MRIDenoising Methods

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A Review on MRI Denoising Methods

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ABSTRACT: Many years ago, a lot of work has been done to enhance the resolution and signal-to-noise ratio of magnetic resonance images for accurate monitoring. However, artifacts and random noise still affects the quality of Magnetic Resonance images. In order to maintain the relevant image content, compensation between noise reduction and preservation of details have to be made. Therefore, noise reduction is a paramount challenge. A published literature review of each technique is discussed along with its advantages and limitations. After the introduction of magnetic resonance imaging (MRI) technology, the famous approaches for denoising MRI images are classified with overview of each method.

Key words: MRI, MR, Denoising, SNR.

INTRODUCTION

Magnetic Resonance Imaging (MRI) is preferred over other methodologies because of its multidimensionality. MRI technology can easily discriminate among tissues including brain tissues. The only limitation of MRI technology is long imaging times. The radio waves are allowed to fall on the part of body placed in strong magnetic field. Then that body tissues is analyzed using advanced MRI techniques.

The medical image quality is degraded by random noise. Medical diagnostic tasks and image analysis techniques (segmentation, registration, reconstruction) both are affected by random noise. Therefore, medical image denoising is of paramount challenge. The main noise in MRI images is thermal noise which follows Gaussian and Rician distribution. In order to denoise medical images, post-processing techniques are applied. SNR and resolution exists in trade-off for MRI. Both can not be improved at a same time. Improving SNR results in degraded resolution. Therefore, a balance must be maintained between SNR and resolution.

Multiple methods of denoising MRI images have been presented in literature which include spatial and temporal filter, bilateral and trilateral filters,
**MRI Denoising Methods**

Anisotropic diffusion filter, non-local means algorithm, wavelet transform, curvelet and contourlet transform, maximum likelihood approach and so on. This paper summarizes the available literature related to MRI images.

**Magnetic Resonance Technology**

In MRI technology, spatial location is mapped in another space using electromagnetic field. When radio frequency waves are removed, another radio frequency signal is generated which is detected by MR imaging system. Both phase and frequency data of MR images is obtained in k-space. Inverse Fourier Transform of this k-space generates the final image in gray scale.

However, the major drawback of MRI is acquisition time which might take several hours. In order to reduce acquisition time, parallel imaging technique is proposed. In parallel imaging, multiple receiver coils are used and all MR signals are evaluated simultaneously. Individual images collected from each coil are processed to obtain final image and missed images are reconstructed. The major advantage of parallel imaging is its wide applications.

**Noise in Magnetic Resonance Images**

The quality of MRI images is degenerated in spite of improvements in scanning technology. Varying amount of noise is added from various sources. Therefore, its necessary to reduce multiple noise components from MRI images for high resolution image. When a volume of tissue is placed in magnetic field, the data collected during MRI scanning process is in the form of complex values. These complex values show the Fourier transform of magnetization distribution.

**Denoising in Magnetic Resonance Images**

Reducing noise results in high SNR and low resolution while more noise results in low SNR and high resolution. Noise can be reduced in two ways. One is by increasing acquisition time, that is, taking repeated measurements and then averaging. The other is post acquisition denoising method, that is, applying denoising method after procedure. The effective way of denoising is post acquisition image denoising as this method preserves the resolution and important features of medical images with low noise power. This paper demonstrates post acquisition denoising methods. Moreover, various denoising methods present in literature are also discussed. Denoising methods are divided in four categories: Filtering, Transform, Statistical, and Combination of all these three methods. Fig. 1 shows a review of denoising methods in MR images.
**FILTERING APPROACH**

**Spatial and Temporal Filter**

Spatial Filter uses a function which is convolved with image. As a result, variance is reduced but sharp edges get blurred according to the function used in convolution. Edges represent high frequencies. So, spatial filter reduces high spatial frequencies in an image. In this filter there is trade-off between reduction of artifacts and loss of spatial resolution. Temporal filter is another type of filter. It avoids aliasing. Temporal filter having broad frequency response introduces noise. On the other hand narrow frequency response removes the signal at the edges Temporal and spatial filters are used for reducing Gaussian noise (McVeigh et al., 1985).

**Anisotropic Filter**

This filter was presented for detection of edges (Perona and Malik, 1990). This filter covers the drawbacks of spatial and temporal filters. Anisotropic filter is also useful for noise removal from MRI images (Krissian and Aja- Fernández, 2009). In this filter, noise standard deviation was calculated. Parameters of filters are set according to estimated noise.

