



Comparison of Different Image Enhancing Techniques for Medical Thermal Images

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Medical infrared (IR) images are, like other medical images, sensitive to noise, which affects directly the temperature measurement of the subject. There are several noise removal techniques that have good performance on digital images, but may produce different temperature readings on thermal images. Hundred and twenty different noisy images were selected from a database and after being processed with several noise removal techniques, the result was statistically analyzed using the standard parameters: maximum, minimum and mean temperature, standard deviation of same region of interest, root mean square error, signal to noise ratio, cross correlation coefficient. In the end, all techniques were compared and graded according with the results. This investigation shows that all techniques produce different results, the recommended method for improving medical thermal images are the Median, Mean and Wiener filters. Results however suggest that noise filtering should only be applied when specifically needed.

Keywords: Image Filtering, Image Enhancing, Infrared Imaging, Medical Thermography, Noise Processing.

1. INTRODUCTION

Medical thermography is a diagnostic and treatment complementary method of medical imaging. It records the radiated energy from the human skin surface and is useful to characterize healthy and pathological physiological stages, namely in the microcirculatory, autonomous nervous and musculoskeletal systems. Each pixel of the thermal image is quantitative and represents a temperature value.¹

Like the other medical image methods, the obtained images from medical thermography are also affected by noise. This noise can be perceived as signal fluctuations that appear in the resultant image and was inexistent in the original scene. It may be caused by electronic limitations and/or environmental surrounding interferences. Normally the presence of noise degrades the image, which in case of medical thermal images can mean a wrong temperature measurement. Noise increases with the sensitivity setting in the camera, length of the exposure, electronic components temperature, and varies amongst different camera models.²

The noise that can be found in this type of images can be classified in two different categories according to the acquisition nature, related with the capture equipment and image noise appearance.²

The noise generated in the image construction at the capture equipment can be of three types:

- Random noise—where there are fluctuations in the intensity of the pixels caused by any exposure length;
- Fixed pattern noise—when a pixel's intensity far surpasses that of the ambient random noise fluctuations. This type of noise is unique and it will show almost the same distribution of high intensity value pixels for the same conditions (temperature, length of exposure, speed);
- Band noise—is highly camera-dependent and is introduced by the camera when it reads data from the digital sensor, being more visible at high speeds in the shadows when the images are brightened.

On other hand the noise image appearance can be grouped in the following types:

- Photo-electronic—can be of two subtypes: photon and thermal. The photon noise is generated by photon arrival statistics and follows the Poisson distribution, being signal dependent. The thermal noise is caused by random fluctuations of the electrons, follows the Gaussian distribution and is signal-independent;
- Impulse—is characterized by data loss or saturation and can be salt noise (data number = maximum possible), pepper noise (data number = minimum possible), salt and pepper noise (mixture of the previous two) and line drop (when part of all of a line is lost);

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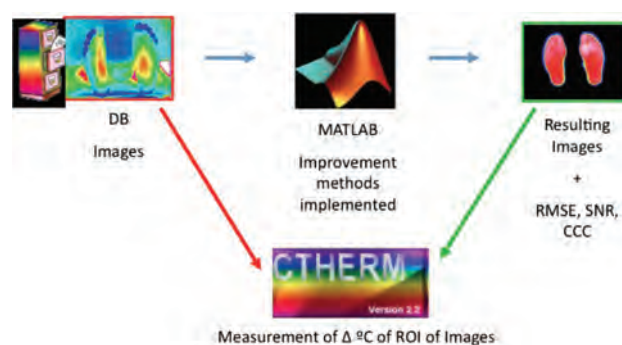


Fig. 1. Experimental procedure setup.

- Structured—can be intended as the signal contributions that have a non-random nature and that only affects a certain area of the image. It can be divided in periodic and stationary (the noise has fixed amplitude, frequency and phase; commonly caused by interference between electronic components); periodic and non-stationary (noise parameters such as amplitude, frequency, phase vary across the image; there is intermittent interference between electronic components); aperiodic (compression and adaptive pulse code modulation) noise); detector striping (calibration differences among individual scanning detectors); and detector banding (calibration changes from scan-to-scan).

