



USING WAVELETS ON DENOISING INFRARED MEDICAL IMAGES

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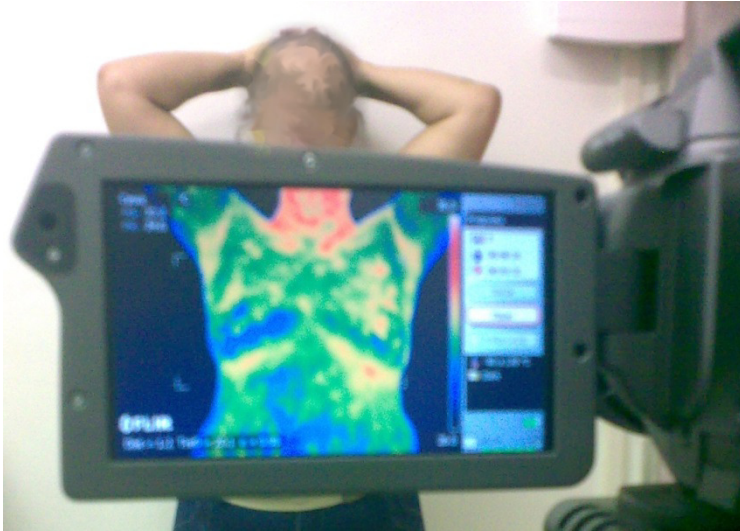
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Introduction

- Computed aided diagnostic - CADx system makes substantial use of image processing and a great amount of data => efficient **content based retrieval from image database**
- Image **restoration** after storage and transition is fundamental for the quality of the other stages in the image processing.
- Studies showed that infrared (IR) based image analysis could **identify breast modifications earlier** than others exams.
- To be efficiently implemented, CADx must first consider a great number of patients followed by years; maintain record and comparison with others types of diagnoses, combine and integrate data to allow **mining** possible conclusions system.



Thermograms are acquired by a thermographic camera that is sensitive to infrared IR.

It is a physiological examination and is 50x cheaper than the mammogram.

IR has potential to detect breast cancer 10 years earlier than the nowadays traditionally golden method.

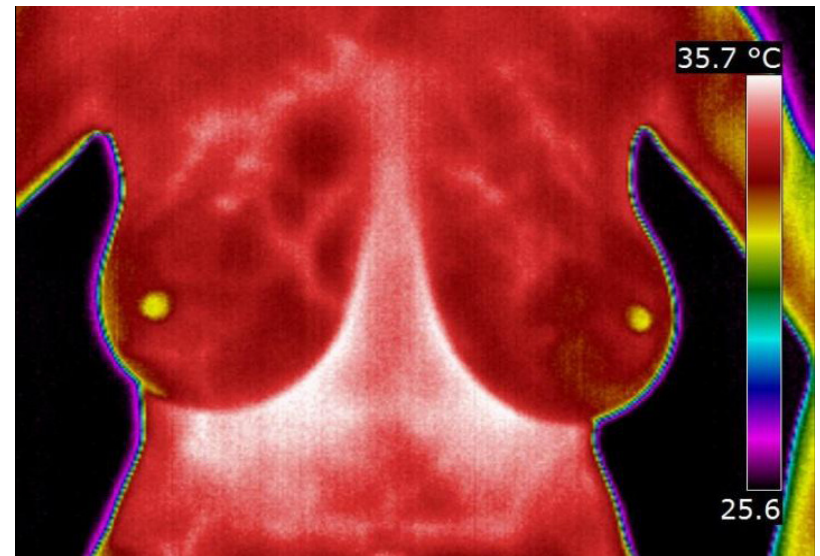
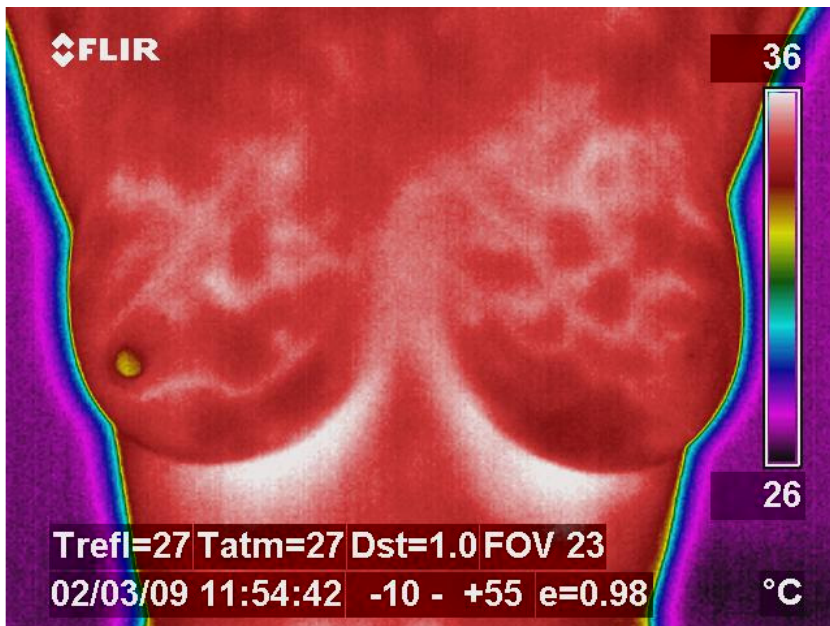
It can also be used for diagnosis of **young women's** tumours (young breasts present dense tissues that makes **difficult early detection** of pathologies by the X-ray).



IR do not use ionizing radiation, venous access (or others invasive procedures), is painless and do not touch the patient.

The problem is the absence of CAD systems to aid the such diagnosis.

Retroareolar Carcinoma



You can see that this is a normal breast (very symmetrical !) but how to make the computer “see” the same?

Main objective:

- Best discrete wavelet (DW) scheme for
 - denoise ,
 - storage and
 - retrieval

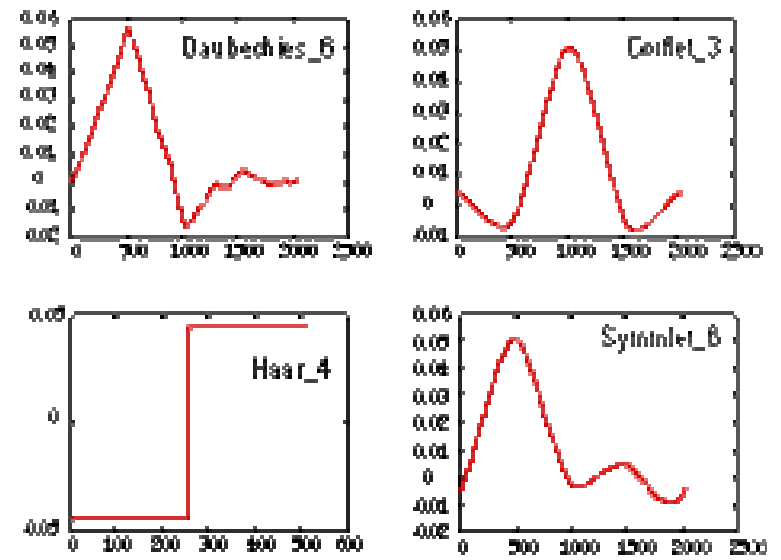
for the project of an infrared image database to aid breast disease diagnostic in a tropical climate country

ProEng project:

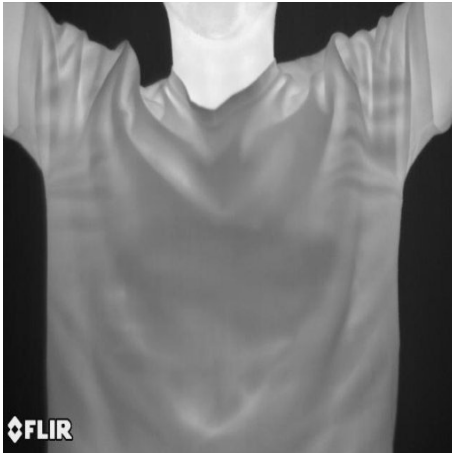
<http://visual.ic.uff.br/en/proeng/>

First part

- Results and conclusions of an experimental study that intent to find the best family of wavelets to reduce noise of medium resolution infrared images.



