A Comparative study on various hybrid filters for de-noising medical images

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Abstract. The important feature of de-noising medical images is to reduce various types of noises namely, Impulse, Gaussian and Speckle noise which are normally found in medical imagery. Technological enhancement has considerably improved for de-noising medical images. This article proposes a comparative study on the various hybrid filters for the de-noise of Gaussian, impulse and Speckle from MRI, CT and ultrasound images respectively. The quality of the improved images is obtained by the statistical quantity measures: RMSE and PSNR values. This comparative study will give a good direction for selecting an appropriate filter in de-noising of medical images.

1. Introduction

Digital topology [10] deal with the topological properties of images. It provides an abstract foundation for significant image processing operations. Digital topology gives the fundamental basis for understanding various properties of images in terms of sets. The topological concepts such as connectedness, adjacency subsets, boundary, interior and exterior etc, are very much used in medical image analysis. Medical images are frequently affected by noises such as Gaussian, Speckle and Impulse noise, in image attainment method. These noises generally influence the quality of the medical images. De-noising of medical images is the removal of noises from MRI, CT and ultrasound images etc. It is a very important procedure that makes diagnosis more useful for physicians. Hu and de Haan [5] in 2006, proposed a classification-based hybrid filters for the field of image analysis. Hybrid median filters have been recommended to merge the properties of linear filter and median filters by the operations of linear and non linear in [4]. To improve the median filter, hybrid median filters[1] have been developed. Gnanambal Ilango and Marudhachalam [2] developed various hybrid filters for the de-noising ultrasound medical images tainted by Gaussian noise. Image de-noising is the significant operation used in medical and communication applications.

This paper proposes a comparative study on the various hybrid filters such as HM filter (H3F), center weighted hybrid max filter (CWHF), hybridization of hybrid min filter and hybrid max filter (HMM), CWHMMF, fuzzy hybrid max filter (FH3F), fuzzy center weighted hybrid max filter (FCWH3F), for the removal of Gaussian, Impulse and Speckle noise from MRI, CT and
ultrasound images respectively. The sections of this paper are organized as follows: In Section 2 preliminaries and definitions are given. Section 3 gives different types of Hybrid filters. In Section 4, Numerical result analysis and discussions are carried out. Section 5 the conclusion obtained by this article.

2. Preliminaries and Definitions

This section provides definitions, preliminaries of topological and digital topological concepts, which will be applied in this paper.

Definition 1. [3] Digital image
A digital image is a mapping \( g: \mathbb{Z} \times \mathbb{Z} \rightarrow [0, 1, \ldots, M - 1] \) in which \( M - 1 \) is a non negative integers in \([0, 255]\). The value of ‘\( g \)’ at the point \( q(y,x) \) is known as gray level or intensity value. It is denoted by \( g(q) \).

The topological metrics [7] \( d_1 \) and \( d_2 \) restricted to \( Z \times Z \) are defined as follows:

\[
d_1(x, y) = \sum_{j=1}^{2} |x_j - y_j|
\]

\[
d_2(x, y) = \max_{1 \leq j \leq 2} |x_j - y_j|
\]

The following various neighborhoods of the points \( x \in Z \times Z \) are defined as

Definition 2. [2] LN neighbours
The LN neighbours of a point \( q(y,x) \) consists of the points \((y - 1, x - 1)\) and \((y + 1, x + 1)\). The \( LN(q) \) consists of the point ‘\( q(y,x) \)’ together with its LN neighbours.

Definition 3. [2] RN neighbours
The RN neighbours of a point \( q(y,x) \) consists of the points \((y - 1, x + 1)\) and \((y + 1, x - 1)\). The \( RN(q) \) consists of the point ‘\( q(y,x) \)’ together with its RN neighbours.

