PROCEEDINGS OF THE

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ROVISP 2003

PENANG, MALAYSIA
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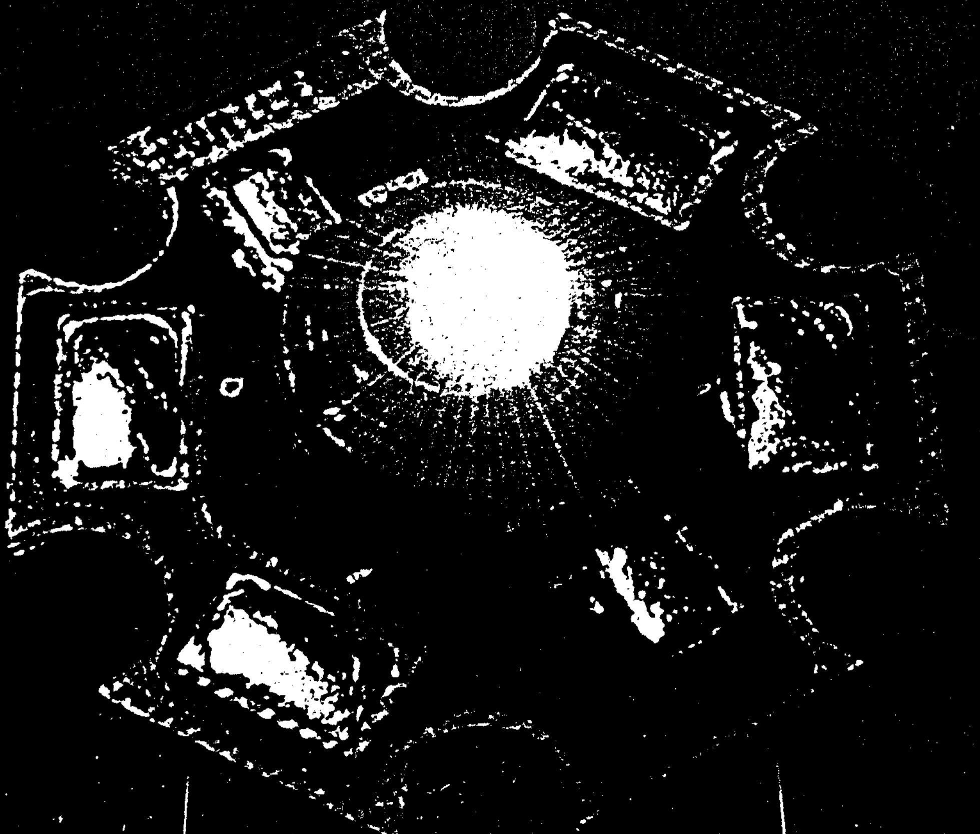

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Proceedings of the International Conference on Robotics, Vision, Information and Signal Processing
January 22 - 24, 2003, Penang, Malaysia

Restoration Techniques for Mammogram and Ultrasound Images

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Abstract

Unprocessed mammograms and ultrasound images are sometimes difficult to assess through the naked eye. Images that are inflicted with degradations due to overexposure, inadequate lighting or faulty electronic imaging equipment can be rendered useful through the process of image restoration. Degradations such as defocus or various types of noises can be removed and thus made more suitable for interpretations in the medical field. For this purpose, a software package named Image Restoration 2 (IR2) was developed. The software was tested on mammograms and ultrasound images obtained from the Hospital Besar Ipoh, Hospital Besar Kuala Lumpur and Hospital Besar Taiping. Three types of degradations have been studied in this research, namely the defocus, short tailed noise and long tailed noise. This paper will present the implementation of the IR2 software.

Keywords:

Image restoration, degradation, mammograms, ultrasound images

Introduction

Image restoration is one of the many techniques of image processing. Image restoration involves the removal of unrequired information from an image so that the image can be discerned. In the medical field, a patient need not be subjected to radiation more than necessary as the unsatisfactory x-ray images can be rendered more useful through the process of image restoration.

In this study, a total of 8 basic techniques have been implemented to restore mammograms and ultrasound images. These are divided into 2 classes, namely non-linear filters and adaptive filters.