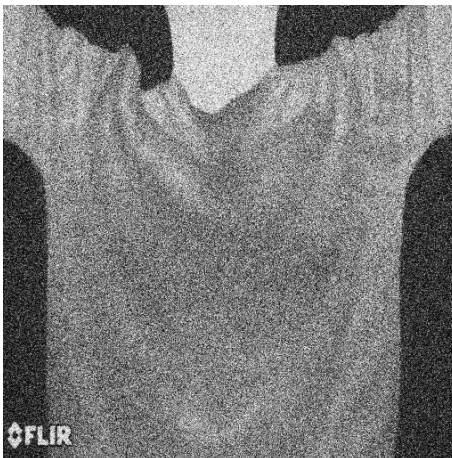
8 different real images + noise



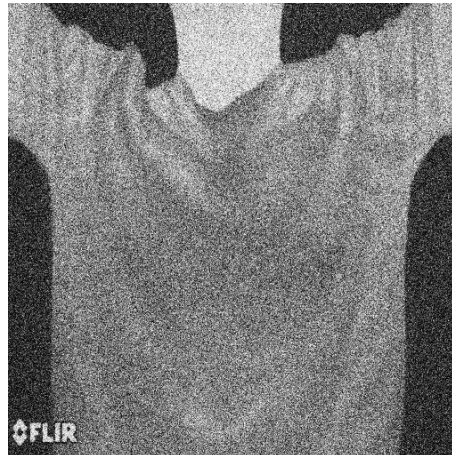
Original



Low noise



High



Medium

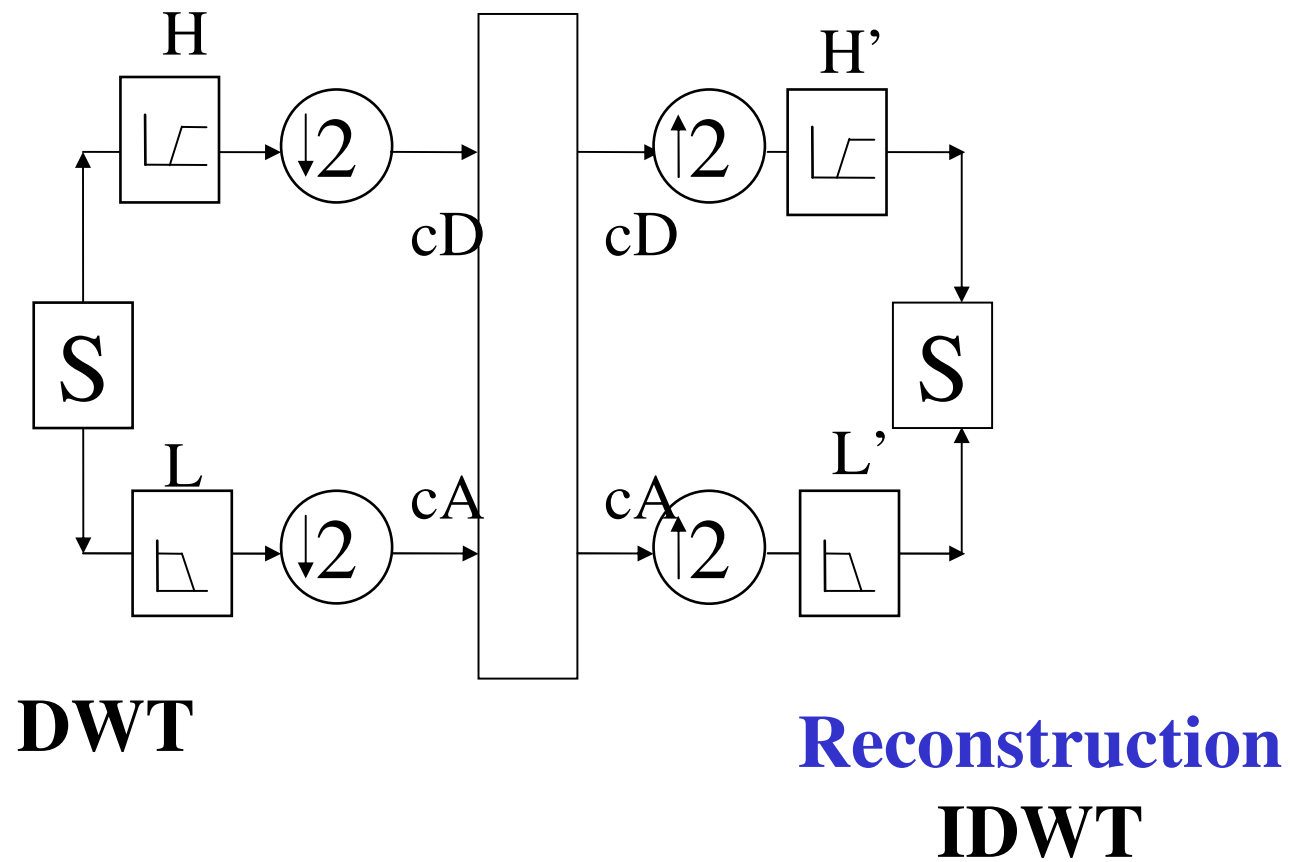
resolution:
640x 480

3 degradation levels
Additive White Gaussian
Noise (AWGN):

$\sigma = 5$,
 $\sigma = 25$,
and
 $\sigma = 50$

Total: 32 images of same type
separated on 4 groups
concerning the level of noise
(0, 5, 25 and 50).

Low and High pass filters



Discrete wavelet transforms (DWT) is very effective in analyzing images because it at same time

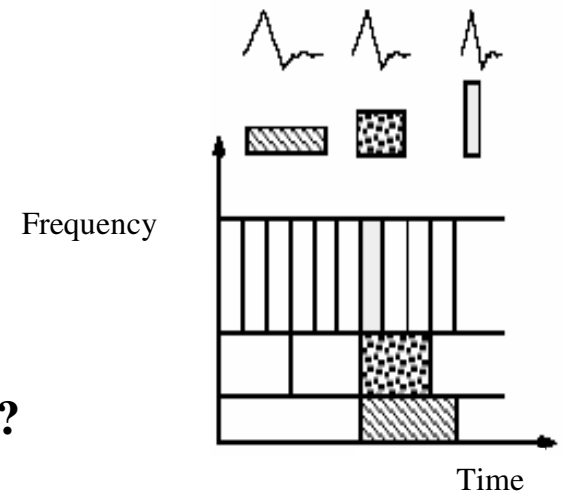
- reduce the storage,
- improve the image quality and
- promote content based retrieval of the data.

What is the best wavelet approach to be used in a project of an **image database for medium resolution infrared images** in screening of breast diseases

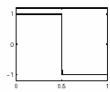
What base?

How denoise?

Wavelet ?

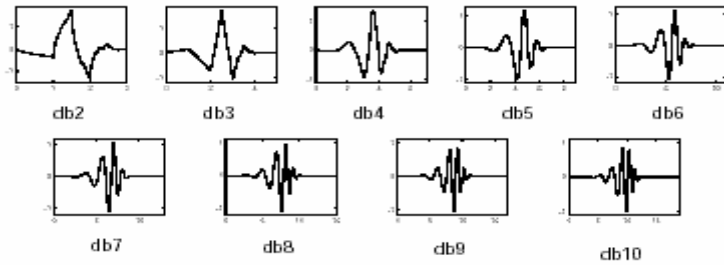


Wavelet

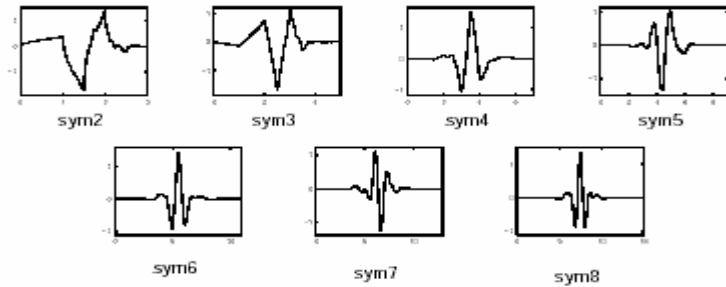


Haar

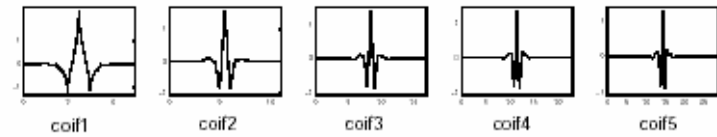
Daubechies



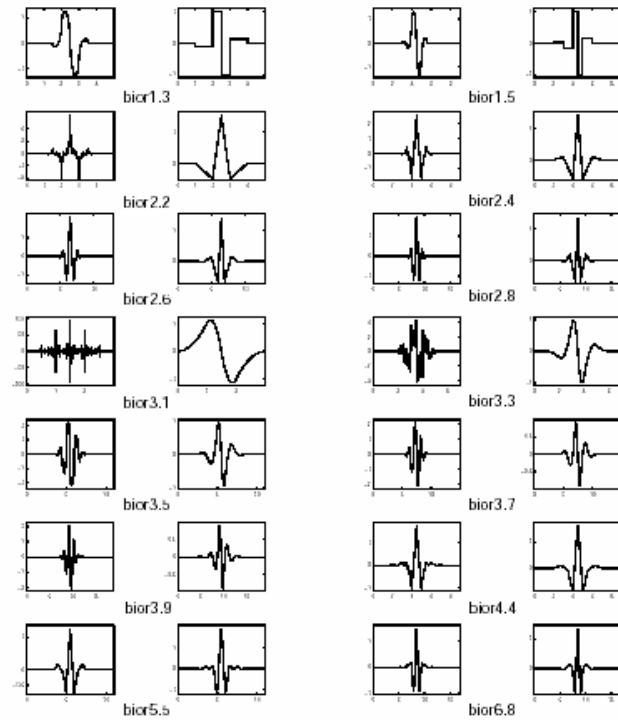
Symlets



Coiflets



Biortogonal



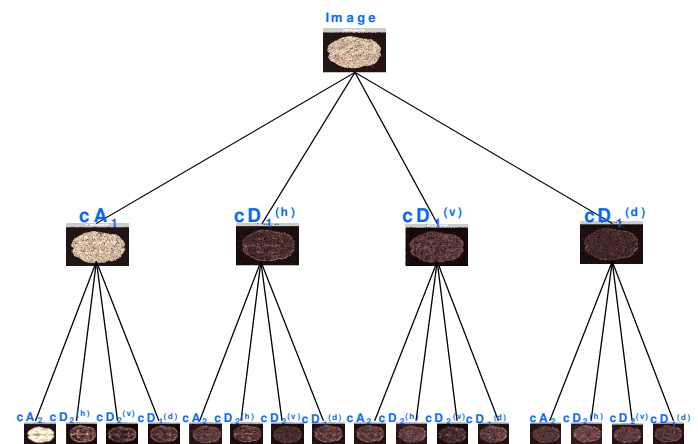
Types experimented (with various vanishing moments)

- Biorthogonal: 1.1 to 6.8
- Coiflets, 1 to 5
- Daubechies, 2 to 45
- Haar,
- Meyer,
- Reverse Biorthogonal: 1.1 to 6.8
- Symmlets - 2 to 28

composing a total of 108 different variations!

Generic denoising procedures by DWT involve three steps:

- wavelet decomposition,
- threshold of coefficients related to noise in the wavelet domain, and
- reconstruction by inverse wavelet transform into the spatial domain



Wavelet **denoising**

- Identify **low** and **high** energy coefficients
- Modify noisy coefficients by **adaptive thresholding**
- We use the **optimal reconstruction threshold:**

$$T = \sigma_n^2 / \sigma$$

σ_n^2 = Noise variance

σ = Original Signal variance

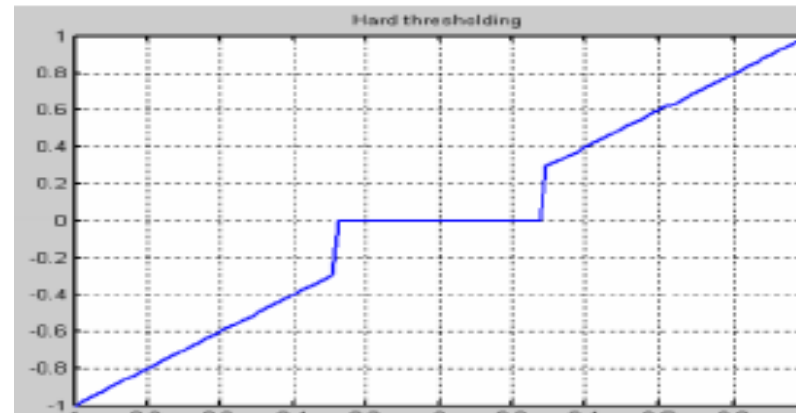
(and Hard & soft Thresholding approach)

Setting to zero value of coefficients which are considered negligible.

$$y_{soft}(t) = \begin{cases} \text{sgn}(x(t)) \cdot (|x(t) - \delta|), & |x(t)| > \delta \\ 0, & |x(t)| < \delta \end{cases}$$



$$y_{hard}(t) = \begin{cases} x(t), & |x(t)| > \delta \\ 0, & |x(t)| < \delta \end{cases}$$



where δ is the threshold value, and $\text{sgn}(\)$ is the *signal function* (it results +1 when the argument is up to zero and -1 otherwise).

The thresholding method proposed is not based *on a unique value* δ for threshold but testing all possibilities for achieving better quality of the denoised image.

Values of threshold in a series of possibilities $\delta(\mathbf{n})$ are defined and related to each element \mathbf{n} of this series.