Medical thermal images are often affected by noise, which can be random, due to the presence of different temperature objects in the surroundings, causing an effect known as flooding,³ can be fixed noise and/or band noise, due to the capture equipment (which may be faulty, or needing to be calibrated), can be photo-electronic, due to the integration time of the sensor to process the radiation perceived into an electrical signal, can be of impulse nature, if the atmosphere in were the investigation is being performed has a presence of gases that affect the camera readings, and can be structural, in the case some sensors are not working properly, affecting the image uniformity.³

In situations where noise is detected in the images and it is not possible to re-take the images in the same conditions, image enhancing should be the first image processing method applied before segmentation and registration. The modality has relevant clinical applications on: inflammatory arthritis, osteoarthritis, soft tissue rheumatism, enthesiopathies, tennis elbow, fibromyalgia, complex regional pain syndrome, peripheral circulation, fever screening, burns, renal dialysis and malignant diseases.^{1,5}

Recently, this technology due to epidemic outbreaks such as SARS or Ebola, has been considered for massive fever screening, having guidelines been proposed.^{6,7} Image enhancing of medical thermal images can contribute significantly for the identification in regions of interest (ROIs) of fever warning situations, where the mean temperature is above the specified thermal threshold, maximizing the posterior image processing methods of analysis based in segmentation and registration in that process.^{8,9}

Another very promising application of image enhancement in medical thermal images is on breast screening, which was one of the first applications of this medical imaging modality. Sensitivity and specificity in this kind of application is very important to prove the effectiveness as some promissory experiments demonstrated,^{10–13} noise removal preceding advanced segmentation algorithms help to extract the thermal shape signature of the

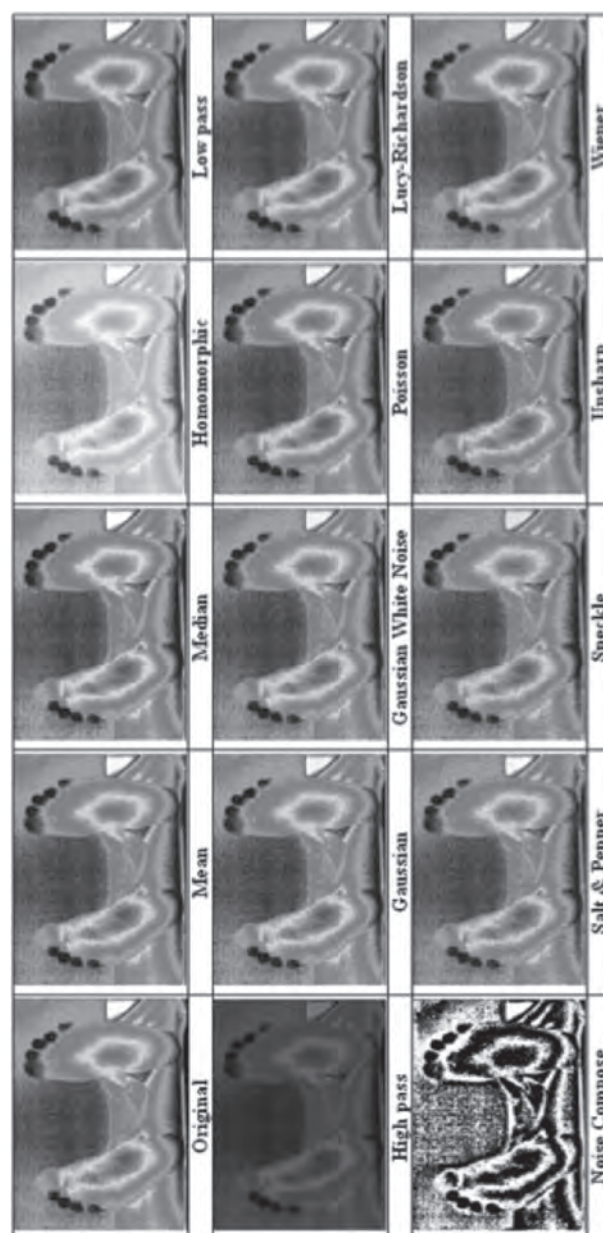


Fig. 2. Example of resulting images from application of the image enhancing filters.

affected ROIs suspicious of being cancerous. On the other hand, improving the identification of early breast neoplasm situations would facilitate the construction of models to test the feasibility of medical thermal imaging as a complementary diagnostic method in the screening of breast cancer.^{14,15}

The aim of this research is to investigate and compare which of the available different image enhancing techniques has better performance for medical thermal images. Those techniques will be better described in the next section of this manuscript.