Objective

The objective of this research is to develop a software package that can restore degraded medical images, i.e. mammogram and ultrasound images, which are grayscale bitmap images, obtained from Hospital Besar Ipoh, Hospital Besar Taiping and Hospital Besar Kuala Lumpur. Degradations can affect and distort the contents of an image. In this work, focus is given to 2 types of degradations: short tailed noise and long tailed noise.

Testing Images

The performance of the restoration techniques was tested on 3 images, which are prepared beforehand, shown as Figure 1, 2 and 3.

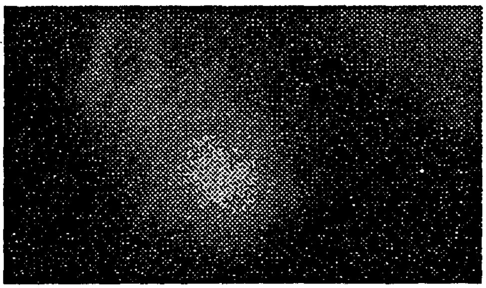

Figure 1: Mammogram X corrupted with short tailed noise

Figure 1 shows mammogram X that is corrupted by short tailed noise. Figure 2 is ultrasound image Y that is corrupted by long tailed noise. Lastly, mammogram Z is inflicted with a combination of both short and long tailed noises, as illustrated in Figure 3.

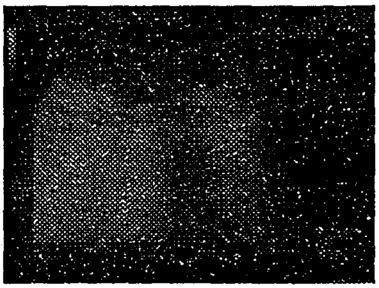

Figure 2: Ultrasound image Y corrupted with long tailed noise

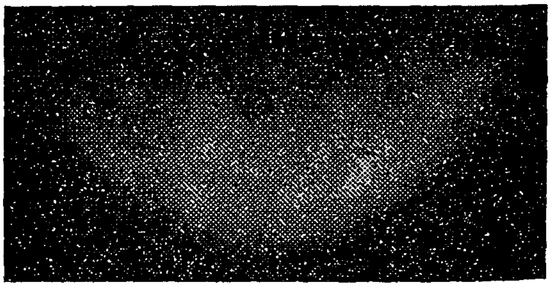

Figure 3: Mammogram Z corrupted with both long and short tailed noise

Algorithms

Image Restoration with Non-Linear Filters

Non-linear filters are important for the qualitative analysis of images. Normally, a non-linear function is calculated within a local mask of an image. There are altogether 7 different types of Non-linear Filters implemented in this study.

Geometric Mean Filter

The Geometric Mean Filter is good at removing short tailed noise and at the same time maintaining the original features of an image.

The workings of the Geometric Mean Filter can be shown in Equation 1. [1]

$$GeoMean(A) = \prod_{(i,j)\in M} A[(x+i, y+j)]^{1/N} \qquad (1)$$

Coordinates x + i and y + j are defined over the original image A whereas coordinates i, j are defined over the mask M. The mask, M, determines which pixel that needs to be involved in the calculation. The value N is the number of pixels involved in the operation. [1]

In the Geometric Mean Filter, all the pixels in a region inside the image is multiplied and then powered by 1/N. The result obtained is the output of the filter. The region involved in this operation is defined by a mask.

Harmonic Mean Filter

The Harmonic Mean Filter is good at removing short tailed noise and at the same time maintaining the original features of an image. The Harmonic Mean Filter is extremely efficient in removing noise that has graylevel values between 200 until 255. Equation 2 shows the operation of the Harmonic Mean Filter.

$$Harmonic(A) = \frac{N}{\sum_{(i,j)\in M} \frac{1}{A(x+i, y+j)}} \qquad (2)$$

Coordinates x + i and y + j are defined over the original image A whereas coordinates i, j are defined over the mask M. The mask, M, determines which pixel that needs to be involved in the calculation. The value N is the number of pixels involved in the operation. [1]

Contra Harmonic Filter

The Contra Harmonic Filter is also more flexible when compared to the Harmonic Mean Filter. Its operation is summarized in Equation 3.