**Fourth Order Partial Differential Equation (PDE)**

You and Kaveh proposed fourth-order PDE to remove noise in the image by anisotropic diffusion filter. This result was obtained by minimizing the energy function. Denoising images in space and time domain is also possible (Lysaker et al., 2003). While Lu et al. adopted this method for MRI denoising. This method allows images to preserve edges.
All techniques described above assume that intensity of noise is uniform all over the image. Afterwards, adaptive non-linear methods were proposed for filtering MRI images with variable noise distribution.

**Non-local Means Filter**

Denoising algorithms remove the noise resulting in preservation of large structures and removal of small structures using local pixels. Non-local means (NLM) filter explores the information redundancy within an image for noise removal. Weighted average of voxels is calculated as a restored voxel (Buades et al., 2003).

**TRANSFORM DOMAIN APPROACH**

**Wavelet Transform**

Wavelets decompose data into multiple frequency components and represent images and data into hierarchy of scales. There are multiples of methods for reducing noise based on wavelet transforms. Discrete wavelet transform preserves edges based on image local features. Denoising using wavelet transform includes following steps: Wavelet transform is applied on original image, then thresholding on wavelet coefficients removes noise, finally inverse wavelet transform is applied.

Simplest wavelet noise reduction methods also exist in literature (Weaver et al. 1991). Another wavelet packed based denoising method was proposed. Wavelet packets provide compact representation of signals. Wavelet denoising algorithms was also applied on parallel MRI images. Wavelet denoising method also gives good result (Yang and Fei ,2011).

**Curvelet Transform**

Candès and Donoho proposed curvelet transform for multiscale analysis. Curvelets represent the direction of edges emphasizing on directionality. Position, scale and orientation are three parameters for curvelet transform. Curvelet basically highlight the curves of various lengths and widths which are superimposed. This can be done by the following steps:
1) Decompose an image into subbands
2) As a result, scales are obtained and analyzed using local ridgelet transform

Various authors used Curvelet transform for denoising MRI images. Followings are steps for denoising MRI images:
1) Calculate the thresholds for curvelets with norms
2) Apply curvelet transform on the noisy image and get curvelet coefficients
3) Apply hard thresholding on the coefficients obtained after curvelet transform
4) Apply inverse curvelet transform on coefficients

**Contourlet Transform**

The wavelet transform represents images with smooth areas with sharp edges. However, it fails in case of smooth curves. The contourlet transform represents images containing contours. Multiscale and multidimensional decomposition constitute contourlet transform. Denoising using contourlet transform includes following steps:
1) Contourlet transform is applied on an image to get different directions
2) Thresholding is applied on contourlet coefficients
3) Apply inverse contourlet transform on contourlet coefficients and restore denoised image.

**STATISTICAL APPROACH**

**Maximum Likelihood Estimation**

Maximum likelihood approach for reducing bias appears in images (Sijbers et al. 1998). This author estimated the image noise
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variance from this method. The nonlocal maximum likelihood estimation was presented (He and Greenshields, 2009). Maximum likelihood estimator was applied on the nonlocal neighborhood for estimating underlying noise. Denoising on ML estimator was also applied (Rajan et al., 2011).

Minimum mean square error estimation
Aja-Fernandez et al. applied linear minimum mean square error for removing noise in MRI images is another technique applied. Later, nonlocal processing was done using LMMSE estimator. Control parameters for noise estimation can be changed (Golshan et al., 2013). This method uses the redundancy in 3D MRI images and find similar structures in an image to estimate local SNR values.

Error Phase Estimation
This estimator corrects the phase of each pixel so that noise is separated easily. Denoising for phase error estimation is also implemented (Tisdall and Atkins, 2005). This method avoids over-smoothing of images. The phase error estimation applies non-linear filters on an image repeatedly.

Non-parametric Estimation method
Awate and Whitaker proposed non-parametric estimation method. This technique uses reduction with Rician noise using higher order statistics of an image. For optimal Bayesian denoising, nonparametric estimation is used.

Absolute Deviation estimator for removing Rician noise within wavelet transform. Wavelet coefficients are calculated then estimation is performed for SNR calculation (Coupe et al., 2010).

