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Removal of Rician Noise from Magnetic Resonance Images: A Review

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ABSTRACT:

In the present era; images are one of the most important entity for all of us. Images are used for various purposes in which medical images are one of the most important entity which are used in medical science. Medical imaging is one of the most essential areas in medical field. In general; medical images are used for the diagnosis of abnormality in the human body. However; only one type of imaging technique is not suitable for all types of detections. Most common medical images are X-ray images, ultrasound image, computed tomography images, Magnetic resonance images, positron emission tomography images etc. These images are to be taken according to the human body part structure and after the consultation of radiologist or doctor. Image acquisition techniques are different in all the imaging techniques and during the acquisition process some noise signals get introduced in these images. The presence of noise signals deteriorate the quality of medical images which leads to any false interpretation by the radiologist or doctor. Hence it is a primary task to remove the noise signals present in the medical images. Some of the most common noise signals are additive white Gaussian noise, speckle noise, salt and pepper noise, rician noise, impulsive noise etc. This paper summarizes various existing techniques, findings and limitations.

Keywords: Medical Images, Magnetic Resonance Images, Gaussian Noise, Rician noise.

1. Introduction

Medical imaging techniques are one of the most important tool which are used to diagnose various types of abnormalities in the human body. Some of the most important imaging techniques are X-Ray Images, Ultrasound (US) Images [1], Computed Tomography (CT) Images[2], Magnetic Resonance Images (MRI)[3], Positron Emission Tomography (PET) [4,5] etc. These images are severely affected by different types of noise signals e.g. CT images are affected by Additive White Gaussian Noise (AWGN)[6], US images are corrupted by speckle noise while MRI images are affected by rician noise [7]. These noise signals have different characteristics and they are introduced in the images during acquisition process [8]. Sometimes more than one noise is also introduced in the medical images. Salt and pepper noise [9] is a signal which introduced in the medical images during transmission and due to any fault[6,10]. These images deteriorate the quality of the medical images[11]. They may suppress the image information like edges, ridges, contours, fine details etc. This information is very important for the doctors and radiologist because after the examination of these details only doctors and radiologist may diagnose any abnormality or disease in the human body. Hence this is very important to remove these noise signals from the medical images. However; it is almost impossible to remove the noise signals completely from the images but they may be suppress to a certain extent to avoid any false analysis. Suppression of noise signal is one of the essential pre-processing task in the image processing and it is referred as image de-noising. Many researchers have developed various techniques to for image de-noising. In this paper; only rician noise signals have been discussed which affect the MRI images severely.

2. Magnetic Resonance (MRI) Image

MRI is a non-invasive technique which uses radio waves along with the magnets to create internal structure images in the body[12]. Patient must be lie down in a table attached with the imaging system. This table slides into the large tube shaped magnet. Now short radio wave pulses are sent to particular part of the body whose images are required[13]. When radio signals are turn off then proton in the body realign and sent out the radio signals. Receiver receives these signals and creates MRI images. It can be used to diagnose torn ligament, tumor, cardiovascular conditions etc. It is also used for the evaluation of brain and spinal cord. MRI is safe and painless but expensive. Doctors advise the patient to remove all the metal in the body otherwise it may affect the images.

3. Rician Noise

It is signal dependent noise signal which affects MRI images and degrades their quality which may affect clinical diagnosis [14]. PDF of this noise signal is rician distribution and it is different from that of AWGN. This noise signal arises due thermal agitation of electron within MRI scanner or object being imaged. Rician noise is not same as Gaussian; its distribution is skewed especially at low signal to noise ratio. Rician noise is modelled as the complex valued magnitude where Gaussian noise is added to both real and imaginary components. Mathematically; the magnitude of image corrupted by rician noise can be calculated as:

$$y = \sqrt{(x + n_1)^2 + n_2^2} \quad \dots(1)$$

where,

x is image intensity of noise free image.

n_1 and n_2 are independent, zero-mean Gaussian noise components with variance n_1^2 and n_2^2 .

Probability Density Function of rician noise is given as:

$$P(y) = \frac{y}{\sigma^2} \exp\left(-\frac{y^2 + x^2}{2\sigma^2}\right) I_0\left(\frac{xy}{\sigma^2}\right) \quad \dots(2)$$

where,

$I_0(.)$ Is the modified 0th order Bessel function of 1st kind.

σ^2 is the variance of underlying Gaussian noise.

4. Literature Review

To understand the procedure of de-speckling; it is desire to review the existing techniques. Various research papers have be studied in which some of the good researches have been discussed in the tabulator form. This table illustrates the findings and limitations of that research so that gap analysis can be done.

S.No	Authors	Title, Publisher, Year	Findings	Limitations
1	L. Wang et al.	3D MR image denoising using a modified adaptive high order singular value decomposition method[15] <i>IEEE conference (2020)</i>	- Effectively reduces rician noise from MRI images. - Utilizes neighboring information for better results. - Separates useful information using higher order tensor decomposition.	- Memory requirement is more. - Decomposition is computationally complex for large dataset of 3D MRI images. - Performance depends on rank and parameter selection.