2. MATERIALS AND METHODS

The thermal images used in this research were collected in the Thermal Physiology lab of the University of South Wales.

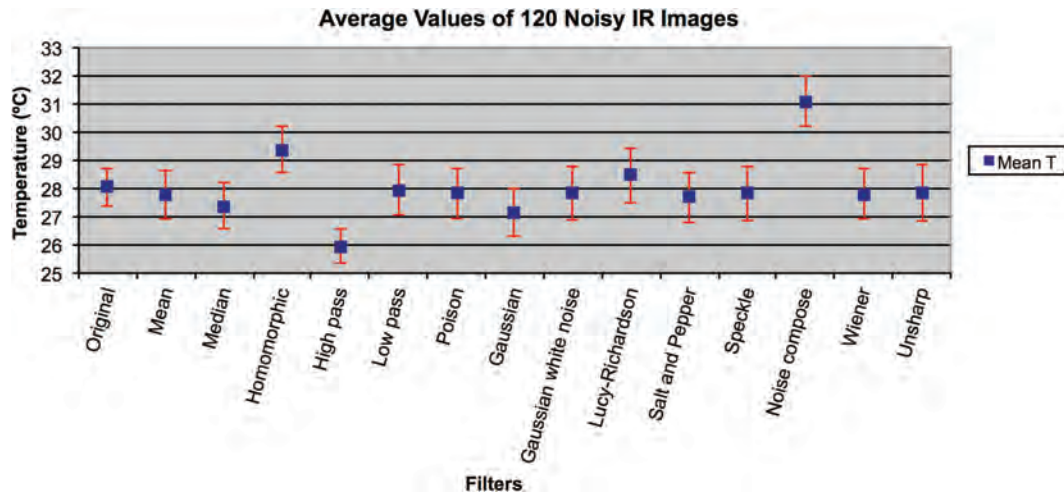


Fig. 3. The average values of mean temperature comparing the results obtained from each algorithm with the original image.

The images were acquired from volunteers of the Human IR Atlas of Normal’s according to the “Glamorgan Protocol,”¹⁴ which specifies the conditions for the room, recording equipment and subject preparation and manner of operation in the exam. All participants have filled the informed consent and EURO-QOL questionnaire.¹⁶ The recorded images were stored in a computer database using the C THERM system.¹⁷ For this experiment a total of 120 images were selected based in the visual assessment of presence of noise.

Changes in image noise do not only occur with environmental changes or when changing the camera model, there are other factors like fluctuations in luminance, “chroma” (color composition), spatial frequency and magnitude that will affect the noise in the image. Noise affects all image regions equally, although darker regions will (percent-wise) be affected more than brighter ones. In brighter areas noise becomes less pronounced.²

There are some techniques known to improve images affected by noise, by reducing its impact. Linear smoothing filters operate by processing the original image with a moving convolution mask. While reducing noise the trade-off is a blurring effect on the image. Examples of this type of filters are: mean, Gaussian, Gaussian white noise, high-pass, low-pass, Homomorphic, and Unsharp. Nonlinear filters do not generate their output

as linear function of the respective input; their function locates and removes noise by determining whether the pixel value is valid or noise affected. Examples for this type of filters are: median, Poisson, Wiener, Lucy-Richardson, speckle, salt and pepper and noise compose.² While these filters produce less or no image blurring they introduce new and not necessarily correct information into the image, as the assumptions on which they are based may not be true. The previously mentioned image enhancing methods were selected because they are the most common implemented in image applications that require noise filtering with small interference with the image.