$$Contra(A) = \frac{\sum_{(i,j)\in M} A(x+i, y+j)^{P+1}}{\sum_{(i,j)\in M} A(x+i, y+j)^{P}} \qquad (3)$$

Coordinates x + i and y + j are defined over the original image A whereas coordinates i, j are defined over the mask M. The mask, M, determines which pixel that needs to be involved in the calculation. The value P is the order of the filter that must be set beforehand. A positive value of P is good to filter out noise with graylevel values ranging from 0 until 55. On the other hand, a negative value of P is good to filter out noise with graylevel values ranging from 200 until 255. [1]

Alpha Trimmed Mean Filter

The Alpha Trimmed Mean Filter is able to filter both short and long-tailed noises. It has the characteristics of both the Mean and Median filters.

To define the Alpha Trimmed Mean filter, firstly all the pixel values within a region, A, is arranged in the ascending order. The series is shown in Equation 4.

$$A_1 \le A_2 \le A_3 \le A_4 \le \ldots A_{N-1} \le A_N \qquad (4)$$

N is the number of pixels to be used in the filtering operation. The Alpha Trimmed Mean Filter is then applied on this series of values. The Alpha Trimmed Mean Filter is defined in Equation 5.

$$\alpha Mean(A) = \frac{1}{N-2P} \sum_{i=P}^{N-P} A_i \qquad (5)$$

The value of P is determined by the user beforehand. P must be a value smaller than 2 times N. A large value of P will cause the filter to act as a Median Filter whereas a small value of P will cause the filter to act as a Mean Filter. [1]

Image Restoration With Adaptive Filters

When a filter is applied to an image, the degradation of the image will decrease. However, some important characteristics of the image will be filtered out too. These characteristics, such as the edges of an object, should be retained.

To solve this problem, a new filter class, the Adaptive Filter class is designed. These filters are able to dynamically alter the internal characteristics of itself in run time, that is it will somehow adapt to the region of the image to be processed.

Minimum Mean Squared Error Filter (MMSE Filter)

The MMSE filter obtains the local variance information to determine whether it needs to mean filter that region or not. This filter is most suitable to remove short tailed noise from the image. The MMSE filter uses the noise variance and the local variance of an image to make a decision whether to execute a mean filter operation or not. The operation is summarized in Equation 6.

$$r(x,y) = (1-\frac{\sigma_n^2}{\sigma_1^2})\cdot g(x,y)+\frac{\sigma_n^2}{\sigma_1^2}K \qquad (6)$$

where
r(x, y) : output image
g(x,y) : noisy image
σ_n^2 : noise variance
σ_1^2 : local variance for a pixel in the coordinates (x, y)
K : Output of a local mean filter

In the background of an image, the variations of the pixel values are mostly due to noise. Thus the local variance will be almost the same as the noise variance. Thus, the MMSE Filter will act as an Arithmetic Mean Filter. [1]

When the mask shifts to an edge or a boundary of an object, the local variance will be much larger than the noise variance. In this case, the MMSE filter will not filter this region.

The noise variance has to be known before applying this filter. If not, this noise variance has to be discovered by trial and error.

Double Window Modified Trimmed Mean Filter (DW-MTM Filter)

The DW-MTM Filter has more advantages when compared with the MMSE Filter because it is capable of removing both long and short tailed noises. This is due to the fact that the DW-MTM Filter uses a median estimator to estimate the value of the local mean. The local mean is calculated by using the pixels with graylevel values that are close to the median value of the region.

The DW-MTM algorithm is shown below:

(i) A pixel with coordinates (x, y) is chosen by the program.
(ii) Median filtering, MED[g(x, y)] is performed on a nxn region that surrounds pixel (x, y).
(iii) The mean value of a larger mask, qxq, is calculated from the pixels surrounding pixel (x, y).
(iv) In the proses of obtaining the mean value, only pixels with graylevel values between MED[g(x, y)] – c and MED[g(x, y)] + c are taken into account.
(v) The value of is calculated with Equation 7.

$$c = K \cdot \sigma_n \qquad (7)$$

where
σn : noise variance
K : variable with a value between 1.5 and 2.5

If the value of K is 0, the DW-MTM filter will act as an nxn Median Filter. For a very large value of K, the DW-MTM filter will act as a qxq Mean Filter. Thus, the smaller the value of K, the more effective the DW-MTM filter is for filtering long tailed noise. However, its effectiveness in filtering short tailed noise is reduced. The reverse happens for a large value of K. [1]

Adaptive Neighborhood Mean Filter

The Adaptive Neighborhood Mean Filter uses the seed based region growing method to filter a region. The flow chart for this filter for a Pixel (x, y) is shown in Figure 4.

