MRI: A versatile medical imaging technology

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ABSTRACT: Magnetic resonance imaging (MRI) is a versatile non-invasive imaging technique that acquires dedicated detail of different part of the human body in the form of two dimensional images (slices) taken from axial, sagittal and coronal planes. A series of successive MRI measurement sequences demonstrate several physical phenomena visually such as blood flow (MR angiography), brain activation (functional MRI), brain connectivity (diffusion MRI) and hence become one of the frequently used tests in surgery and neurology. In this paper, many issues involved regarding MRI acquisition such as different quantitative MRI techniques mapping, various sources of noise, artifacts, Signal-to-noise ratio, acquisition time and MRI denoising methods is presented.

KEYWORDS: MR angiography, MRI denoising, Signal-to-noise ratio, acquisition time, functional MRI

INTRODUCTION

MRI is accepted as the imaging method of choice for the visualization of internal structures and has become one of the indispensable tool in surgical planning and surgical navigation. Unlike other medical imaging techniques, MRI does not use ionizing radiation and rely primarily on simple transmission and/or reflection of energy. Generally, MRI is used in a qualitative way where the images are interpreted by a skilled observer for clinical diagnosis. Therefore, to increase the image quality for correct detection is the primary concern. MRI acquisition process generally involved with tradeoff between acquisition time, signal to noise ratio and resolutions which seriously affects the visual assessment and medical diagnosis due to poor image quality. Increase the acquisition time is not a good practical solution due to patient comfort and technical limitations.

BACKGROUND

SIGNAL GENERATION

When a magnetic field B_0 is applied uniformly around the body, the magnetic moment μ of water nuclei of the body parts being observed will precess about this magnetic field with an angular frequency known as the Larmor frequency $\omega_L = \gamma B_0$ where γ represent gyromagnetic ratio of nuclei. The alignment of water nuclei of the tissue perturbed from its equilibrium state by an external radio frequency (RF) excitation pulse. The water nuclei absorb energy and go to higher energy state. After some time, these nuclei relax and the net transverse precessing magnetization will induce a small voltage in a conducting Radio frequency (RF) coils placed in transverse plane during resonance at Larmor frequency (ω_L). The signal received by RF coil is called Magnetic Resonance (MR) signal [1]. The amplitude of MR signal in the form of oscillating damped sine wave will decay exponentially characterized by T_2 relaxation time which depends on tissue physical properties. Different type of tissue will generate MR signals with different intensities that reflects as image contrast in Nuclear Magnetic Resonance (NMR). Time to Echo (TE) is the time required to receive echo signal after the RF excitation pulses. The time gap between two successive external RF excitation pulses is called the repetition time (TR). The contrast weighting is influences by varying the TE, TR and flip angles of a gradient echo sequence.

Image formation

In MRI, spatial localization of the NMR signals is achieved by varying Larmor-frequency across the body in Z-direction with the help of Gradient coils. As a result, only a specific slice of the body has magnetization vectors in resonance with the RF pulses. Hence, the tissue being scanned in the slice can be excited. The gradient strength and RF pulses bandwidth is used to control the slice thickness. Gradient coils also vary in X and Y direction to select a tiny volume within a slice called voxels (volumetric pixels). This voxels location in X-Y plane is controlled by Phase and frequency encoding.

K-space and image reconstruction

The received signal is the sum of all precessing magnetization vectors. The 2D encoded k-space data sampled at several frequencies have information from each location in the imaged plane. K-space acquired data is converted into 2D imaged plane using Inverse Fourier transformation to corresponding gray levels pixels in the form of 2D matrix arrangement as shown in Figure 1 [2].

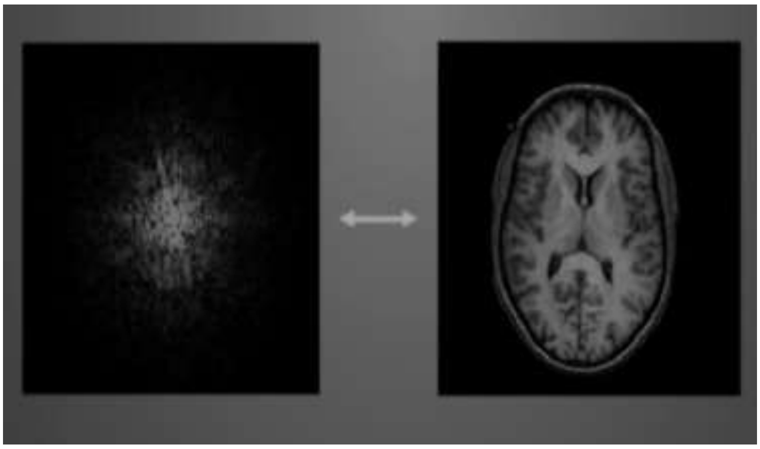

Fig. 1: The image formation from the k-space data by using a discrete Fourier transform.

The frequently used MRI sequences weights are longitudinal (T1) and transverse (T2) relaxation time [3]. Different types of tissue have different longitudinal and transverse relaxation time properties which affect the contrast and brightness of the T1/T2 weighted images respectively as shown in Figure 2 [4]. T1-weighted images can be acquired by taking shorter TE and TR times whereas for T2-weighted images, longer TE and TR times should preferred.

