Chapter 1 : INTRODUCTION

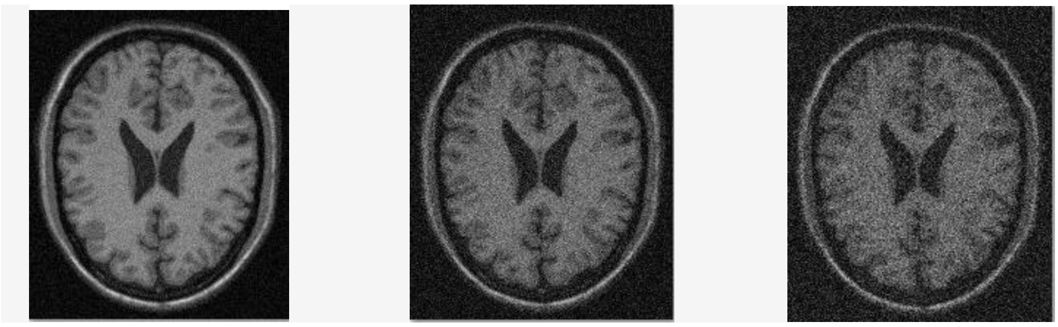
This chapter presents introduction to the problems discussed in this thesis, motivation behind the present work, and objectives of the thesis. Finally, the chapter concludes with a list of contributions of this thesis in field of restoration and enhancement of MRI.

1.1. Introduction

Non-invasive imaging technique has been of great help for medical practitioners for many decades. Starting from X-Ray imaging, the technique of medical imaging has traveled a long way and is constantly being extremely helpful for diagnosis. With the introduction of digital techniques, medical imaging got its strength in recent years. The science of medical imaging has matured a lot in last few decades. More sophisticated machines and non-invasive techniques have made medical imaging popular and have thereby made the diagnosis more accurate. However, the main premise of accurate diagnosis is noise free images which are still elusive. Parallel research on removing artifacts/noise arising out of hardware, software and physical problems are going on. The present thesis is an attempt in this direction. In particular, techniques to estimate original data from its noisy form are presented for various noise models. The type of medical image considered is Magnetic Resonance Imaging (MRI) of brain tissues.

1.2. Overview of MRI

Magnetic Resonance Imaging (MRI) is one of the most popular clinical imaging methods developed alongside Computer Tomography (CT) and X-Rays Technology. It is an ionization and radiation free modality, hence is a non-invasive technique and safer than CT, X-Ray and other techniques. It also provides a better soft tissue contrast and



(a) T1 (b) T2 (c) PD

Figure 1.1: Sample images from BrainWeb Database [1]

image resolution for diagnostic purpose [2], [3]. The MRI modality built upon phenomenon of Nuclear Magnetic Resonance (NMR), was discovered by F. Bloch and E. Purcell independently in 1946 (both awarded Nobel prizes in 1952). Further investigation of NMR phenomena led it to be useful for human society in notable works by Richard Ernst, Paul C. Lauterbur and Sir Peter Manseld who won the Nobel prize in 1991, 2003 and 2003 respectively.