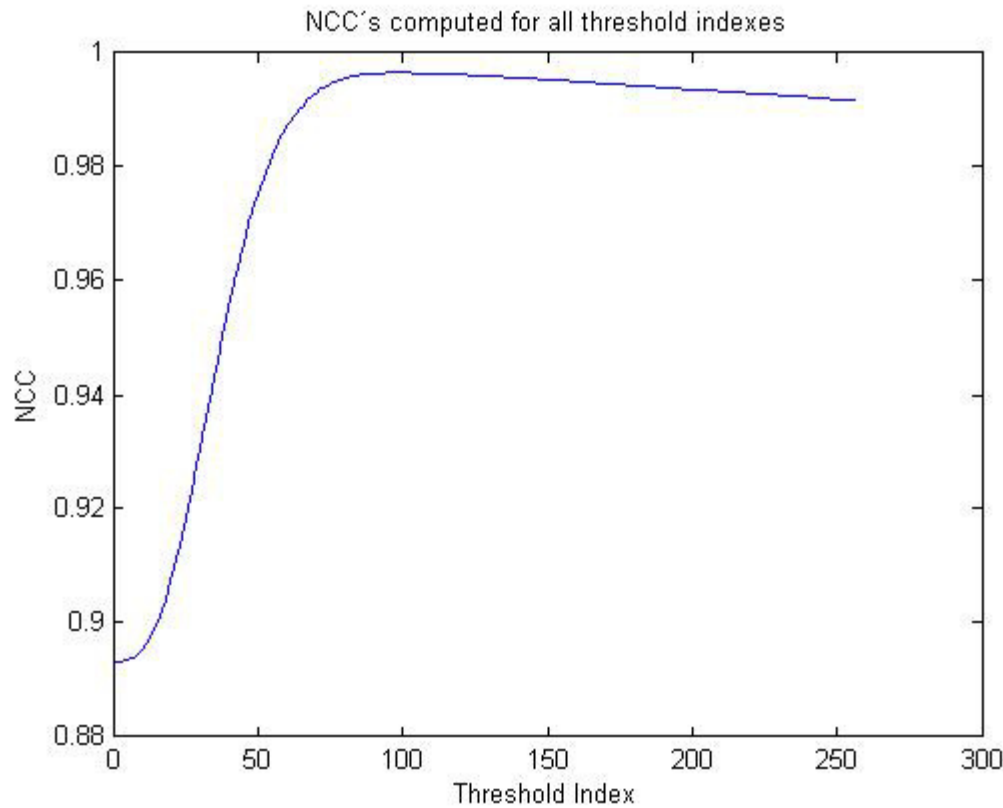
To consider the reconstructed image quality the normalized cross correlation (NCC) between the original and the denoised images is estimated.

In this case when more correlated are the images better is the δ .

Then the best threshold value for a given image is found automatically

- by the system considering best quality possible for the restored image when all others parameters are defined.
- Such search is put in an admissible computational time by using discrete possibilities previous delimited the best δ is found by a function of complexity $O(\log(\mathbf{n}))$.

Optimal reconstruction threshold



Example of the concave function relating threshold index and NCC for the best result of the base Biorthogonal 1.3.

Decomposition on levels 3

- ($j=3$) levels of high (**H**) and low (**L**) sub bands.

| | | | |
|--------|--------|--------|--------|
| LL^3 | LH^3 | LH^2 | LH^1 |
| HL^3 | HH^3 | | |
| HL^2 | HH^2 | | |
| HL^1 | | HH^1 | |

1, 2, 3 --- Decomposition
Levels

H ----- High Frequency
Bands

L ----- Low Frequency
Bands

Steps used on experiments with synthetic added noise images

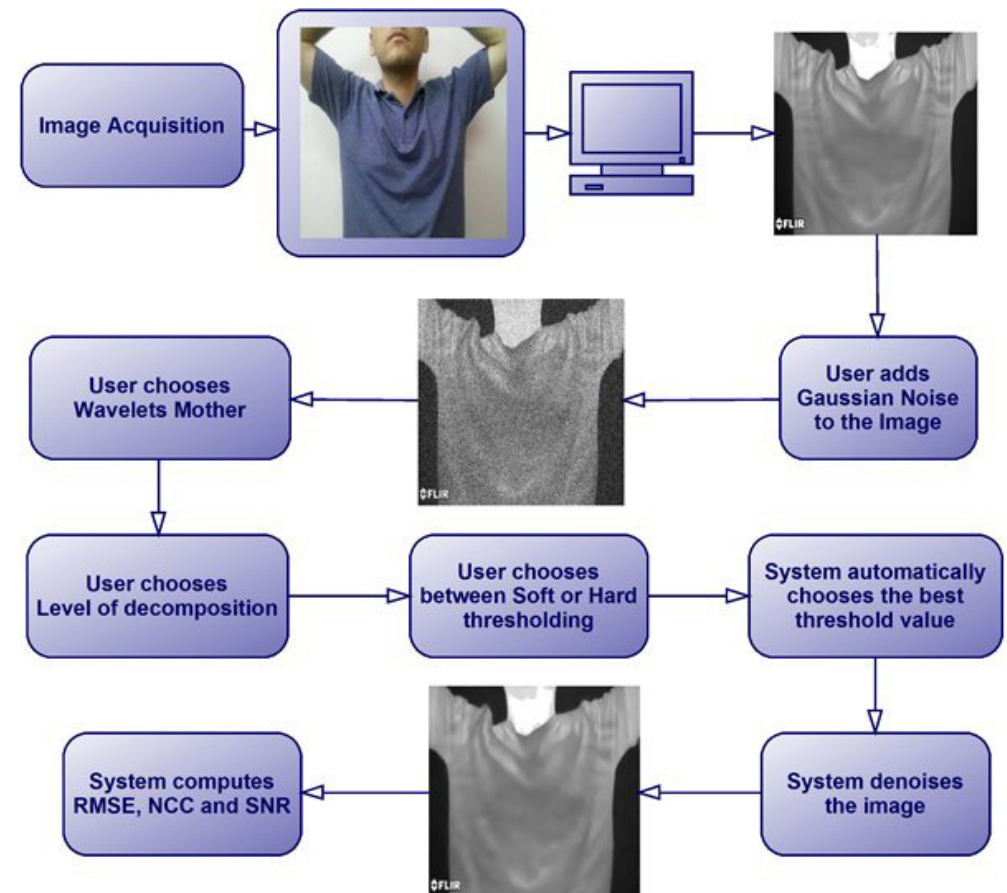
Step 1: Image acquisition and storage as a raw data.

Step 2: Gaussian noise addition. Three levels of a standard deviation value ($\sigma_{\text{noise}} = 5, 25$ and 50) are added.

Step 3: Define the type of wavelet, level of adaptive decomposition and the threshold process. Then the system select the coefficient for threshold based on the normalized cross correlation (NCC) that produces greater correlation

Step 4: Image restoration

Step 5: Verification





Results

- For the 8 images, each of the 108 bases are tested for levels 3 and 4 of the decomposition (L3 and L4), and the 2 possible way of coefficient thresholding (soft and hard).
- Each configuration has been considered for the images with added Gaussian noise at three different levels, with the best thresholding value automatically computed, resulting in a total of **10368 experiments**

MATLAB 7.12.0 (R2011a)

For each configuration the evaluators are:

$$RMSE = \sqrt{\left[\frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} [G(x, y) - F(x, y)]^2 \right]} \quad (1)$$

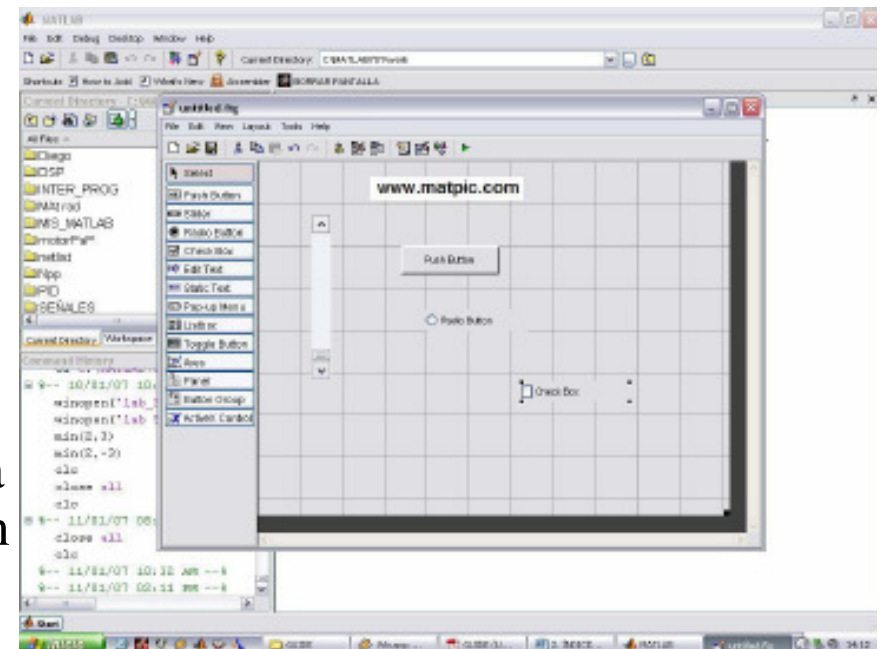
$$SNR_{ms} = \frac{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} G(x, y)^2}{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} [G(x, y) - F(x, y)]^2} \quad (2)$$

$$SNR_{rms} = \sqrt{SNR_{ms}} \quad (3)$$

$$PSNR = 20 \log_{10} \left(\frac{2^n - 1}{RMSE} \right) \quad (4)$$

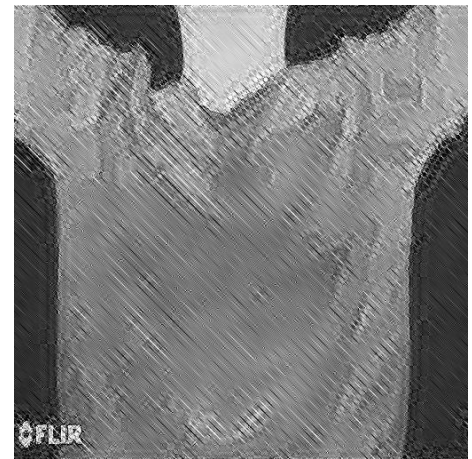
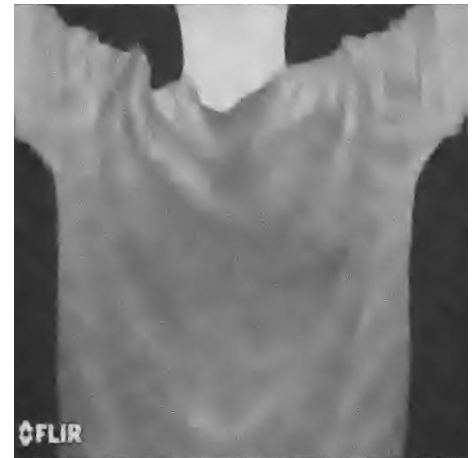
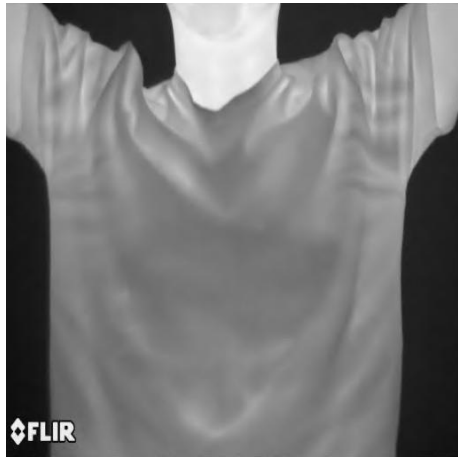
Used WT types