Firstly, the tolerance of the filter, q, is determined by the user. A region is grown from the Pixel (x, y) using the seed-based region growing method. After that, the Arithmetic Mean Filter is then applied on this region and the result is used to replace the graylevel value of Pixel (x, y). These steps are repeated until all the pixels within the image are processed. [2]

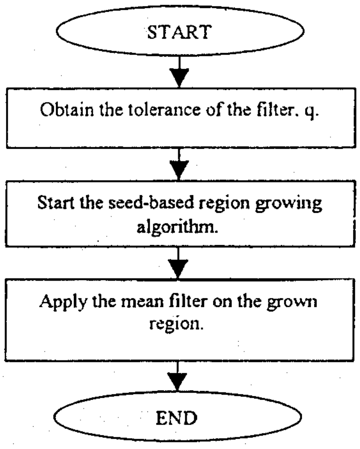

Figure 4: Adaptive Neighborhood Mean Filter (for 1 pixel)

Adaptive Neighborhood Median Filter

The application of the Adaptive Neighborhood Median Filter is almost the same as that of the Adaptive Neighborhood Mean Filter. It uses the Median Filter on the grown region instead of the Mean Filter. Figure 5 shows the flowchart of the application of an Adaptive Neighborhood Median Filter on a Pixel (x, y).

Firstly, the tolerance of the filter, q, is determined by the user. A region is grown from the Pixel (x, y) using the seed-based region growing method. After that, the Median Filter is then applied on this region and the result is used to replace the graylevel value of Pixel (x, y). These steps are repeated until all the pixels within the image are processed[2].

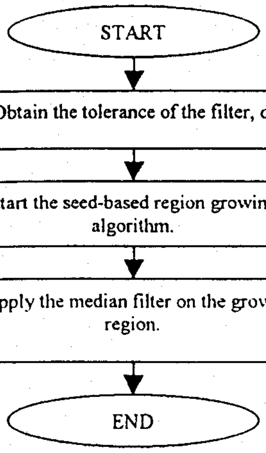

Figure 5: Adaptive Neighborhood Median Filter (for 1 pixel)

Results

The algorithms above are tested on Figure 1, 2 and 3. The results are shown below.

Geometric Mean Filter

The Geometric Mean Filter can filter out short tailed noise with minimal loss (Figure 5). However, it is not effective against long tailed noise (Figure 6).

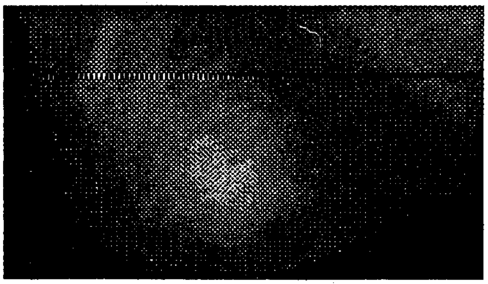

Figure 5: X processed with the Geometric Mean Filter

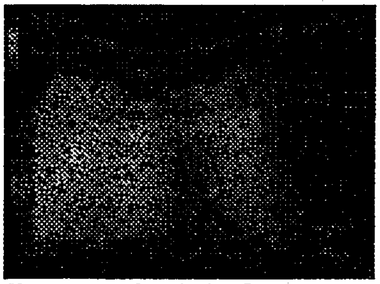

Figure 6: Y processed with the Geometric Mean Filter

Harmonic Mean Filter

The Harmonic Mean Filter is effective against short tailed noise (Figure 7). However, similar to the Geometric Mean Filter, it is not able to filter long tailed noise (Figure 8).