Singularity Function Analysis
Singularity function analysis (SFA) denoising method was based on image spectrum (Luo et al., 2009). Spectral energy is uniformly distributed along whole image in spectral domain. The wavelet denoising methods remove high frequency components of an image which was a problem. This drawback of distorting original image is removed by Luo et al (2010). He proposed averaging denoising method. The reconstruction reduces noise while preserves the image details.

Combination of Filtering, Transform and Statistical Approach
Another algorithm was proposed based on combination of filtering, transform and statistical approaches removing the drawbacks of each technique. ‘Non-local Principal Component Analysis PCA and Transform Domain Filter’ proposed outperforms all previously presented techniques and gives highest SNR.
MRI Denoising Methods

Table 1. MRI denoising techniques comparison

<table>
<thead>
<tr>
<th>Types of Noise</th>
<th>Different Filters</th>
<th>Noise Standard deviation $\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauss</td>
<td>OB-NLM3D</td>
<td>42.4</td>
</tr>
<tr>
<td></td>
<td>OB-NLM3D-WM</td>
<td>42.5</td>
</tr>
<tr>
<td></td>
<td>ODCT3D</td>
<td>43.7</td>
</tr>
<tr>
<td></td>
<td>PRI-NLM3D</td>
<td>44.0</td>
</tr>
<tr>
<td></td>
<td>BM4D</td>
<td>44.7</td>
</tr>
<tr>
<td></td>
<td>PRI-NL-PCA</td>
<td>45.8</td>
</tr>
<tr>
<td></td>
<td>PRI-NL-PCA+ 4D transform</td>
<td>45.3</td>
</tr>
<tr>
<td>Rician + VST</td>
<td>OB-NLM3D</td>
<td>42.4</td>
</tr>
<tr>
<td></td>
<td>OB-NLM3D-WM</td>
<td>42.5</td>
</tr>
<tr>
<td></td>
<td>ODCT3D</td>
<td>43.7</td>
</tr>
<tr>
<td></td>
<td>PRI-NLM3D</td>
<td>44.2</td>
</tr>
<tr>
<td></td>
<td>BM4D</td>
<td>44.6</td>
</tr>
<tr>
<td></td>
<td>PRI-NL-PCA</td>
<td>45.7</td>
</tr>
<tr>
<td></td>
<td>PRI-NL-PCA+ 4D transform</td>
<td>45.1</td>
</tr>
</tbody>
</table>

Non-local PCA and Transform Domain Filter

This filter combines NL-PCA and Transform filter. Firstly, similar cubes are grouped then median filter is applied due to its sparsity. Then Principal Component Analysis decomposition is performed on each similar group of cubes. PCA decomposition results in eigenvectors on which hard thresholding is performed. Finally, the denoised image consists of combined estimates. This method is named as Pri-Non Local PCA (PRI-NL-PCA). Secondly, resulting image is again grouped in similar cubes and 4D transform is applied along with Weiner Filter. At the end, inverse 4D transform results in the denoised image.

MRI denoising Methods Comparison

There are various quantitative measures for measuring the performance of MRI images. These methods include: peak signal-to-noise ratio, mean square error and root mean square error. The visual quality of the images are also measured.

The spatial filter blurs the edges by averaging pixels while temporal filter introduces aliasing effect which is undesired. Bilateral and trilateral filter preserves large structures. Wavelet transform introduces artifacts. Nonlocal mean filter is complex and have computation burden.

The experiments were performed on MRI images taken from online available database called ‘Brain Web’. Three types of
images called T1, T2 and PD weighted images are used. The voxel volume is $181 \times 217 \times 181$ with voxel resolution of 1 mm3. Both types of noises (Gaussian, Rician) ranging from 1% to 17% is added and all techniques are applied. Table 1 shows all denoising techniques with SNR values. PRI-NL-PCA with 4D transform outperforms all proposed techniques for denoising MRI images. Table 1 shows the comparison all MRI denoising techniques with different noise standard deviation. Hence, PRI-NL-PCA with 4D transform outperforms all other techniques with highest SNR.

CONCLUSION

MRI images are corrupted by random noise. This paper summarizes different MRI denoising techniques and also compared their performance in terms of SNR. The focus of this survey paper is to bring all denoising techniques on one platform. This will help researchers to devise new MRI denoising technique based on previous ones. Also one can choose best denoising method among multiple techniques from the SNR results.

REFERENCES