| | A | B | C | D | E | F | G | H | I | J | K |
|----|----------|----------|-------|-------|-------|-------|----------|----------|----------|--------|--------|
| 1 | Bior 1.1 | Bior 3.7 | db 1 | db 11 | db 21 | db 31 | db 41 | rbio 2.2 | rbio 5.5 | sym 10 | sym 20 |
| 2 | Bior 1.3 | Bior 3.9 | db 2 | db 12 | db 22 | db 32 | db 42 | rbio 2.4 | rbio 6.8 | sym 11 | sym 21 |
| 3 | Bior 1.5 | Bior 4.4 | db 3 | db 13 | db 23 | db 33 | db 43 | rbio 2.6 | sym 2 | sym 12 | sym 22 |
| 4 | Bior 2.2 | Bior 5.5 | db 4 | db 14 | db 24 | db 34 | db 44 | rbio 2.8 | sym 3 | sym 13 | sym 23 |
| 5 | Bior 2.4 | Bior 6.8 | db 5 | db 15 | db 25 | db 35 | db 45 | rbio 3.1 | sym 4 | sym 14 | sym 24 |
| 6 | Bior 2.6 | coif 1 | db 6 | db 16 | db 26 | db 36 | Dmey | rbio 3.3 | sym 5 | sym 15 | sym 25 |
| 7 | Bior 2.8 | coif 2 | db 7 | db 17 | db 27 | db 37 | Haar | rbio 3.5 | sym 6 | sym 16 | sym 26 |
| 8 | Bior 3.1 | coif 3 | db 8 | db 18 | db 28 | db 38 | rbio 1.1 | rbio 3.7 | sym 7 | sym 17 | sym 27 |
| 9 | Bior 3.3 | coif 4 | db 9 | db 19 | db 29 | db 39 | rbio 1.3 | rbio 3.9 | sym 8 | sym 18 | sym 28 |
| 10 | Bior 3.5 | coif 5 | db 10 | db 20 | db 30 | db 40 | rbio 1.5 | rbio 4.4 | sym 9 | sym 19 | - |

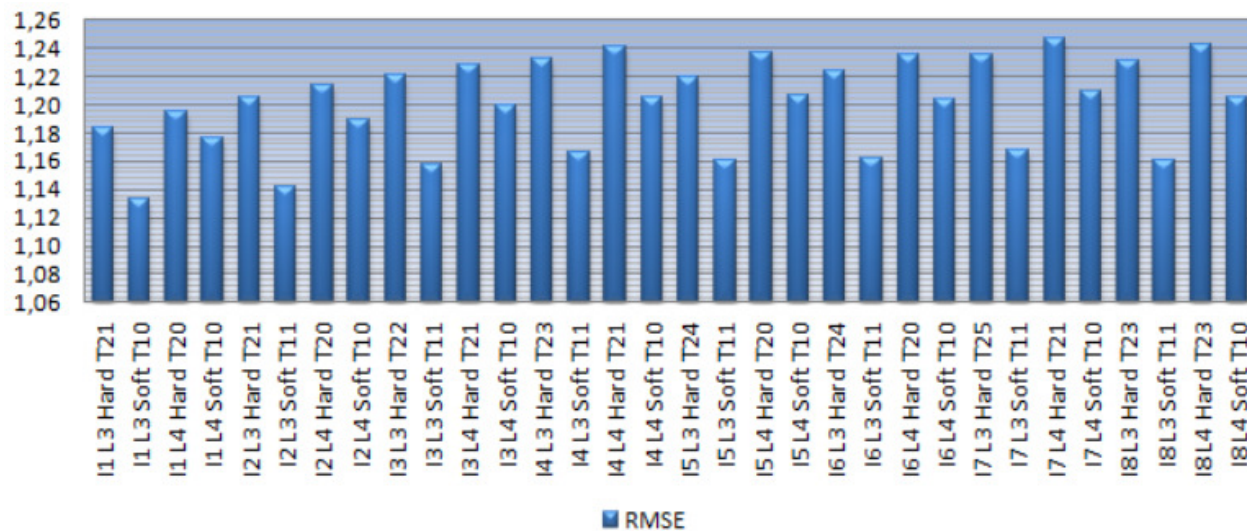


All image used are acquired by a Flir S45 camera (with sensibility of 0.08°C) in 640x480 resolution and encoded using 8 bit per pixels.