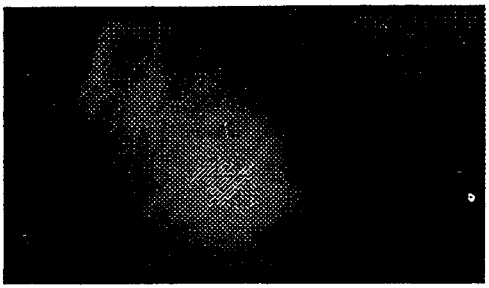

Figure 7: X processed with the Harmonic Mean Filter

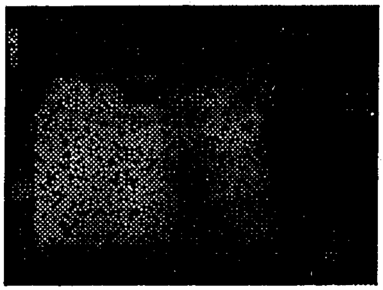

Figure 8: Y processed with the Harmonic Mean Filter

Contra Harmonic Mean Filter

A Contra Harmonic Mean Filter with value P negative can effectively remove short tailed noise (Figure 9). However it is not good at removing long tailed noise (Figure 10).

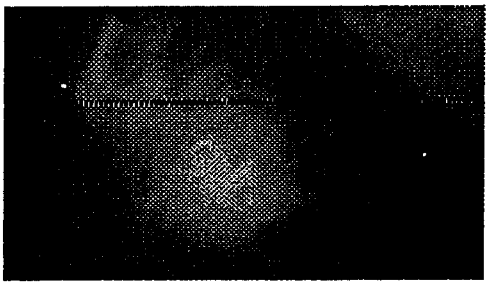

Figure 9: X processed with the Contra Harmonic Mean Filter with P = -2

For a value of P positive, the Contra Harmonic Mean Filter cannot filter both short and long tailed noises (Figure 11 and Figure 12).

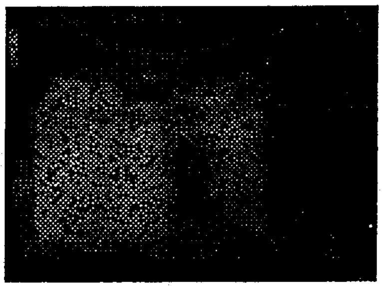

Figure 10: Y processed with the Contra Harmonic Mean Filter with P = -2

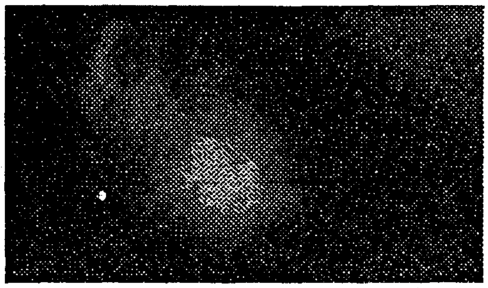

Figure 11: X processed with the Contra Harmonic Mean Filter with P = 2

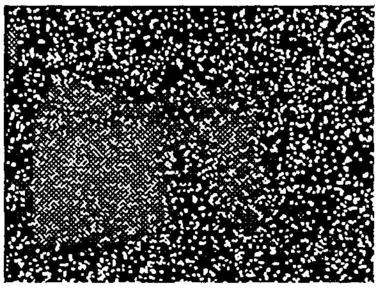

Figure 12: Y processed with the Contra Harmonic Mean Filter with P = 2

Alpha Trimmed Mean Filter

The Alpha Trimmed Mean Filter can effectively filter short tailed noise (Figure 13), long tailed noise (Figure 14) and a combination of both short and long tailed noises (Figure 15).

The advantage of an Alpha Trimmed Mean Filter is that it can change its characteristics to a mean or a median filter based on the value of P. For a low value of P, it will act as a mean filter whereas for a high value of P, it will act as a median filter.

