



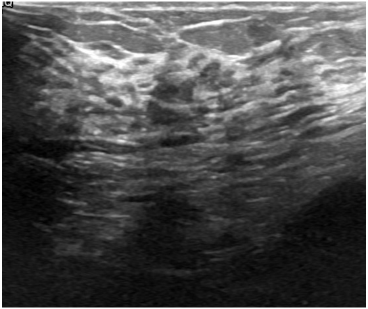
b- Synthetic noisy image denoising with 9 different filters

Figure: Results on synthetic data

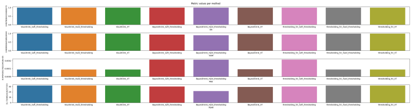
Real dataset presentation

Limited set of ultrasound images sourced from Kaggle.

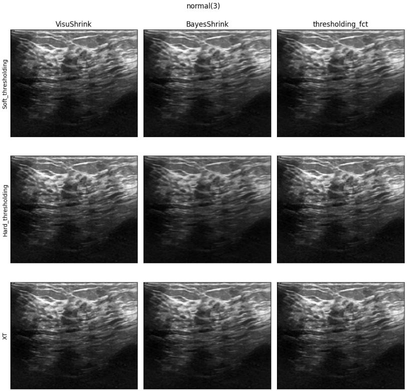
- 2 normal ultrasound images
- 1 benign
- 1 malignant



Results: Ultrasound images dataset



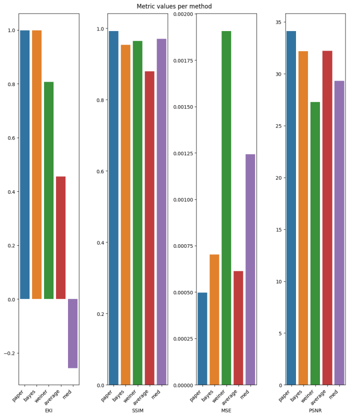
a- Wavelet's performance on ultrasound images



b- Implementation of different filters on ultrasound images

Figure: Results on ultrasound images

Results: Ultrasound images dataset



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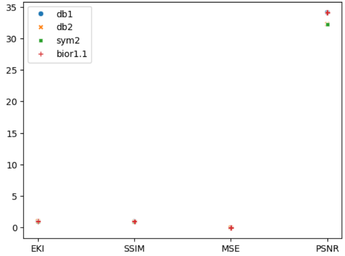

b- Wavelet's performance on ultrasound images

Figure: Results on ultrasound images

Conclusion

- Novel multi-scale approach
- Thresholding function combining soft and hard thresholding
- Wavelets allow the dissection of a discrete-time signal into various scale components and orientations
- Effective pre-processing step that outperforms single-scale methods
- Results: despeckled images with preserved edges, boundaries and structures

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- Novel multi-scale approach
- Thresholding function combining soft and hard thresholding
- Wavelets allow the dissection of a discrete-time signal into various scale components and orientations
- Effective pre-processing step that outperforms single-scale methods
- Results: despeckled images with preserved edges, boundaries and structures
- Limitations:
    - Sparse detailed components due to lack of variation
    - Implementation challenges
        - Contradiction regarding threshold computation (global vs. local)
        - Noise variance of noisy image σ_i computation
        - Computation time