Definition 4. [11] 4-neighbourhood
The 4-neighbourhood of a point \( q(y,x) \) are its 4 vertical and horizontal points \((y, x \pm 1)\) and \((y \mp 1, x)\). A point ‘\( q(y,x) \)’ and its 4-neighbours is denoted by \( N_4(q) \).

\[
N_4(q) = \{ p \in \mathbb{Z} \times \mathbb{Z} / d_1(p, q) \leq 1 \}.
\]

Definition 5. [11] 8-neighbourhood
The 8-neighbourhood of a point \( q(y,x) \) obtained by its 4-neighbours together with its diagonal 4-neighbours \((y + 1, x \mp 1)\) and \((y - 1, x \mp 1)\). A point ‘\( q(y,x) \)’ and its 8-neighbours is \( N_8(q) \).

\[
N_8(q) = \{ p \in \mathbb{Z} \times \mathbb{Z} / d_2(p, q) \leq 1 \}.
\]

Definition 6. [2] Cross neighbourhood
The cross neighbourhood of a point \( q(y,x) \) obtained by the neighbours \((y + 1, x \mp 1)\) and \((y - 1, x \mp 1)\). A point ‘\( q(y,x) \)’ and its cross neighbours is \( C_4(q) \).

\[
C_4(q) = N_8(q) - N_4(q).
\]

3. Hybrid Filters
In this section, the various filters have been proposed based on various neighbourhoods which are used to de-noise the medical images tainted by speckle, impulse and Gaussian noises.
3.1. HM Filter \((H_3F)\)

In max filter [3], the value of each output pixel can be replaced by maximum intensity value of \(N_8(q)\). HM filter is not a regular max filter. \(H_3F\) is used to de-noise the digital images. It is defined as:

\[
f(q) = \max \left\{ \text{median}\{g(q), q \in LN(q)\}, \text{median}\{g(q), q \in RN(q)\}\right\}
\]

3.2. HMM Filter

HMM filter is a hybridization of hybrid min and HM filter [2]. It is expressed as:

\[
f(q) = \min \left\{ \text{median}\{g(q), q \in LN(q)\}, \text{median}\{g(q), q \in RN(q)\}\right\}
\]

\[
h(q) = \max \left\{ \text{median}\{f(q), q \in LN(q)\}, \text{median}\{f(q), q \in RN(q)\}\right\}
\]

3.3. CWHM Filter

The CWHM filter is used to de-noise the medical images. It is defined as:

\[
f(q) = \max \left\{ \text{median}\{2\oplus g(q_c), g(q), q \in LN(q)\}, \text{median}\{2\oplus g(q_c), g(q), q \in RN(q)\}\right\}
\]

where \(\oplus\) denotes replication operator and \(g(q_c)\) is intensity value of the center pixel.

3.4. CWHMM Filter

CWHMM filter is a combination of center weighted hybrid median and center weighted hybrid mean filter[2]. It plays a major role in image analysis. It is planned to de-noise the medical images. It is defined as:

\[
f(q) = \max \left\{ \text{median}\{2\oplus g(q_c), g(q), q \in LN(q)\}, \text{median}\{2\oplus g(q_c), g(q), q \in RN(q)\}\right\}
\]

\[
h(q) = \max \left\{ \text{mean}\{2\oplus f(q_c), g(q), q \in LN(q)\}, \text{mean}\{2\oplus f(q_c), g(q), q \in RN(q)\}\right\}
\]

3.5. Fuzzy filter [8]

Let \(h(q)\) be the intensity value of the point \(q(y,x)\) of input image and \(f(q)\) is the intensity value of the corresponding point of the output image of a 2D fuzzy filter. It is expressed as :

\[
f(q) = \frac{\sum_{q \in N_8(q)} H(q).h(q)}{\sum_{q \in N_8(q)} H(q)}
\]

where \(H(q)\) is the 8-neighbour function [12].
3.6. \textit{FH}_3F \textit{Filter}

Fuzzy hybrid max filter [9] is defined using hybrid max value of the 8-neighbours of a point ‘q’. Here \( G(q) \) is defined as:

\[
G(q) = \begin{cases} 
1 & \text{for} \ g(q) = \text{mv}(q), q \in N_8(q) \\
0 & \text{otherwise}
\end{cases}
\] (8)

where \( \text{mv}(q) \) is the maximum of median pixel value of LN neighbours of the point ‘q’, median intensity value of RN neighbours of the point ‘q’ and intensity value of ‘q’.