S.No	Authors	Title, Publisher, Year	Findings	Limitations
2	R. Singh and L. Kaur	Magnetic Resonance Image Denoising using Patchwise Convolutional Neural Networks[16] IEEE Conference (2021)	• Patch wise CNNs effectively learn noise pattern and reduces noise signal from MRI images. • Preserves edge information efficiently. • Reduces memory requirement as compare to those techniques which require entire image processing at a time.	• Requires large training dataset. • Subtle structures may be lost during denoising. • Sometimes gives better results quantitatively but not qualitatively. • Individual patch processing may introduce boundary artifacts.
3	Kumar and K. Sutariya,	Adaptive Multi Scale Products Threshold-Based MRI Denoising [17] IEEE conference (2022)	• Reduces the rician noise effectively. • Threshold can be adjusted according to local image characteristics. • Better preservation of small anatomical structures. • Proper threshold minimizes the noise related artifacts. • Can potentially applied on different MRI dataset.	• Multi scale decomposition requires significant time for processing. • Performance completely depends on selection of scale and threshold value. • Improper selection of threshold may lead to ringing artifacts and blurring. • Improper threshold selection cause loss of fine details.
4	R. K. Painam and M. Suchetha	Comparative Performance Analysis of Spatial Domain Filters for Removing Rician Noise in SAR images [3] IEEE Conference (2022)	• Comparative analysis is done. • Suppresses rician noise and improves visual quality. • Preserves the features while removing rician noise. • Spatial domain fitters are computationally not complex.	• Smoothes textures sometimes. • Spatial resolution is lost. • Not suitable for high level of rician noise. • Performance of filter depends upon parameter selection. • Fail to exploit global image characteristics.

S.No	Authors	Title, Publisher, Year	Findings	Limitations
5	S. K. Maji and A. Mahajan,	A Joint Denoising Technique for Mixed Gaussian–Impulse Noise Removal in HIS [6] <i>IEEE Geoscience and Remote Sensing Letters</i> (2023)	- Removes mixed Gaussian and impulsive noise from hyperspectral images. - Combined filtering techniques provides better noise suppression. - Higher values of performance parameters are obtained as compare to other techniques.	- Preservation of fine structure is challenging especially in high noise condition. - Algorithm involves multiple processing stages which increases the complexity and processing time.
6	J. J. V and A. J. S	Application of Bilateral Filters for Denoising Rician Noise in MRI Images [18] IEEE Conference (2023)	- Since it is non-iterative technique hence faster than many iterative techniques. - Implementation is easy. - Provide balance between noise suppression and edge preservation.	- Improper parameter selection may lead to deterioration of image quality. - Do not perform high level of noise. - Effectiveness may differ with noise level.
7	K. Sikhakhane et al.	Evaluation of Rician Noise Reduction Filters and Machine Learning Algorithms for MRI Images[19] IEEE Access (2024)	- Suppresses rician noise effectively from MRI images. - Machine learning technique provides better performance by learning complex noise pattern. - Provides better structural preservation.	- Machine learning models require large and high quality dataset. - Performance completely depends upon training data distribution. - Algorithms are highly complex
8	R. F. Gusa et al.	Rician Noise Reduction in MRI Images Using Various Denoising Techniques [12] <i>IEEE conference</i> (2024)	- Comparison of existing techniques is done. - Adaptive spatial techniques perform better than conventional techniques. - Preserves structural details. - Computationally efficient.	- Highly sensitive to kernel size and smoothing coefficients. - Performances of various techniques are not consistent. - Uses only local neighborhood information.

S.No	Authors	Title, Publisher, Year	Findings	Limitations
9	V. Kumar et al.	Study of Synthetic Aperture Radar (SAR) Images Under the Purview of Rician Noise Mitigation [20] <i>IEEE conference (2025)</i>	- Rician noise degrades SAR images significantly. - Characteristics of rician noise are different from white Gaussian noise. - Quality of SAR images degrades with increase in level of rician noise.	- Study consider only rician noise but not speckle or mixed noise. - Study lacks validation on large scale real world SAR dataset.
10	S. Mirzaei	Direct Rician-Domain Processing for Noise-Aware MRI Denoising and Microstructure Preservation[14] <i>IEEE Conference (2026)</i>	- Direct processing improves noise estimation. - Better preservation of micro structures. - Does not alter the image details.	- Low contrast structures may be lost. - Requires careful selection on noise related parameters. - Performance may decrease if noise does not follow rician distribution.

5. Conclusion and future Scope

From the literature review; it is clear the MRI images are severely affected by rician noise signals. Rician noise removal is one of the most essential pre-processing task from the MRI images. The main aim of this pre-processing step is not only remove rician noise from MRI images but retain the structural information present in MRI images. This information may be edges, ridges, contours, or other fine structures available in the MRI images. Since rician noise is signal dependent and it affects the low intensity regions in the MRI images hence the techniques which are used to remove Gaussian noise do not provide satisfactory results. Many literatures related to the rician noise suppression have been studied which include spatial and transform domain approaches. The used techniques must maintain the balance between noise suppression and preservation of anatomical structural details. Many existing techniques gives better results than the conventional techniques but there are still the room to get better results quantitatively and qualitatively. For this purpose many performance evaluation parameters have been used. Some of the most common parameters are Power Signal to Noise Ratio (PSNR), Signal to Noise Ratio (SNR) and Structural Similarity Index Measure (SSIM). There are many challenges for suppressing the noise while preserving the structural details present in MRI images. Conventional techniques remove rician noise from MRI images but suppress details. Spatial domain and transform domain based techniques performs well but there are still room to get better results. Deep learning techniques give better results among all techniques but they require large data set and training which make the system computationally complicated and increase processing time.

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