Since in this particular application the goal is to remove only the noise and not perform any edge detection, image enhancement using wavelets was not considered. The use of wavelets would reduce consecutively the image by the powers of two, using a set of variable functions for subsampling, which is difficult to maintain constant from one application to another, once there are innumerable functions available. Additionally, it is difficult to ensure that the reconstruction of an image from a sub-sampled is processed with the same set of variable functions.^{18–22} Using wavelets there is a risk of losing significant information from the image, which is composed of quantitative measurements, by considering it noise.

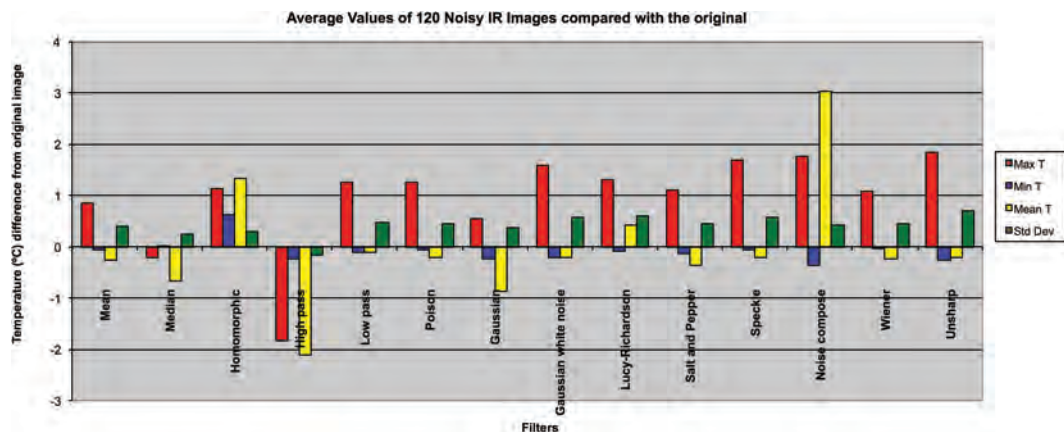


Fig. 4. Temperature differences in average values from the resulting images from filter applications to the original image in terms of maximum, minimum and mean temperatures and standard deviation.

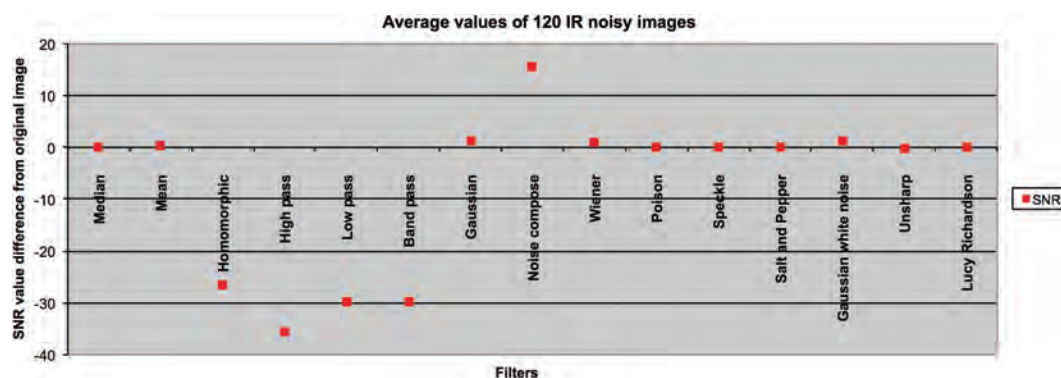


Fig. 5. Signal to noise ratio comparison between the noise filtered images and the original.