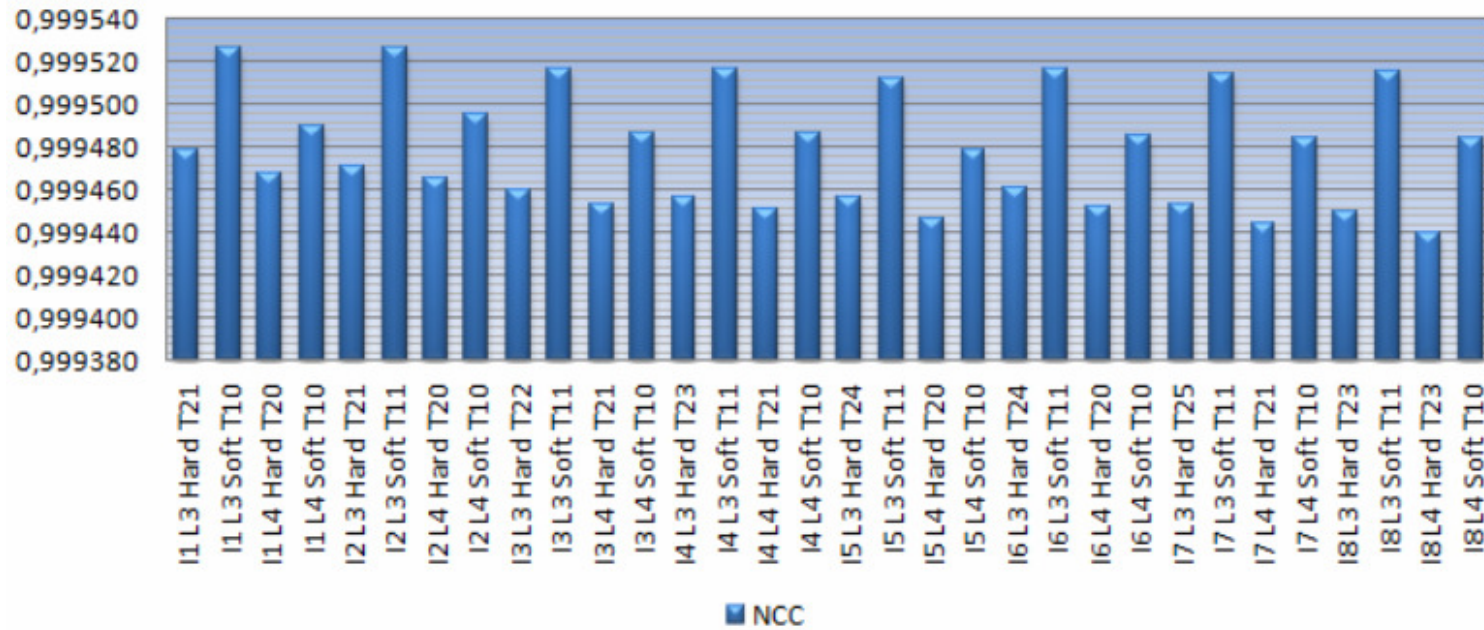
Restoration by best and worst results



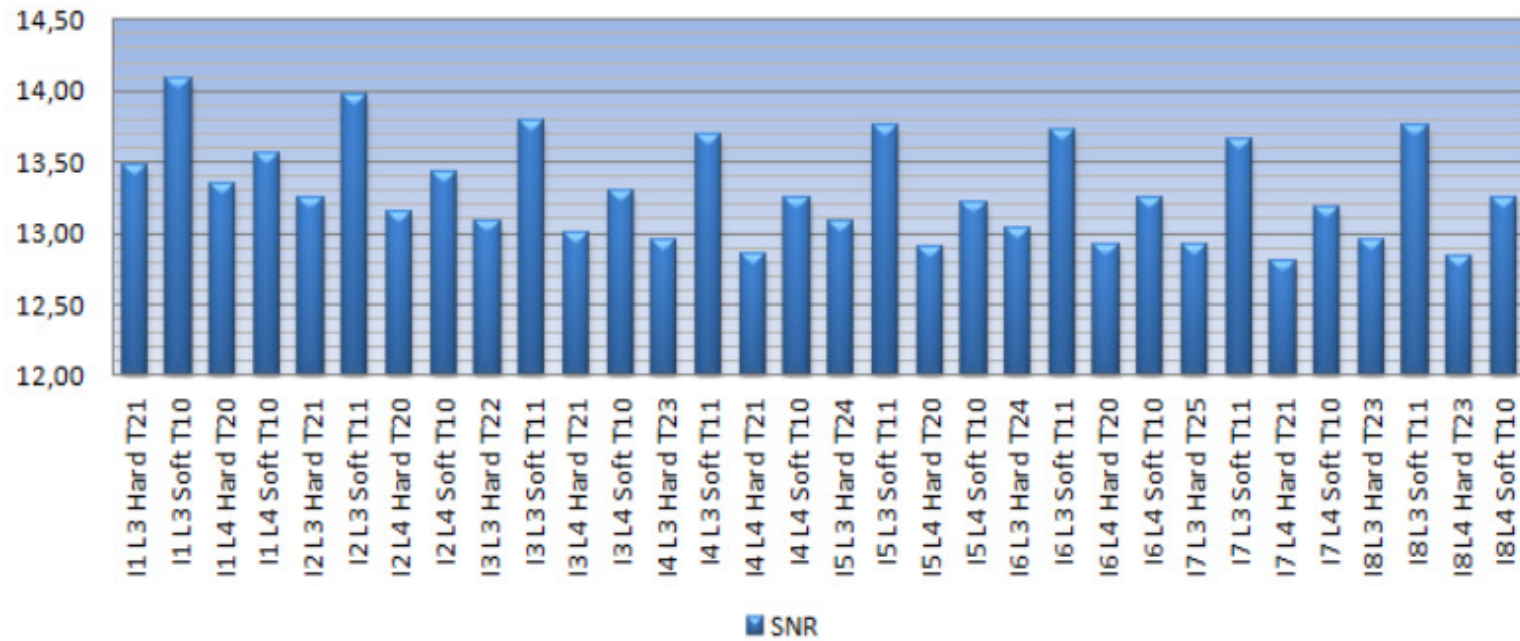
RMSE - Low noise



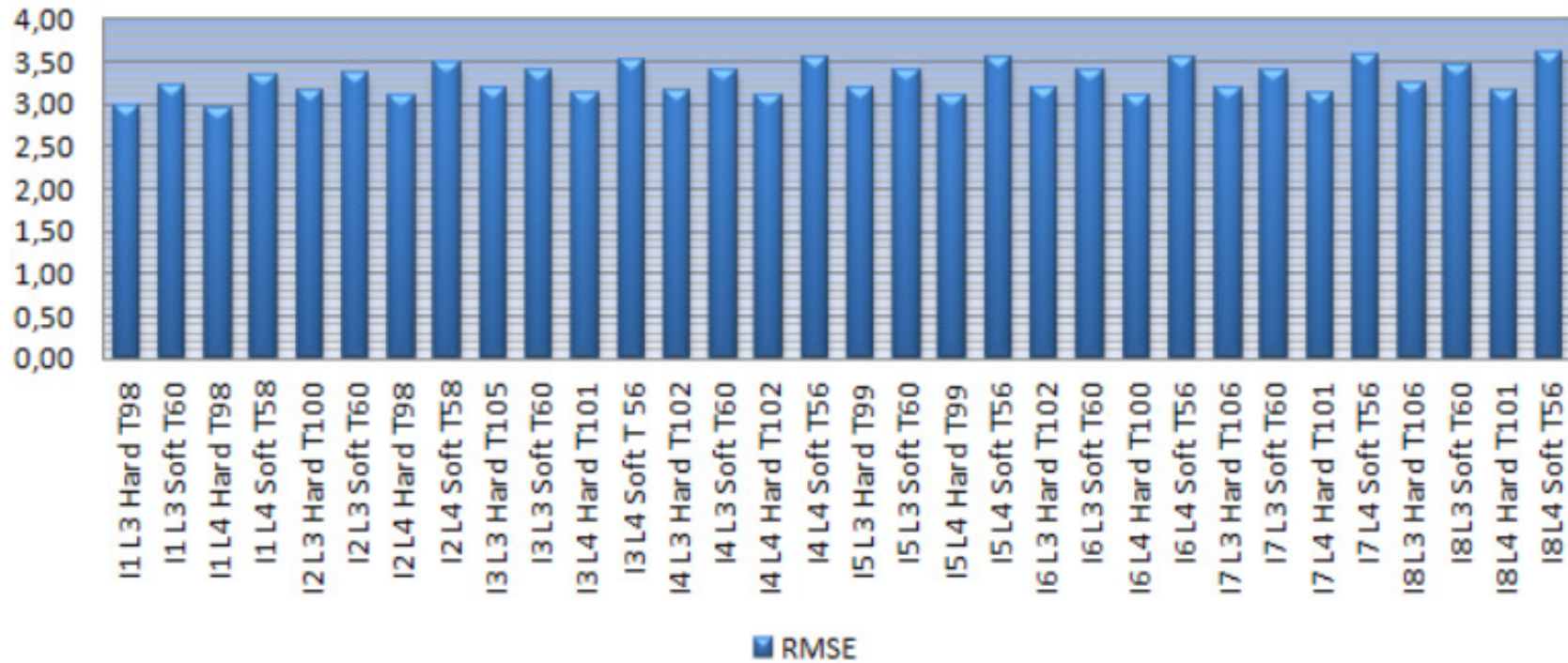
NCC low noise



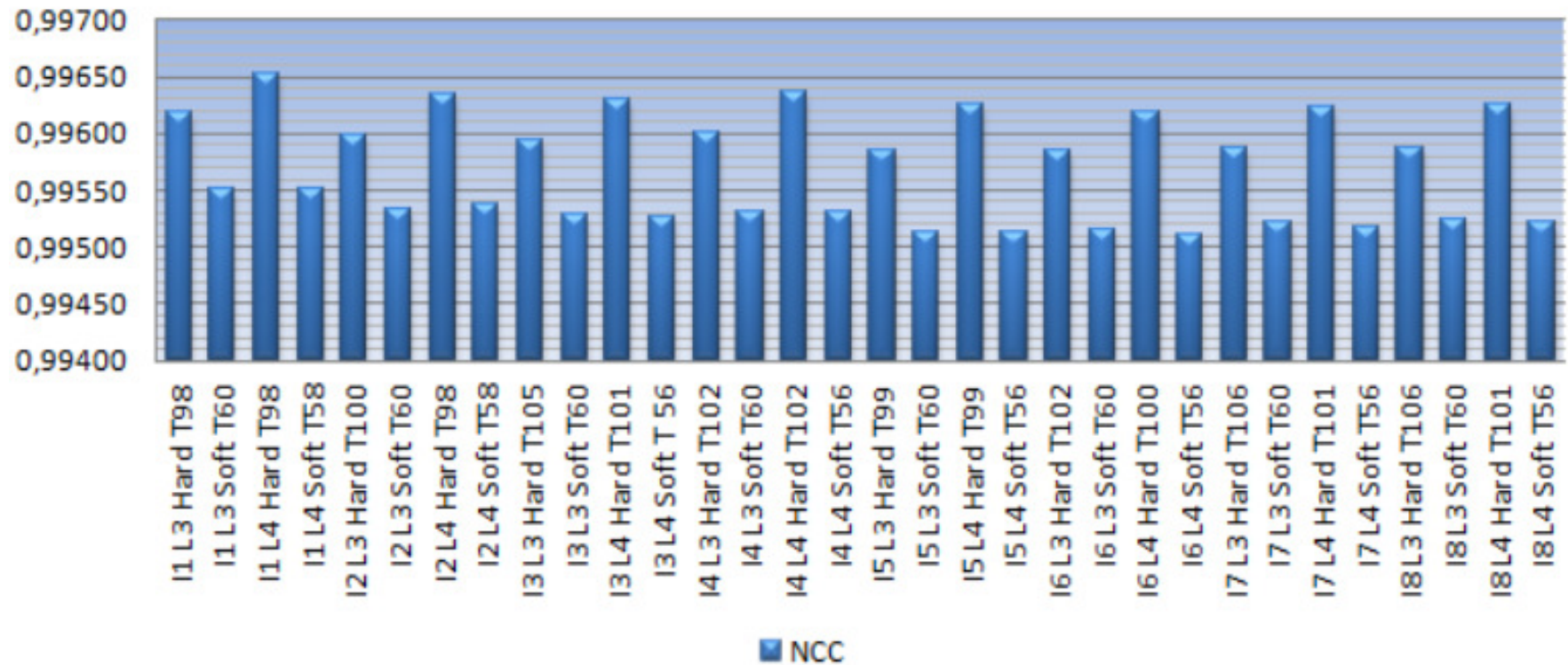
SNR – low noise



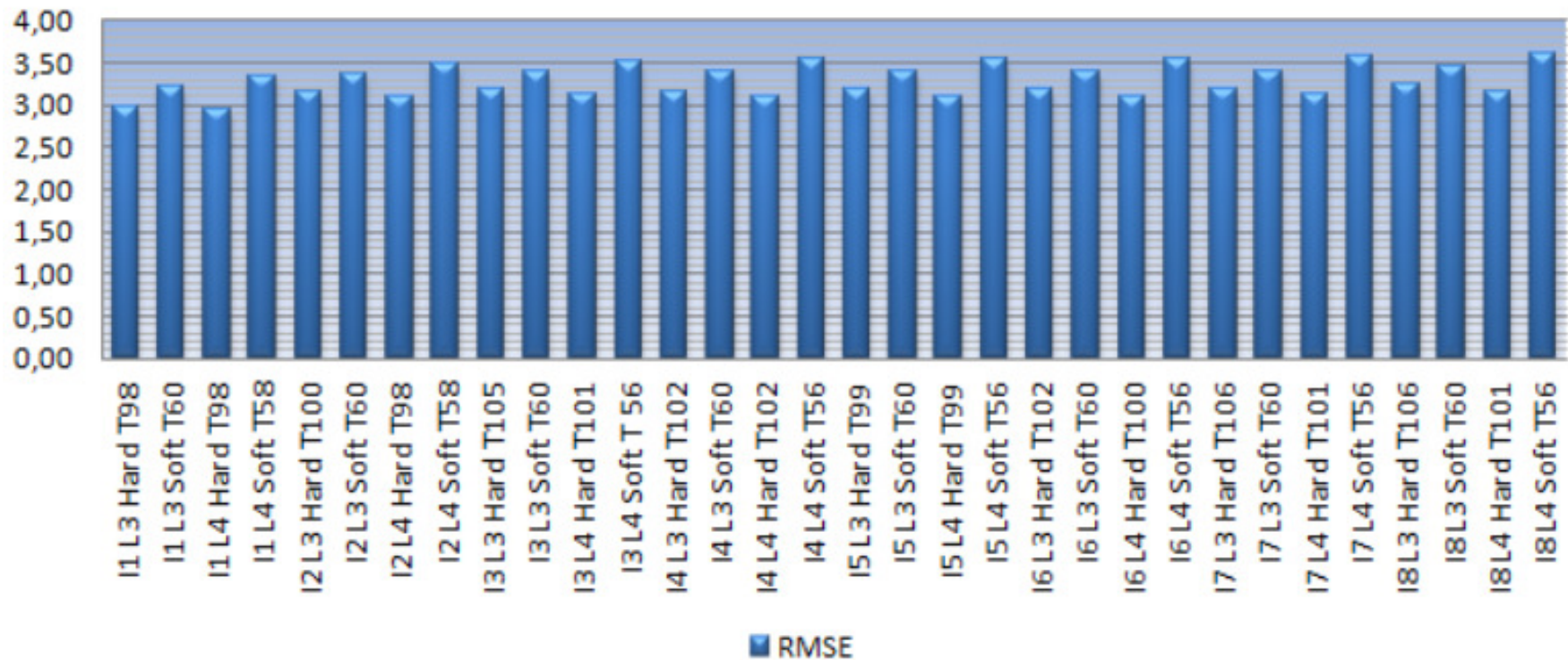
RMSE - medium noise



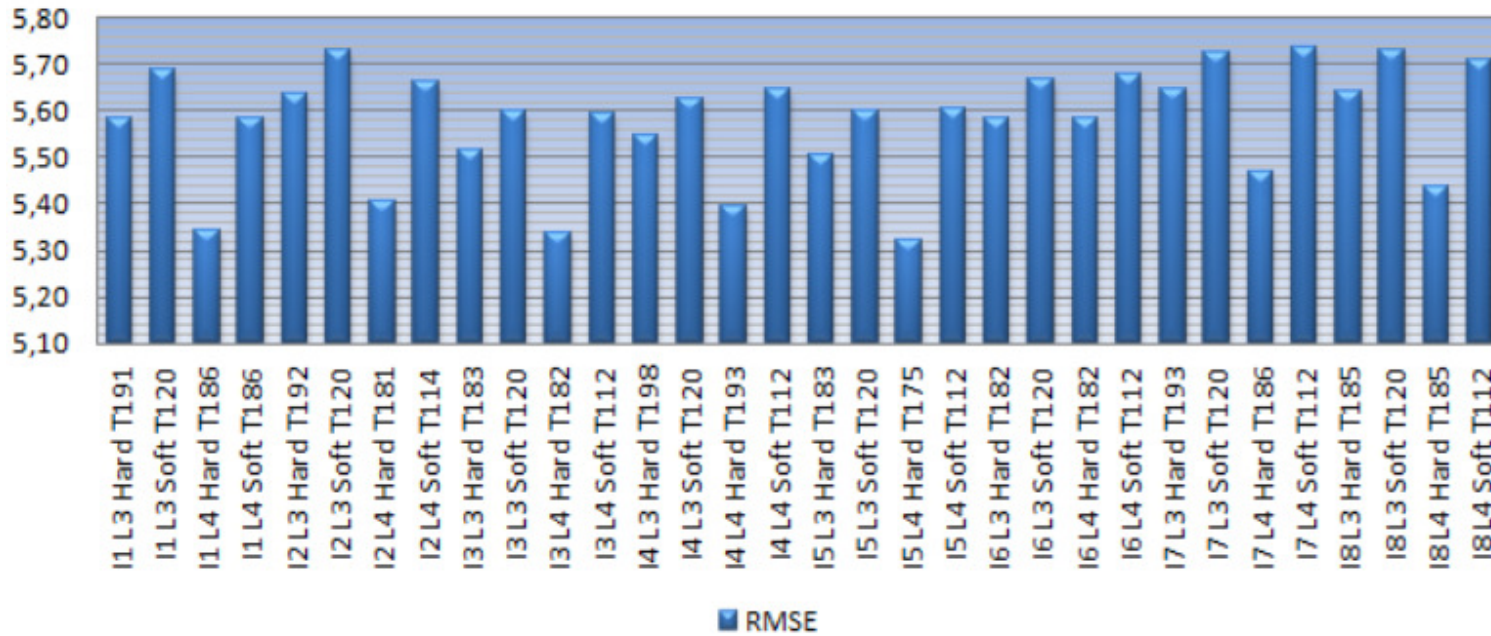
NCC medium noise



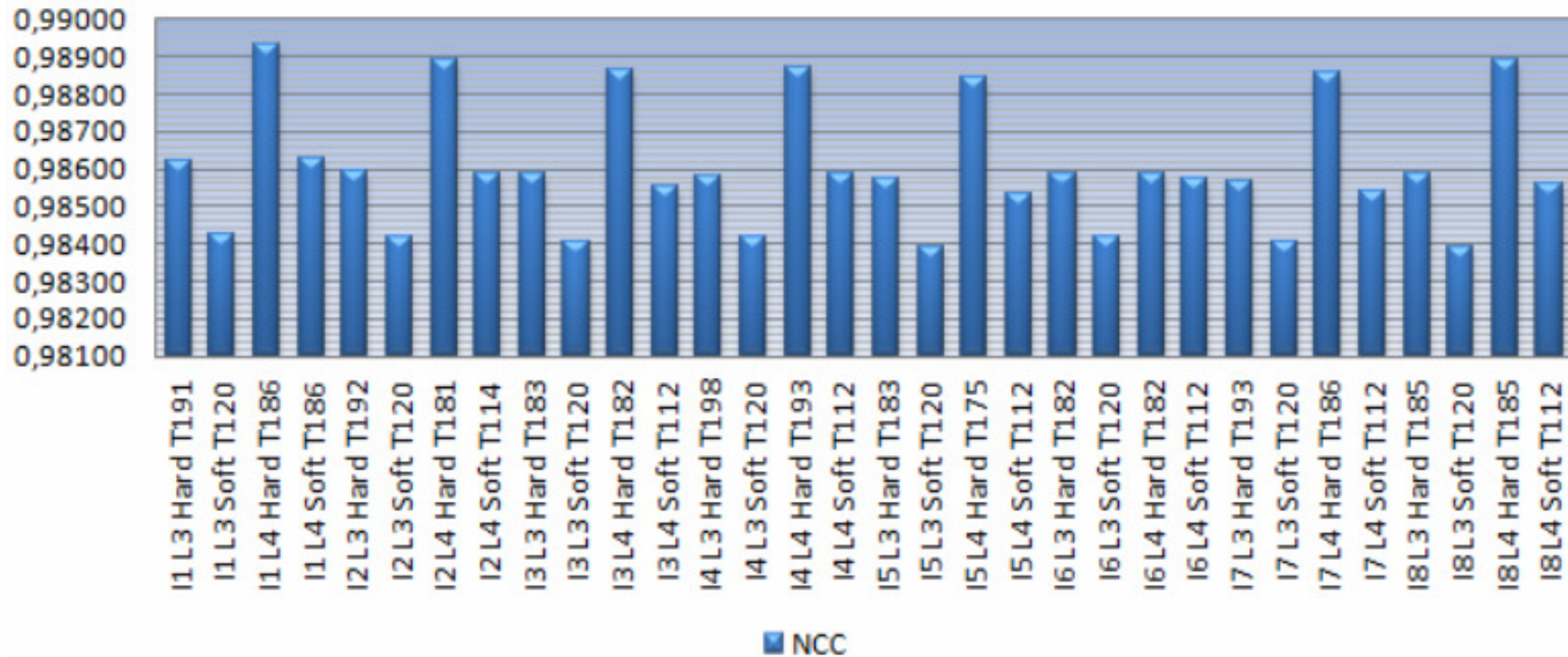
PSNR - medium noise level



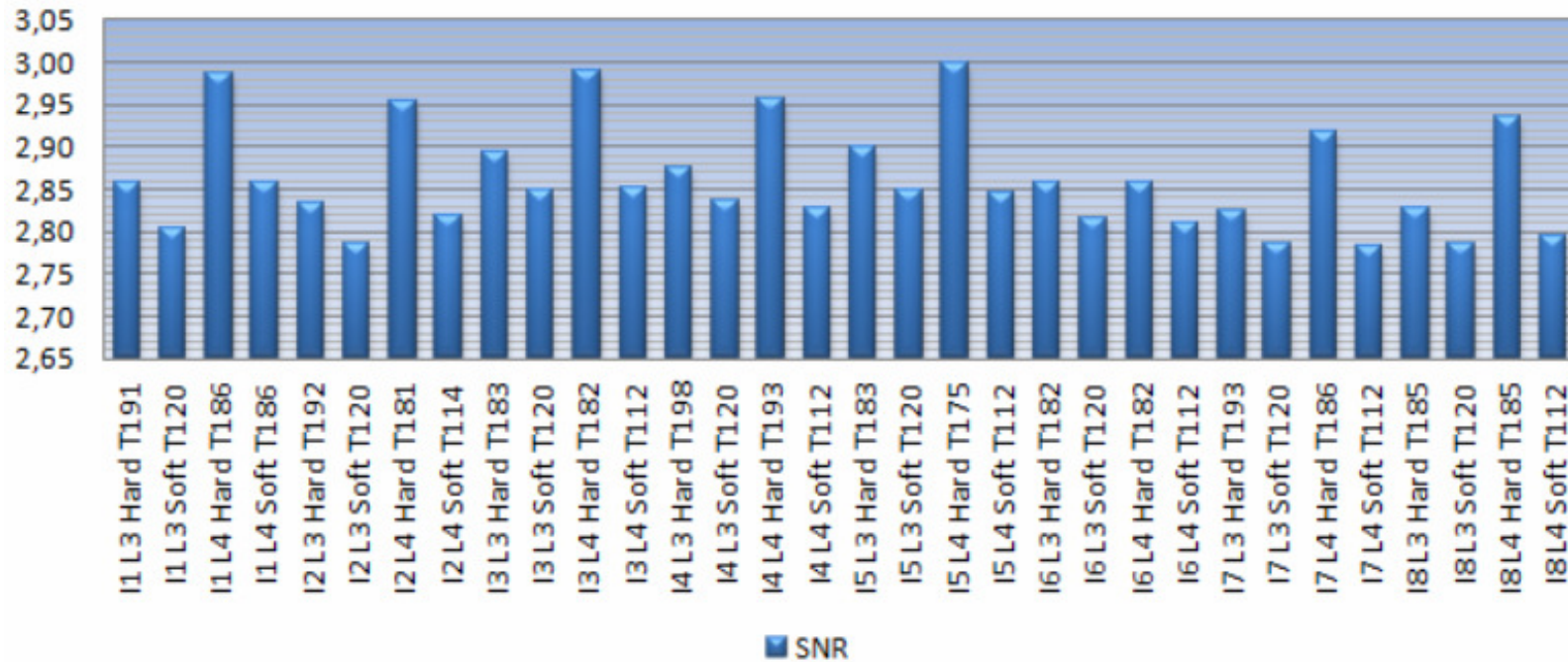
RMSE - high noise level



NCC - high noise level



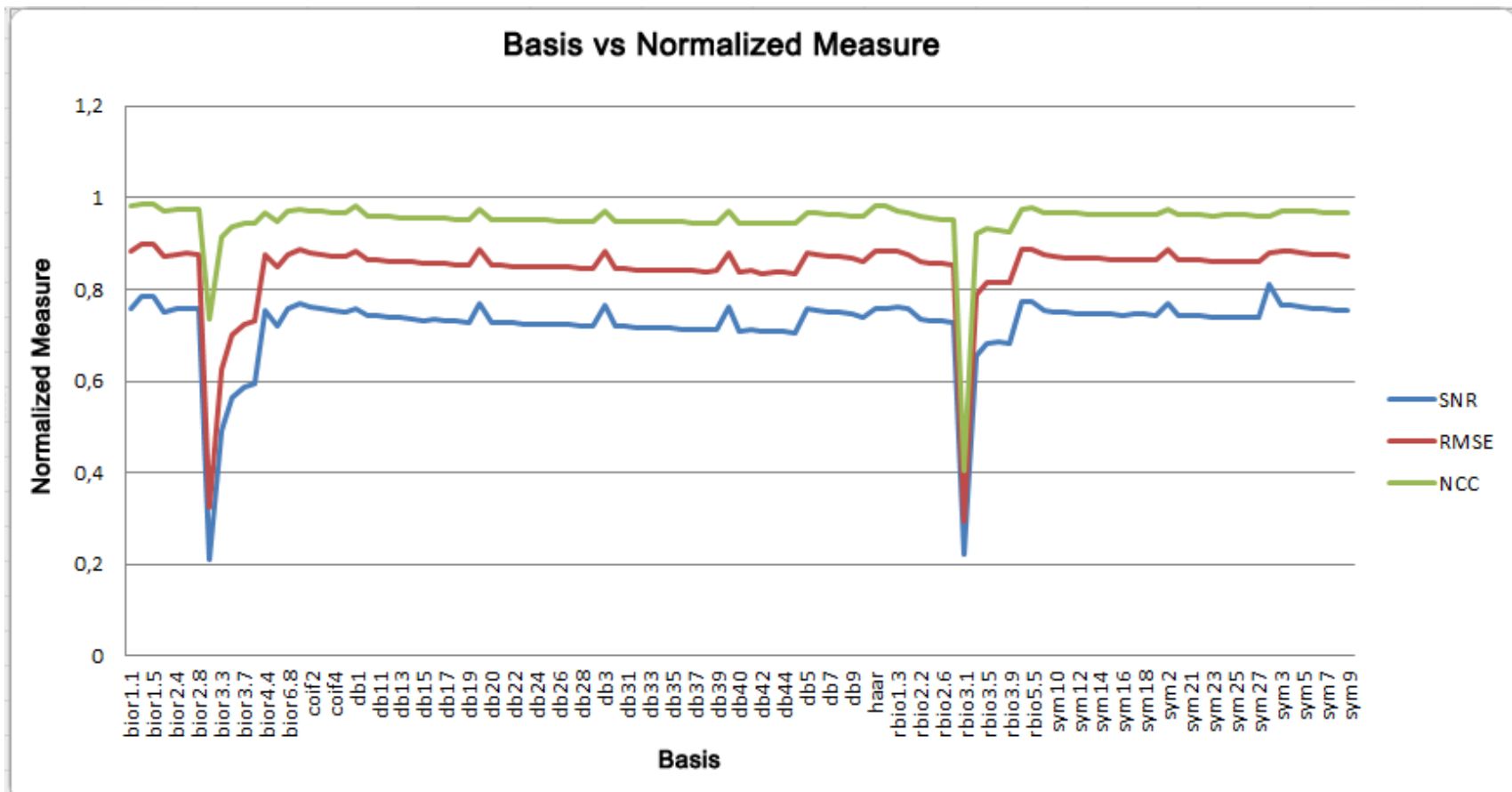
PSN - high noise level



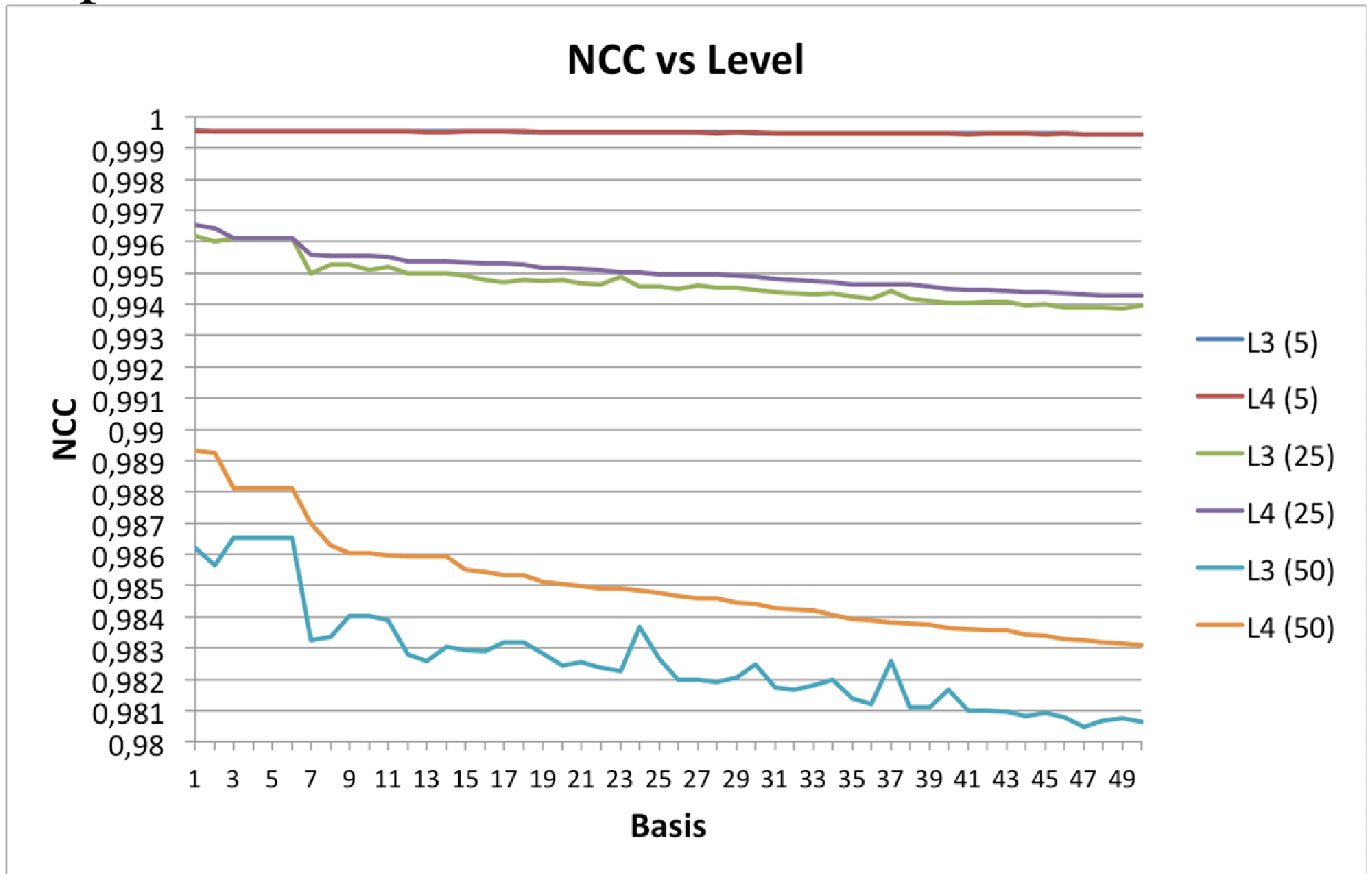
Comparison of the average NCC values for all images on all noise level for the used denoising methods.

| | A | B | C | D | E | F | G | H | I | J | K |
|----|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1 | 0.9933 | 0.9896 | 0.9933 | 0.9906 | 0.9897 | 0.9891 | 0.9887 | 0.9908 | 0.9927 | 0.9915 | 0.9911 |