3.7. \textit{FCWH}_3F \textit{Filter}

Fuzzy center weighted hybrid max filter [9] is defined using center weighted max value within 8-neighbours of a point ‘q’. Here \( G(q) \) is defined by

\[
H(q) = \begin{cases} 
1 & \text{for} \ h(q) = \text{cwmv}(q), q \in N_8(q) \\
0 & \text{otherwise}
\end{cases}
\] (9)

where \( \text{cwmv}(p) \) is maximum of median of two times \( g(q_c) \) and LN neighbours of the point ‘q’, median pixel value of two times \( g(q_c) \) and RN neighbours of the point ‘q’ and pixel value of ‘q’.

where \( g(q_c) \) is intensity value of center pixel.

4. Numerical Result Analysis

The 3 steps are to be followed to test the performance of the various hybrid proposed filters.

\( * \) At first, uncorrupted medical images say magnetic resonance image of liver, ultrasound image of heart or computed tomography image of heart are taken as input.

\( * \) Secondly low, medium and high level noises are added to the medical images artificially. Here, speckle noise is added to the ultrasound medical images, Gaussian noise is added to the MRI image and impulse noise is added to computed tomography image.

\( * \) Thirdly, well behaved filter in each category are applied to the noisy image and their statistical measures are calculated.

\( * \) Comparison of the quality of the filters are done using quantitative techniques.

\( * \) The best filter is highlighted in the table.

4.1. De-noising speckle noise from ultrasound medical image

The noisy ultrasound image of heart with different noise levels such as speckle noise of variances 0.03, 0.05 and 0.07 are taken as input image and de-noised ultrasound image is obtained by the different hybrid filters. Table 1 shows the statistical measures of the different hybrid filters namely, HM filter (\( H_3F \)), center weighted hybrid max filter (\( CWHF \)), (\( HMM \)) filter, center weighted hybridization of hybrid min filter and HM filter (\( CWHMMF \)), fuzzy hybrid max filter (\( FH_3F \)), fuzzy center weighted hybrid max filter (\( FCWH_3F \)) for ultrasound medical image of a heart.

4.2. De-noising of Gaussian noise from magnetic resonance medical image

The noisy magnetic resonance image of a liver with various noise levels such as Gaussian noise of variances 0.03, 0.05 and 0.07 are taken as input image and filtered MR image is obtained by the different hybrid filters. Table 2 shows the statistical measures of the different hybrid filters namely, HM filter (\( H_3F \)), center weighted hybrid max filter (\( CWHF \)), (\( HMMF \)) filter, center weighted hybridization of hybrid min filter and HM filter (\( CWHMMMF \)), fuzzy hybrid max filter (\( FH_3F \)) and fuzzy center weighted hybrid max filter (\( FCWH_3F \)) for magnetic resonance medical image of a liver.
### Table 1. PSNR and RMSE values at different variances 0.03, 0.05 and 0.07.

| Variance (σ²) | Filters | Low, 0.03 | Medium, 0.05 | High, 0.07 |
|---------------|---------|-----------|--------------|------------|
|               | RMSE    | PSNR      | RMSE         | PSNR       |
| 3.3047        | 37.7486 | 3.5816    | 37.0498      | 3.6199     |
| 1.2854        | 45.951  | 1.2853    | 45.9514      | 1.287      |
| 0.194         | 62.3729 | 0.166     | 63.728       | 0.1543     |
| 0.1992        | 62.14731| 0.179     | 63.0737      | 0.1417     |
| 2.2708        | 41.0078 | 2.3694    | 40.6386      | 2.5445     |
| 2.1571        | 41.454  | 2.2779    | 40.9807      | 2.3788     |