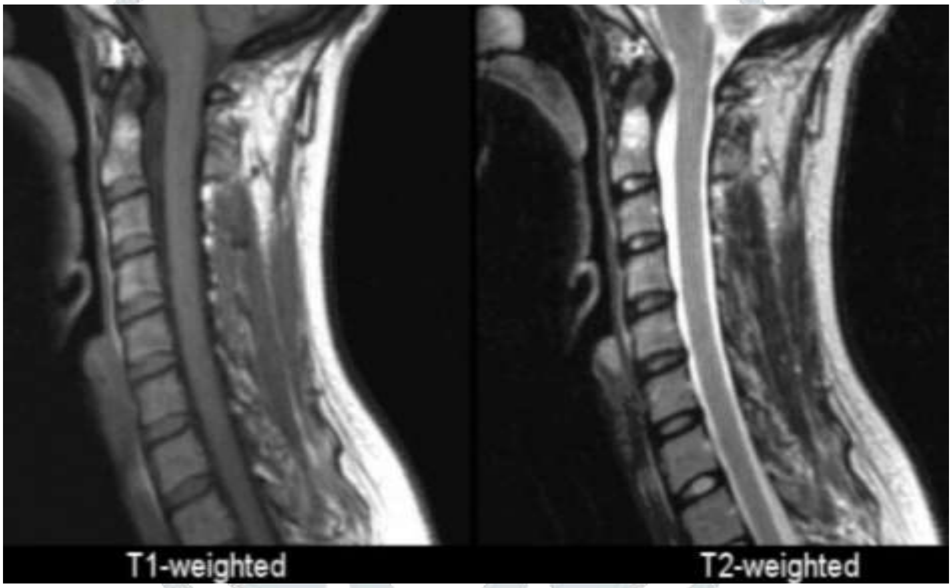

Fig. 2: Comparison of T1-weighted and T2-weighted scans of Spine

SOURCES OF INTERFERENCE IN MRI RECORDING

MRI recording normally undergoes through motion artifacts due to spontaneous physiological motion such as respiratory movements, cardiac pulsation of blood flow or swallowing which leads to blurring. The motion artifacts can be minimise by cardiac/respiratory gating and patients body motion restriction. A very fast MR imaging technique such as echo-planar imaging can overcome the problem of motion artifacts.

Metallic objects within the patient's body such as Dental implants, Neurosurgical clips, Orthodontic appliances (ferromagnetic material) may result magnetic susceptibility artefact.

Tissue-related Susceptibility artefacts might be seen at natural interfaces such as sinuses and the skull base due to magnetic susceptibility differences between adjacent regions [7]. The magnetic field irregularities result in spatial mismapping of the MR signal within and outside of voxels.

Chemical shift artifacts occur due to spatial misregistration of fat and water molecules and it might be seen as dark or bright bands at the lipid-water interface. This artifact generates because of differences between the resonance frequencies of protons in fat and water molecules because of magnetic shielding generated by the electron cloud. In the diagnosis of focal fatty liver or adrenal adenomas, chemical shift artifacts used as tissue -characterization.

Aliasing artifacts, also known as wrap-around occur when the field-of-view (FOV) is not sufficient to capture the complete object dimensions.

DENOISING METHODS IN MRI

The noise will deteriorate the contrast of the MRI and it may affect diagnostic decisions such as tissue identification, boundary information and segmentation. Since noise is an inherent part of image acquisition of MRI data, denoising is the main attention of medical image analysis process. Several filtering methods in the past decades have been developed to improve images resolution and SNR.

Statistical Noise Model Approach

The noise in MR data in the k-space is supposed to be uncorrelated Gaussian process. Therefore, statistical noise Model is preferred at high SNR locations in MRI [6]. For single coil systems and multiple (independent) coils systems Rician and chi (nc-χ) distributions have been used respectively in the MR [9]. The modern MRI acquisition systems along with reconstruction methods like SENSE [10], GRAPPA [11] gather subsampled k-space data to suppress the aliasing artifacts. Few works based on statistics and estimation has been reported for MRI denoising such as Maximum Likelihood (ML), adapted non-local mean schemes, Linear minimum mean square error estimation, non-parametric Markov random field estimater [12], quasi Monte-Carlo estimation [13].

Linear Filtering Approach

Different filter like temporal and Spatial filter has been used for MRI smoothening. This linear convolution filtering approach reduce gaussian noise but SNR remain unaffected [14].

Non- Linear Filtering Approach

Few works based on Non- Linear Filtering Approach has been reported for MRI denoising such as nonlocal means filtering(NML) [15], Anisotropic Diffusion Filter [16], bilateral and trilateral filter [17]. These Non- Linear filtering approach doesn't preserve small structures detail.

Transform Domain Approach

Discrete Wavelet transform(DWT) based denoising methods provide multiresolution analysis of MRI [18-19]. It defines local features and filter out local noise and doesn't alter edges details.

Comparison between Denoising Methods

The quantitative effect of different MRI denoising algorithm is scaled on parameter such as peak signal to noise ratio (PSNR), Bhattacharyya coefficient(BC) and structural similarity index method (SSIM). Table 1 lists the Advantages and disadvantages of different Filtering Approach.

Table 1. Advantages and disadvantages of Filtering Approach

Filtering Approach	Advantages	Disadvantages
Statistical Noise Model Approach	More robust to remove uncorrelated Gaussian noise and preserved the fine structure	It is computationally expensive.
Linear filters Approach	Computationally simple	fine structure and the edges details are lost because of blurring.
Non- Linear Filtering Approach	More robust to reduces flat regions denoise and preserved the fine structure	It is computationally expensive because of high iterations. It degrades the resolution and fine structure.
Transform Domain Approach	More robust to separate signal from local noise	Fine details lost in highly noisy images

CONCLUSION

In this paper a detailed description of the basic concepts of MRI is provided such as Magnetic Resonance (MR) signal generation and MRI image reconstruction from the k-space. However, noise is one of obstacles in visual assessment of biomedical imaging. The noise reducing is very important in MRI for medical diagnosis. Further, this paper gives a critical analysis of different Filtering Approach for MRI. These Approach are compared based on their performance. This will help for the new researchers who are trying to understand and develop superior technique for MRI pre-processing.

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