| 2 | 0.9938 | 0.9897 | 0.9925 | 0.9905 | 0.9896 | 0.9891 | 0.9886 | 0.9905 | 0.9917 | 0.9914 | 0.9911 |
| 3 | 0.9937 | 0.9917 | 0.9922 | 0.9903 | 0.9895 | 0.9890 | 0.9886 | 0.9901 | 0.9925 | 0.9914 | 0.9910 |
| 4 | 0.9921 | 0.9894 | 0.9919 | 0.9902 | 0.9895 | 0.9890 | 0.9886 | 0.9898 | 0.9922 | 0.9913 | 0.9909 |
| 5 | 0.9924 | 0.9918 | 0.9916 | 0.9901 | 0.9894 | 0.9889 | 0.9885 | 0.9308 | 0.9922 | 0.9913 | 0.9910 |
| 6 | 0.9924 | 0.9925 | 0.9913 | 0.9901 | 0.9894 | 0.9889 | 0.9909 | 0.9863 | 0.9920 | 0.9912 | 0.9911 |
| 7 | 0.9923 | 0.9921 | 0.9912 | 0.9900 | 0.9893 | 0.9888 | 0.9933 | 0.9877 | 0.9919 | 0.9912 | 0.9910 |
| 8 | 0.9705 | 0.9919 | 0.9910 | 0.9899 | 0.9893 | 0.9888 | 0.9933 | 0.9874 | 0.9917 | 0.9912 | 0.9908 |
| 9 | 0.9868 | 0.9917 | 0.9908 | 0.9898 | 0.9892 | 0.9888 | 0.9920 | 0.9871 | 0.9917 | 0.9912 | 0.9935 |
| 10 | 0.9890 | 0.9915 | 0.9907 | 0.9897 | 0.9892 | 0.9887 | 0.9916 | 0.9925 | 0.9916 | 0.9910 | - |