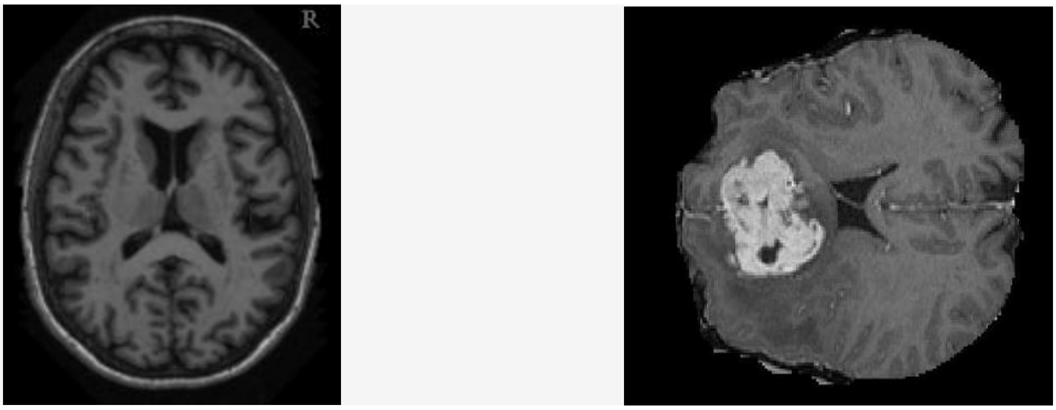
The principle of NMR involves quantum and classical mechanics, which involve processing of protons (present in human body) under external Magnetic field. The crux of MRI modality is utilization of abundance containment of hydrogen nucleus present in human body in the form of water. The protons of H-atoms are aligned by the external field. Under a radio frequency (RF) pulse, protons release their energy generating an electromagnetic signal that gets recorded by receiver coils of MRI scanners. These electromagnetic signals get encoded in phase and frequency components. The Inverse Fourier transform of raw data generates image slice either 2 or 3 dimensional, also known as k-space. The reconstruction process from raw signal to image space, provides an added choice to generate any particular slice in 2D form or complete volumetric (3D) representation [4], [5]. MRI offers various modalities, in addition, namely T1, T2, PD (Proton Density) modality, shown in Figure 1.1.

Although a versatile technique, the quality of image is often affected during image acquisition process. The artifacts can mainly be classified as:

- Hardware Related: such as power supply instability, thermal noise etc.
- Software Related: such as error in decoding pulse sequence, intensity in homogeneity etc.
- Patient Related: such as body movement, holding breath for a long time, blood flow etc.
- Physics Related: such as magnetic susceptibility, Gibbs ringing artifacts etc.

Many of the artifacts mentioned above are taken care of by MR scanner available. Some noise/artifacts still remain in the scan which needed to be removed. Otherwise, it may affect post-processing step which involves tissue identification, tissue segmentation and other diagnostic decisions.

In the reconstruction step, there is always an uncertainty involved due to sampling of Fourier domain to spatial domain, interpolation techniques used etc. This uncertainty can be defined as whether a spatial location is representing an actual tissue information of the subject or a true signal is may be affected by encoding scheme or effect of neighborhood and so on. This uncertainty leads to some undesirable visual effects, commonly referred as noisy image, which are needed to be overcome by some Software/mathematical modeling (referred as Image De-noising Problem). Here, Figure 1.2 shows two real sample images of different subjects (human) from benchmark databases [6], [7] where noise is clearly visible. The image de-noising problem is in fact an inverse problem which tries to reconstruct a true noise-free image [8], hence, can ease the image segmentation, disease identification etc.



(a) OASIS database [6] (b) BRATS database [7, 120]

Figure 1.2: Sample images from Real Databases

The acquisition process of medical images is sensitive to noise or undesired signals. Since noise is an inherent part of MRI data, de-noising becomes a crucial ingredient of medical image analysis process. Hence, there are two sets of problems: (a) estimation and analysis of noise model/parameter and other artifacts such as intensity in homogeneity, bias correction etc. and (b) construction of adaptive models for denoising purpose. However, these can be considered independent problems or one can use the first one as guided input for the other. An inaccurate noise model may lead to doubt on reliability of de-noising method. Traditionally, Gaussian model is preferred at high SNR locations in MRI [9]. A lot of efforts have been put to build a statistical noise model in MRI [9], [10], [11], [12]. Similarly, efforts have been made to estimate parameters of models in [25], [13], [14], [15].