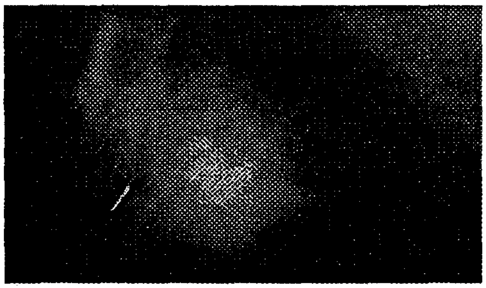

Figure 13: X processed with the Alpha Trimmed Mean Filter with P = 8

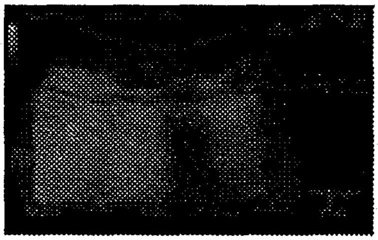

Figure 14: Y processed with the Alpha Trimmed Mean Filter with P = 8

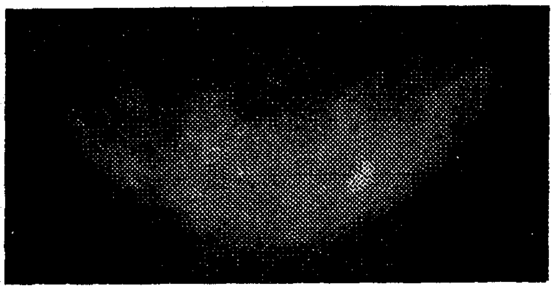

Figure 15: Z processed with the Alpha Trimmed Mean Filter with P = 8

Minimum Mean Squared Error Filter (MMSE) Filter

The MMSE Filter is effective against short tailed noise. (Figure 16 and Figure 17). For a low noise variance, less noise will be filtered out. However more characteristics of the original image will be preserved (Figure 16). The opposite occurs for a high noise variance (Figure 17).

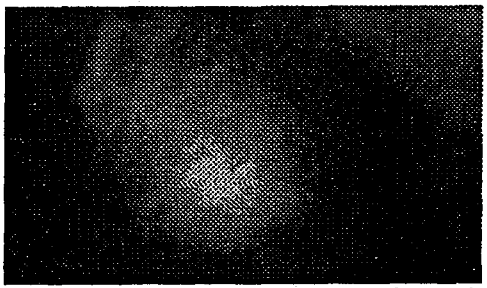

Figure 16: X processed with the MMSE Filter with noise variance of 200

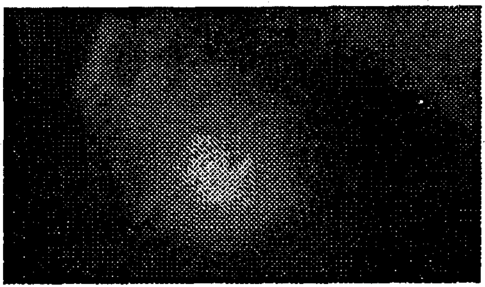

Figure 17: X processed with the MMSE Filter with noise variance of 800

Double Window Modified Trimmed Mean Filter

The DW-MTM Filter can filter out short tailed noise (Figure 18) and long tailed noise (Figure 19). From Figure 20, the DW-MTM Filter can also filter out a combination of both long and short tailed noises.

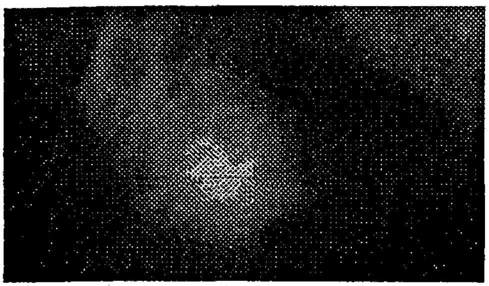

Figure 18: X processed with the DW-MTM Filter with K = 1.5 and noise variance of 400

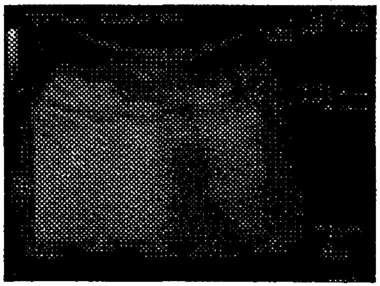

Figure 19: Y processed with the DW-MTM Filter with K = 3.0 and noise variance of 0