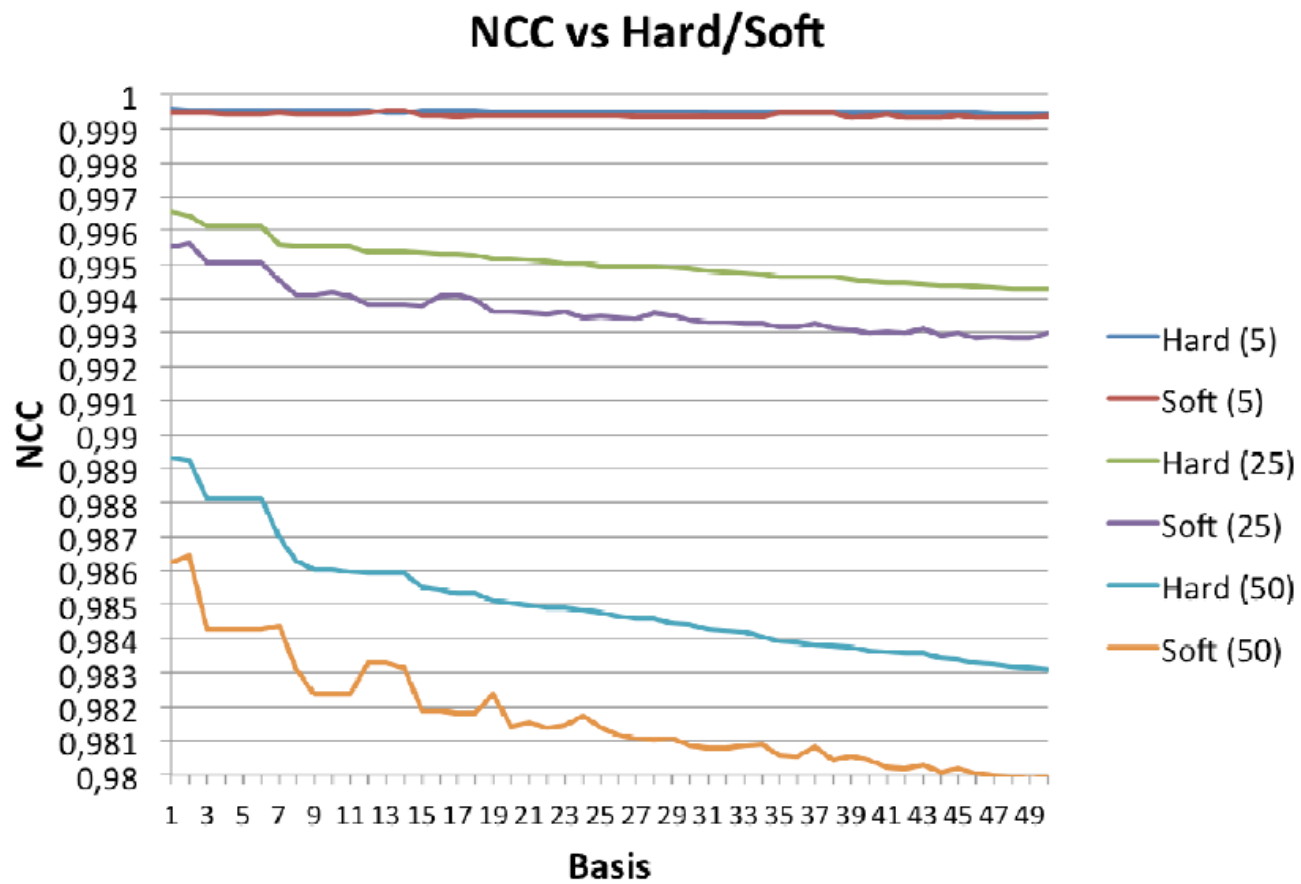
Comparing the measures SNR, NCC and RMSE for each type of wavelet used.



top 50 results



top 50 results



The 10 best combinations of characteristics for low noise level

| Base | Level | H/S | NCC | SNR | RMSE |
|----------|-------|-----|----------|------------|----------|
| Coif 1 | L3 | H | 0.999557 | 117.865253 | 1.133402 |
| Coif 1 | L4 | H | 0.999552 | 117.273865 | 1.146983 |
| Sym 2 | L3 | H | 0.999551 | 117.129401 | 1.135497 |
| Db 2 | L3 | H | 0.999551 | 117.129401 | 1.135497 |
| Sym 3 | L3 | H | 0.999548 | 116.427425 | 1.14867 |
| Db 3 | L3 | H | 0.999548 | 116.427425 | 1.14867 |
| Sym 2 | L4 | H | 0.999547 | 116.664894 | 1.148594 |
| Db 2 | L4 | H | 0.999547 | 116.664894 | 1.148594 |
| Bior 2.6 | L4 | H | 0.999547 | 116.628034 | 1.142708 |
| Rbio 5.5 | L4 | H | 0.999547 | 116.483195 | 1.143878 |

Results for the best case of each noise level.