On the other side, to develop de-noising methods according to noise model in MRI is highly sought. In this regard, many conventional methods have been modified accordingly to adjust the nature of MRI data [16], [17], [18], [19]. However, one needs to take care of the tissue information and boundary information in image and keep them intact at the end of de-noising process. In fact, Cerebrospinal Fluid (CSF), Gray Matter (GM) and White Matter (WM) play significant role in differentiating healthy brain from an abnormal one and also in clinical examinations [20]. So, even a small change in it may produce a wrong clinical decision. Hence, any preprocessing part must preserve the structure and properties of tissue as in the human subject. A large review on de-noising methods in MRI can be found in [21].

1.3. Motivation of the work

It is already stated that noise from different sources and for different conditions accumulate in MR images. Hence, the main motivation of this work is to get MR images which are noise free by pre-processing techniques before going into image analysis such as tissue segmentation, restoration and enhancement. Noise most naturally affects boundaries of different tissues, thereby making it most different to identify proper edges. Another motivation of the thesis, rather than first motivation is to get edges as proper as possible from the noisy image.

Moreover, study revealed that the noise model present in MR images is very different from that of natural images. This happens due to several unique sources of noise generation and their combination. Thus, it is quite obvious that the technique used in natural image de-noising may not work properly for medical images. Another motivation was to investigate such noise and explore the techniques of removal of noise.

In MRI data, many edge detection methods failed and were not able to capture all the edges [22]. The edges, that we are looking for, give rise to object boundaries which must be closed in nature. The purpose of closed boundaries is to govern de-noising process near the boundary regions where two different tissues may interact. Otherwise, de-noising of one type of tissues may affect/disturb another type of tissues at boundary. However, most of the methods proposed earlier [23] [24], fail to get such closed boundaries while finding the edges.

Another significant difference (between natural images and medical images) lies in the noise realization. Commonly, noise in natural images is considered as additive and white in nature, defined as $y = x + \eta$, where x is the actual signal and η is the error component or noise inducted in the acquisition process. Here, noise occurrence has been assumed to be independent and identically distributed (IID) noise. The Rician noise was built from white Gaussian noise in the complex domain, defined below

$$y = \sqrt{(x + \eta_1)^2 + (\eta_2)^2} \tag{1.1}$$

where x is the noise free image, $\eta_1 \in N(0, \sigma_n)$, $\eta_2 \in N(0, \sigma_n)$ and σ_n is the standard deviation of the added white Gaussian noise. The signal dependency behavior makes it difficult to implement many de-noising methods in straight forward manner. However, some methods are acquainted with Variance Stabilization Techniques (VST) for Rician data, proposed in [25]. In addition, MRI de-noising with Rician noise needs to have bias correction module [19]. However, some methods also suggest for bias correction in [26], [27], [28], [29].

Disturbances or noise induced in acquisition process lower down the quality of the signal. Hence, it is desirable to have de-noising methods suitable for Rician kind of distribution while sustaining the integrity of the image scan. Noise brings uncertainty in data and changes image intensity abruptly. Hence, it is difficult to find the amount of change at each location in the MRI. One can only estimate/approximate the possibility of true value at each location using other information from data.

A keen observation about MRI brain images is that they are symmetrical many a times, hence one can use this kind of structural property in de-noising process (also evident in Figure 1.1 and 1.2). This property can be useful in patch based processing non locally. In recent years, image de-noising literature has dealt in patch based de-noising where idea is to get the similar patches with in the image space. However, finding similar patches for each patch is tedious and time consuming. Hence, such methods are restricted to find similarity with a given local neighborhood of the underlying patch.

1.4. Objective of the Thesis

The main objective of this thesis is to handle the uncertainty due to noise present in MR image and make it as clean as possible. The clean image is expected to lead towards robust diagnosis. The noise present in the image is assumed to be an uncertainty model as no prior information is available to decide whether a pixel of the image is noisy or non-noisy. Emphasis is given to deal this uncertainty through PDE based approach.

The objectives of this thesis are as follows:

(i) Comprehensive literature review and comparative study of various classical as well as state-of-the art methods for restoration and enhancement of magnetic resonance images. Further design, new and efficient algorithms for restoration and enhancement of MRI.