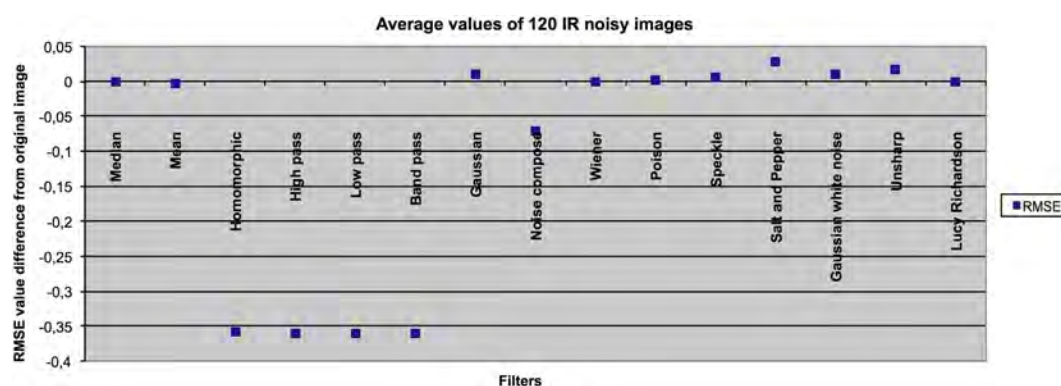


Fig. 6. Root mean square error comparison between the noise filtered images and the original.

For image quality comparing measure, were suggested:²³ the signal to noise ratio (SNR), the calculation of the root mean square error (RMSE) and the cross-correlation coefficient (CCC). The SNR is a ratio of the mean pixel value to the standard deviation of pixel values; the higher this ratio, the less obstructive the noise is. The RMSE measure is used to assess how well a method to reconstruct an image performs relative to the original image; the closer to the value of the original image the better. A standard method of estimating the degree to which two images are correlated is the CCC; the closer to the original image the more advantageous it is.

The images were loaded in the analysis software CTHERM¹⁸ and there were drawn ROIs in which mean, maximum and minimum temperatures and standard deviation were measured

and registered. Then those images were loaded into the Matlab software package were the imaging enhancing algorithms described previously were implemented, resultant images from the application of those algorithms to the input images produced the quality evaluation parameter described in the last paragraph per resultant image. The new output images were then loaded back into the CTHERM and the temperature parameters were calculated again using the same ROIs. The Figure 1 exemplifies the whole procedure.

3. RESULTS

The Figure 2 demonstrates the resultant images from an original noisy image. From the naked eye it can be acknowledge that the

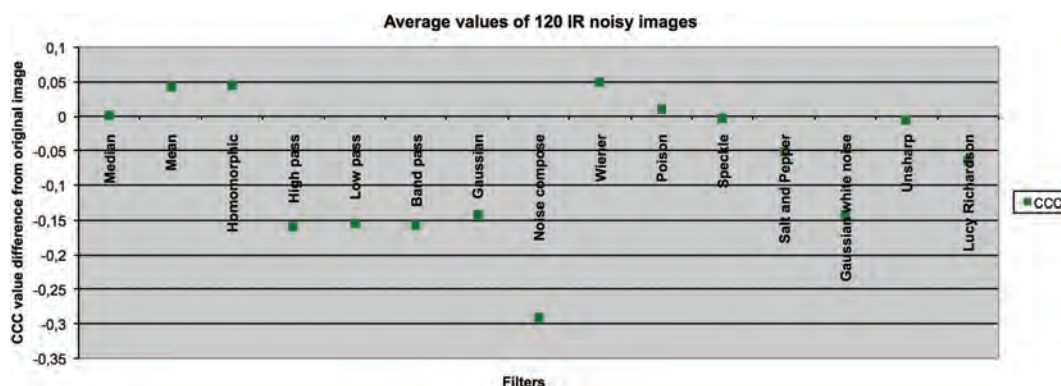


Fig. 7. Cross Correlation Coefficient comparison between the noise filtered images and the original.

Table I. Classification of the performance of the thermal images enhancer filters.

Filter	Classification according to the difference from the original image							Values difference		
	Min	Max	Mean	SD	RMSE	SNR	CCC	Overall	Mean	SD
Median	1°	1°	10°	2°	2°	8°	1°	1°	-0.67	0.25
Mean	3°	3°	7°	5°	4°	5°	5°	2°	-0.25	0.4
Wiener	2°	4°	6°	8°	1°	4°	7°	2°	-0.23	0.45
Poisson	5°	7°	4°	8°	3°	10°	4°	4°	-0.21	0.45
Gaussian	10°	2°	11°	4°	8°	3°	11°	5°	-0.88	0.36
Speckle	4°	11°	5°	11°	6°	11°	2°	6°	-0.22	0.57
Gaussian white noise	9°	10°	2°	11°	7°	2°	11°	7°	-0.2	0.57
Salt and pepper	8°	5°	8°	7°	10°	7°	8°	8°	-0.36	0.44
Lucy-Richardson	6°	9°	9°	13°	4°	6°	9°	9°	0.42	0.6
Low-pass filter	7°	7°	1°	10°	13°	13°	13°	10°	-0.1	0.46
Homomorphic	14°	6°	12°	3°	12°	12°	6°	11°	1.33	0.29
Noise compose	13°	12°	14°	6°	11°	1°	10°	12°	3.04	0.42
Unsharp	12°	13°	2°	14°	9°	9°	3°	13°	-0.2	0.7
High-pass filter	10°	14°	13°	1°	13°	14°	14°	14°	-2.1	0.17
								Average	-0.05	0.44