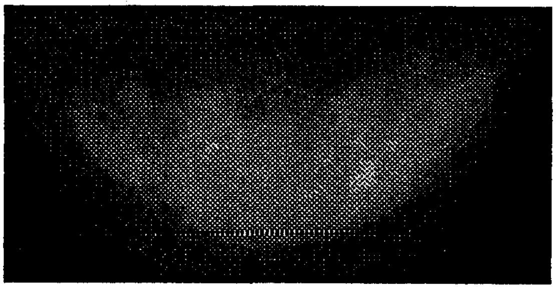

Figure 20: Z processed with the DW-MTM Filter with K = 1.5 and noise variance of 200

For a minimum K, the DW-MTM filter can filter long tailed noise but not effective against short tailed noise (Figure 21). For a large K, the DW-MTM filter can filter both short and long tailed noises, with a significant blurring of the image. (Figure 22).

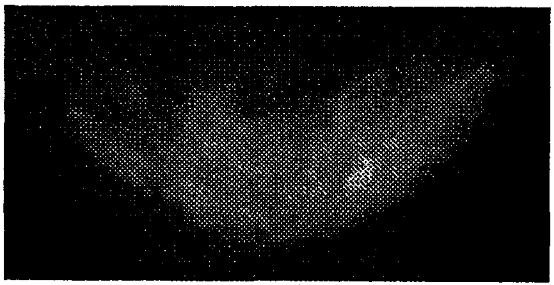

Figure 21: Z processed with the DW-MTM Filter with K = 0 and noise variance of 200

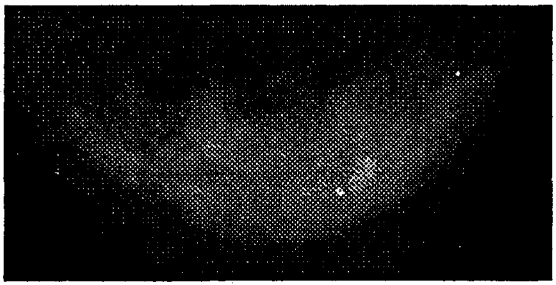

Figure 22: Z processed with the DW-MTM Filter with K = 4.0 and noise variance of 200

The effects of the value of noise variance against the DW-MTM filter will be discussed. The higher the noise variance defined, the more the characteristics of the original image will be filtered out (Figure 23 and Figure 24).

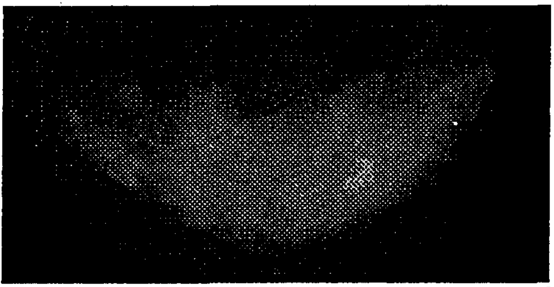

Figure 23: Z processed with the DW-MTM Filter with K = 1.5 and noise variance of 0

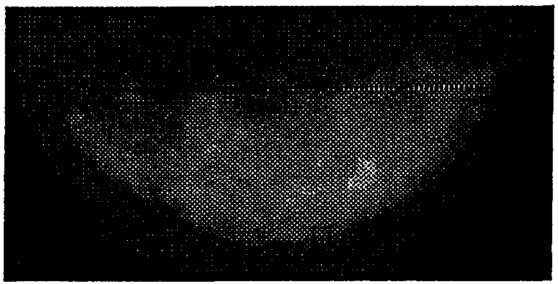

Figure 24: Z processed with the DW-MTM Filter with K = 1.5 and noise variance of 1000

Adaptive Neighborhood Mean Filter

The Adaptive Neighborhood Mean Filter is effective against short tailed noise (Figure 25) but not long tailed noise (Figure 26).

Adaptive Neighborhood Median Filter

The Adaptive Neighborhood Median Filter can be used to filter short tailed noise (Figure 27) and long tailed noise (Figure 28).

It can also be used to filter a combination of both long and short tailed noise (Figure 29).