### Table 2. RMSE and PSNR values at different noise levels 0.03, 0.05 and 0.07.

| Variance (σ²) | Filters | Low, 0.03 | Medium, 0.05 | High, 0.07 |
|---------------|---------|-----------|--------------|------------|
|               | RMSE    | PSNR      | RMSE         | PSNR       |
| 3.6515        | 36.8818 | 3.0115    | 38.5557      | 2.6404     |
| 2.1881        | 41.3292 | 2.1993    | 41.2857      | 2.1978     |
| 0.5874        | 52.7533 | 0.6067    | 52.4725      | 0.5618     |
| 0.587         | 52.7594 | 0.5719    | 52.9844      | 0.6213     |
| 4.9492        | 34.2405 | 5.1094    | 33.9638      | 5.3011     |
| 4.6992        | 34.6908 | 4.8258    | 34.4599      | 5.0437     |

### Table 3. PSNR and RMSE values at different variances 0.3, 0.5 and 0.7.

| Variance (σ²) | Filters | Low, 0.3 | Medium, 0.5 | High, 0.7 |
|---------------|---------|----------|-------------|-----------|
|               | RMSE    | PSNR     | RMSE        | PSNR      |
| 2.9594        | 35.7071 | 3.7617   | 36.6236     | 3.1937    |
| 4.2149        | 35.6355 | 6.1579   | 32.3426     | 7.8713    |
| 0.7878        | 50.2027 | 0.8925   | 49.1193     | 0.8667    |
| 0.8764        | 49.277  | 0.8982   | 49.0639     | 0.9324    |
| 9.239         | 28.8187 | 9.7999   | 28.3067     | 10.9836   |
| 9.5392        | 28.5409 | 10.4531  | 27.7462     | 11.8373   |

### 4.3. De-noising of impulse noise from computed tomography image

The noisy computed tomography image of a heart with various noise levels say, impulse noise of variance 0.3, 0.5 and 0.7 are taken as input image and filtered computed tomography image is obtained by the proposed hybrid filters. Table 3 shows the the behaviour of the different hybrid filters namely, HM filter ($H_3F$), center weighted hybrid max filter ($CWHFM$), ($HMMF$) filter, $CWHMMF$, fuzzy hybrid max filter ($FH_3F$) and fuzzy center weighted hybrid max filter ($FCWH_3F$) for computed tomography image of a heart.

### Table 3. PSNR and RMSE values at different variances 0.3, 0.5 and 0.7.

| Variance (σ²) | Filters | Low, 0.3 | Medium, 0.5 | High, 0.7 |
|---------------|---------|----------|-------------|-----------|
|               | RMSE    | PSNR     | RMSE        | PSNR      |
| 2.9594        | 35.7071 | 3.7617   | 36.6236     | 3.1937    |
| 4.2149        | 35.6355 | 6.1579   | 32.3426     | 7.8713    |
| 0.7878        | 50.2027 | 0.8925   | 49.1193     | 0.8667    |
| 0.8764        | 49.277  | 0.8982   | 49.0639     | 0.9324    |
| 9.239         | 28.8187 | 9.7999   | 28.3067     | 10.9836   |
| 9.5392        | 28.5409 | 10.4531  | 27.7462     | 11.8373   |

### 5. Conclusion

The performance of the different well behaved hybrid filters for the de-noise of Gaussian, Speckle and impulse noises are measured using quantitative performance measures. The following conclusions are obtained.

* The experimental results indicate that the hybrid filtering technique $HMM$, $CWHMMF$ and $CWHF$ perform significantly better than the other hybrid filtering techniques with respect to both different types of images and different types of noises.
Table 4. Performance rating(Images) : 1- Outstanding, 2-Excellent, 3-Good.

| Filters   | Ultrasound image | MRI image | CT image |
|-----------|------------------|-----------|----------|
| HMM       | 1                | 1         | 1        |
| CWHMMF    | 2                | 2         | 2        |
| CWHF      | 3                | 3         | 3        |

The filters HMM, CWHMMF and CWHF behave well when compared to other filters. The performance rating of these filters with respect to different types of images are given in table 4.

* Though the filtering techniques HM filter $(H_3F)$, fuzzy hybrid max filter $(FH_3F)$ and fuzzy center weighted hybrid max filter $(CWFH_3F)$ are not as good as the above mentioned three filters, their performance levels are commendable.

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