| Noise l. | Base | Dec.l. | H/S | Thr. index | SNR | RMSE | NCC |
|----------|----------|--------|-----|------------|---------|-------|-------|
| 5 | coif 1 | 3 | h | 18 | 117.865 | 1.098 | 0.999 |
| 25 | bior 1.3 | 4 | h | 98 | 33.615 | 3.857 | 0.996 |
| 50 | bior 1.3 | 4 | h | 183 | 16.850 | 7.611 | 0.989 |

Conclusion :

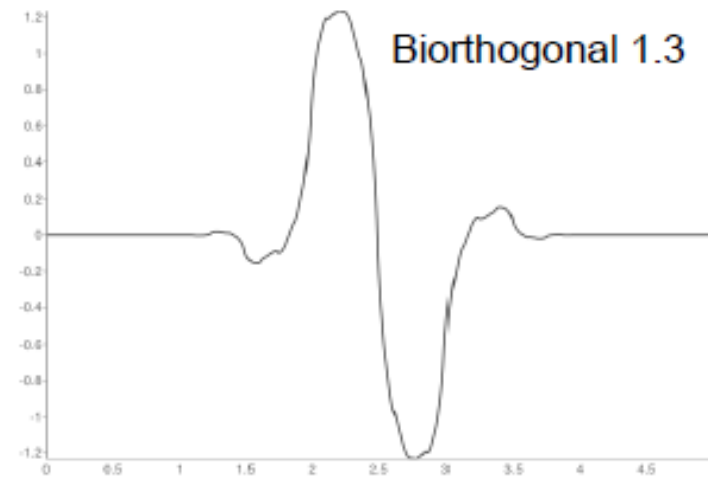
Averaging all noise level:

The most relevant are:

Coiflet 1, Symmlet 2, Daubechie 2,
Symmlet 3, Daubechie 3, Biortogonal 2.6
and Reverse biortogonal 5.5.

The hard threshold is always better.

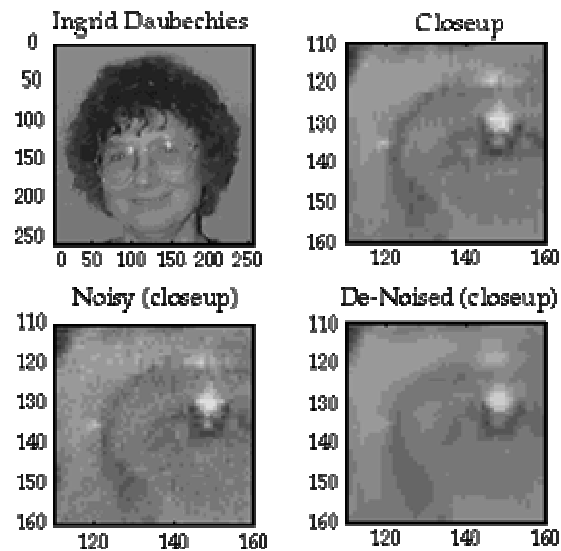
For low level of noise only the three levels of
decomposition can be used.



Famous example of Daubechies (1993) denoise

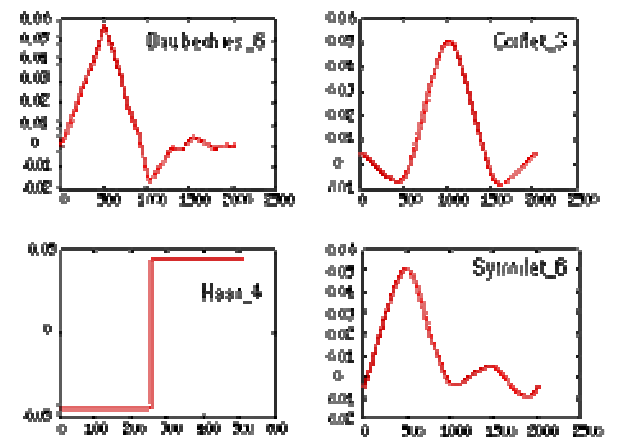
Donoho denoise:

- Coiflets-3
- threshold
- inverse



Second part

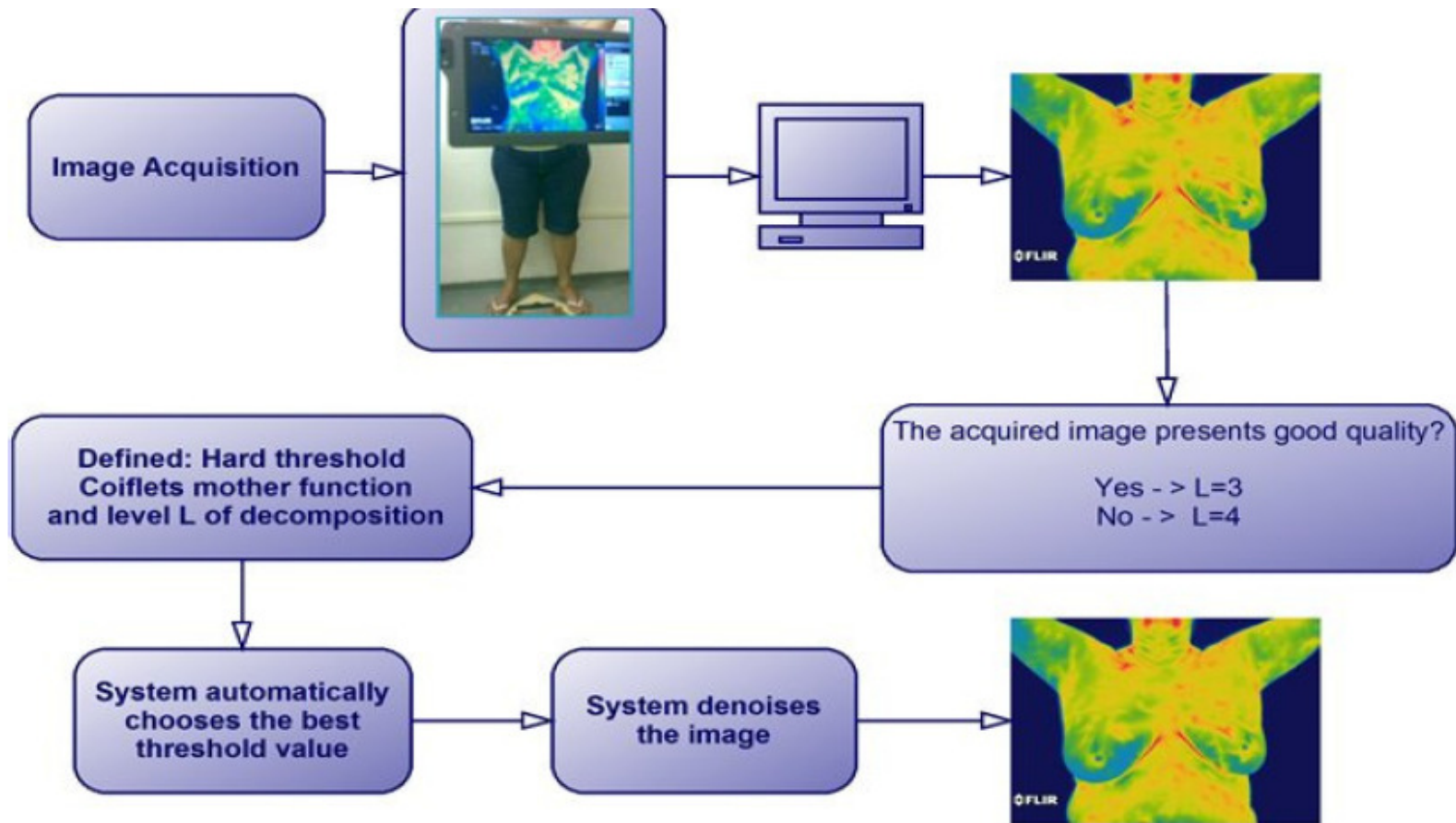
- Use these conclusions for the database project.



Steps to perform an efficient restoration scheme for infrared images considering the noise level.

- 1: Image acquisition and storage as a raw data
- 2: Evaluation of noise level and decision about decomposition in level 3 or 4.
- 3: Coiflet wavelet and hard threshold are used.
- 4: Coefficients for thresholding is select automatically based on the NCC.
- 5: The image is reconstructed using the modified coefficients.

Restoration of real infrared of whatever noise levels

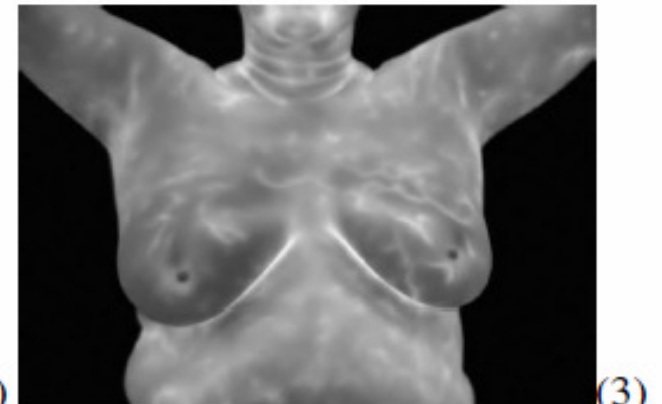
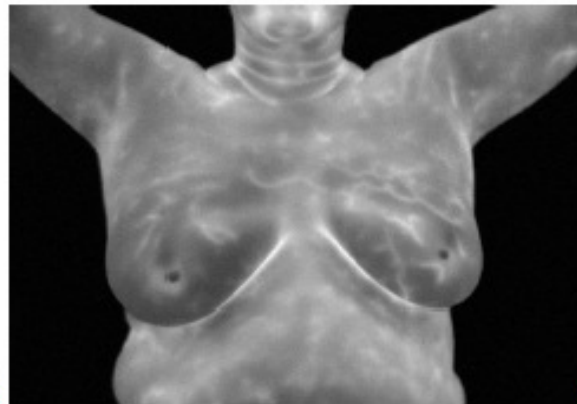
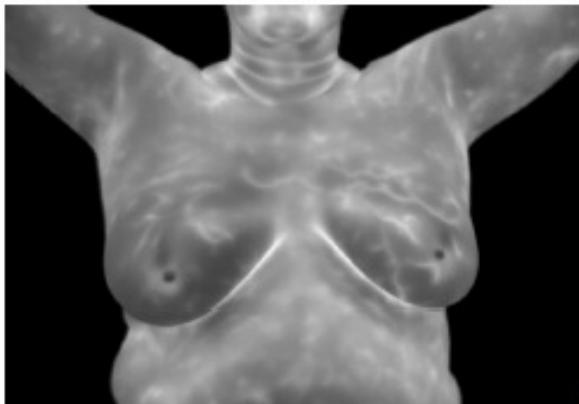


Comparing achieved characteristics for typical breast image.

Results

Original : 49.519 bytes (1),
image after storage and transmission:
50.846 byte (2) and
denoised image by the proposed scheme:
15.869 bytes (3).

| images | SNR | RMSE | NCC | Size (bytes) |
|--------|---------|--------|--------|--------------|
| 1 - 2 | 5.9197 | 2.2273 | 0.8202 | 50.846 |
| 1 - 3 | 16.0751 | 0.8202 | 0.9997 | 15.869 |



Thanks

- aconci@ic.uff.br
- www.ic.uff.br/~aconci