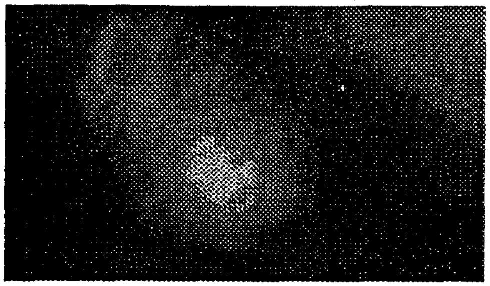

Figure 25: X processed with the Adaptive Neighborhood Mean Filter with q = 10

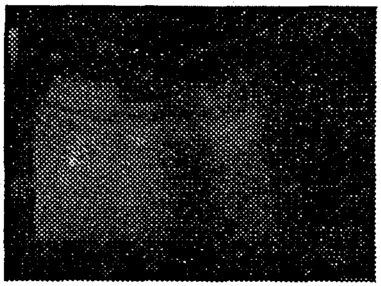

Figure 26: Y processed with the Adaptive Neighborhood Mean Filter with q = 10

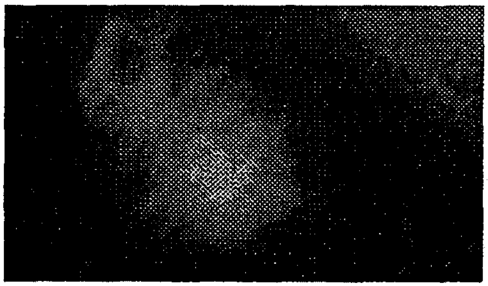

Figure 27: X processed with the Adaptive Neighborhood Median Filter with q = 10

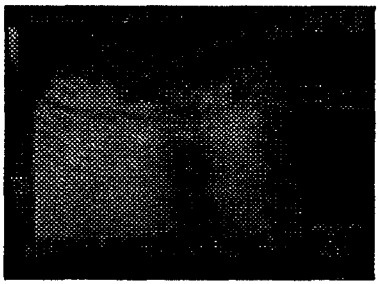

Figure 28: Y processed with the Adaptive Neighborhood Median Filter with q = 10

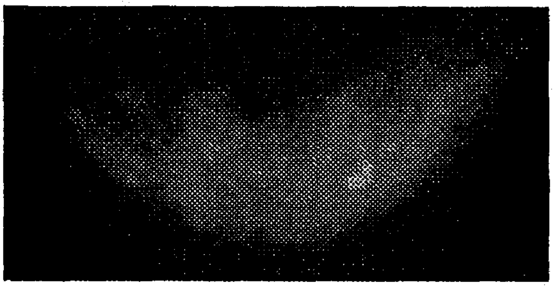

Figure 29: Z processed with the Adaptive Neighborhood Median Filter with q = 10

Discussion

It can be observed that all types of filters has the capability of removing at least one type of noise from an image. To remove short tailed noise, all the filters in the Non-linear Filter and Adaptive Filter class can be used. Amongst them, the Alpha Trimmed Mean Filter is the most efficient in removing short tailed noise and at the same time maintaining the original characteristics of the image.

To remove long tailed noise, Alpha Trimmed Mean Filter, DW-MTM Filter and Adaptive Neighborhood Median Filter are able to perform admirably. All these filters can perform at almost the same standard for an unfiltered image.

If there is a combination of both short and long tailed noise in an image, the Alpha Trimmed Mean Filter, DW-MTM Filter and Adaptive Neighborhood Median Filter can be used. The most flexible of these filters is the DW-MTM filter because its characteristics can be changed by the user to filter different types of noises.

Conclusion

It can be summarized that the objective of this research is met. A total of 8 image restoration techniques are implemented successfully. A software package with all this techniques is also developed. This software is capable of removing degradations that are commonly found in medical images such as short tailed noise and long tailed noise.

Through observation, it can be found that the images restored have higher qualities compared to the original images and it can be discerned more clearly with the naked eye.

References

[1] Myler, R.H. and Weeks, R.W., (1993), The Pocket Handbook of Imaging Processing Algorithms in C, Prentice Hall, New Jersey.

[2] Paranjape, R.B, Rangayyan, R.M. and Morrow, W.M., (1994), Adaptive Neighborhood Mean and Median Image Filtering, Journal of Electronic Imaging, 3(4), 360-367