filters that have produced high quality results were the Wiener, Lucy-Richardson and the low-pass filter.

The chart present in Figure 3, compares the differences in mean temperatures of the AOI in 120 images produced by each algorithm to the value of the originals. It can be observed that Noise Compose, Homomorphic and Lucy-Richarsson methods presented a higher temperature. On the other hand Median, High pass and Gaussian filters have shown a decreased temperature when compared with the baseline. The only algorithm presenting a similar temperature with the original was the Low-pass filter.

The Figure 4 shows a comparison between the maximum, mean and minimum temperature and standard deviation obtained from each image enhancing method against the original image. It is possible to observe that the algorithm that least affected the maximum temperatures is the Median, and of minimum temperatures is the Median and Wiener. The closest to correct mean temperatures is the Low-pass and least sensitive to standard deviation is the High-pass filter. The filter with the greatest affect on maximum temperature and of standard deviation is the Unsharp and of minimum temperatures and more variant from mean temperatures is the Noise Compose.

The Figure 5 presents the comparison between the average obtained images from the application of each filter against the calculated average of the original images in terms of Signal to Noise Ratio indicator. The Noise Compose filter presented a higher value than the reference and Homomorphic, Low pass, Band pass and High pass filters presented a substantially inferior value.

In the Figure 6 it is presented a comparative relationship in Root Mean Square Error between the original images and images filtered, Salt and Pepper and Unsharp filters presented a value significantly above the reference, a substantially reduced value has been shown by Homomorphic, High pass, Low pass and Band pass filters.

The Cross Correlation Coefficient comparison between resultant images from the application of the image enhancing filters and the original images is presented in the Figure 7. It can be observed that Mean, Homomorphic and Wiener filters have the highest value of this indicator than the reference, on the other hand High pass, Low pass, Band pass, Gaussian and Gaussian white noise filters present a substantially reduced value.

The Table I presents an overall classification of the image enhancing filters in thermal images (the recommended methods are in green and the non recommended in red), all methods are graded by order of performance per parameter. The parameters used were: sensitivity to minimal temperatures, to maximum temperatures, to mean temperatures, to standard deviation, Root Mean Square Error, Signal to Noise Ratio and Cross Correlation Coefficient. From these results the recommended noise removal filters according to this experiment were Median, Mean and Wiener. The methods to be avoided for thermal images are Noise Compose, Unsharp and High pass filters.

4. DISCUSSION AND CONCLUSION

The results of this experiment do not agree with suggested methods for digital images³ in terms of recommended method. Those methods were focused on the qualitative aspect of the data, the quantitative characteristics of the data was not taken into consideration. On IR images the quantitative feature is more important than the qualitative. The recommended noise filtering methods to be implemented for IR images are Median, Mean and Wiener. Filtering should be avoided on principle, but in some situations it offers unique opportunities to retrieve information.

The results of this experiment provide a benchmark for disagreements between measurements produced by different software packages that implement various improvement techniques.

Recommended noise-filtering methods to be implemented in medical thermal images are Median, Mean and Wiener. However, filtering should be avoided on principle, but in some situations it offers unique opportunities to retrieve information. The results of this experiment provide benchmark for disagreements between measurements produced by different software packages that implement various improvement techniques.

As future directions in research, it is suggested to study more in detail the possibility of using wavelet transformations to improve image enhancement defining a common set of variable functions to ensure that only noise is reduced and not significant data.

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