(ii) To design an efficient PDE-Based nonlinear filter adapted to Rician noise for restoration and enhancement of magnetic resonance images.

(iii) To design a modified complex diffusion based nonlinear filter for restoration and enhancement of magnetic resonance images.

(iv) To design an orientation dependent anisotropic adaptive fuzzy diffusion based filter for restoration and enhancement of magnetic resonance images.

(v) To design a PDE-Based general framework adapted to Rayleigh's, Rician's and Gaussian's distributed noise for restoration and enhancement of MRI.

1.5. Contributions to the Thesis

This section describes the important contributions of the thesis in the field of restoration and enhancement of MRI which are as follows:

(i) Exploited different properties of MRI denoising, and demonstrated their suitability and application to solve different problems such as: artifacts, blurring, detection and removal of additive and multiplicative noises.

(ii) Presented a comprehensive literature review and comparative study of various classical as well as state-of-the art methods for MRI denoising. Further, a new improved an efficient PDE-Based nonlinear filter adapted to Rician noise for restoration and enhancement of magnetic resonance images using anisotropic diffusion based prior is proposed. The proposed algorithm is capable to remove Rician noise which is the prominent noise in MRI.

(iii) Proposed a method, Modified complex diffusion based nonlinear filter adapted to Rician noise for restoration and enhancement of magnetic resonance images.

(iv) Exploited different features using proposed methods, orientation dependent anisotropic adaptive fuzzy diffusion based filter for restoration and enhancement of magnetic resonance images and removal of Gaussian and Rician noise patterns by measuring SNR value in MRI.

(v) Proposed a methods for removal of main area as well as background area of the magnitude MR images. A PDE-based general framework adapted to Rayleigh's, Rician's and Gaussian's distributed noise for restoration and enhancement of MRI is proposed. This makes the algorithm to work not only in the case of additive type of noises but also in the case of multiplicative type of noise.

1.6. Outline of the Thesis

This thesis consists of six chapters. Outline of the thesis is as follows:

Chapter 1 presents a brief introduction of the problems addressed in this thesis followed by the objectives of the thesis. Finally chapter concludes with a brief account on contributions of this thesis in field of medical image processing.

Chapter 2 discusses the theoretical background for restoration and enhancement of magnetic resonance images. In this chapter, we have also given an over view of magnetic resonance images. Further, in this chapter a literature survey of prominent approaches for restoration and enhancement of MRI are given.

Chapter 3 is organized to design and development of nonlinear PDE based filters for restoration and enhancement of MR images. This chapter presents two methods, the first method handles an efficient PDE-Based nonlinear filter adapted to Rician noise for restoration and enhancement of magnetic resonance images are developed. Further, second method handles a modified complex diffusion based nonlinear filter for restoration and enhancement of magnetic resonance images. The proposed method and other state-of-the-art methods have been tested on different types of brainwave dataset viz. normal MRI, noisy MRI. Quantitative performance of the proposed method has been evaluated and compared with other state- of-the-art methods in terms of different performance metrics viz. peak signal to noise ratio, structural similarity index map, root mean squire error, correlation parameter etc.

Chapter 4 presents an orientation dependent anisotropic adaptive fuzzy diffusion based filter for restoration and enhancement of magnetic resonance images. This chapter deals with removal of Rician's and Gaussian's noise patterns. Robustness of the proposed methods in comparison to other state-of-the-art methods has been tested for different types of MR images. Finally, the quantitative performance values for different cases have been computed for the proposed method and other state-of-the-art methods and then compared in terms of different performance evaluation metrics.

Chapter 5 addressed the problem of PDE-Based general framework adapted to Rayleigh's, Rician's and Gaussian's distributed noise for restoration and enhancement of MRI. In this chapter, general filter based on various priors TV, AD and CD is proposed. Performance of this method has been analyzed in terms of quantitative matrices.

Chapter 6 presents conclusions and summarizes main findings of the research work. This chapter also proposes possible future perspectives of restoration and enhancement of MRI.