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Magnetic Resonance Imaging with a priori Constraints: Possibilities and Limitations

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ABSTRACT

This paper addresses the issues related to using *a priori* information to improve the speed, efficiency and accuracy of magnetic resonance imaging. Several examples are discussed to demonstrate the strengths and limitations of such a constrained imaging approach.

I. INTRODUCTION

The mathematical basis of magnetic resonance imaging is conventionally rooted in the well-established Fourier or Radon transform theories, so that image quality is mainly dependent on how the data space is sampled. In practice, physical and temporal constraints often prevent a sufficient coverage of the data space, resulting in various image artifacts, such as Gibbs ringing, resolution degradation, and various motion effects. Although improvements in excitation protocols can be helpful, the key to dramatic improvements in performance of such a system lies in the use of *a priori* information. In practice, valid *a priori* information is available in a variety of forms. In this paper, we will discuss how it can be used for faster and more accurate imaging in two important applications: dynamic imaging and spectroscopic imaging. A potential danger of such a constrained imaging approach is that the results may be biased by the prior assumptions imposed during data acquisition or processing. Image distortions produced by the Fourier method are at least partially understood and discounted; those of new methods may be more insidious. These issues will also be discussed.

II. DYNAMIC IMAGING

Dynamic imaging experiments are characterized by the acquisition of a time series of images, $\rho_1(x)$, $\rho_2(x)$, $\cdots$, $\rho_L(x)$, from the same anatomical site. These images are useful for a number of applications including dynamic studies of injected contrast agents and measurement of relaxation time constants and diffusion coefficients. A challenge with such an imaging experiment is to obtain both high spatial and temporal resolutions simultaneously. Conventional Fourier imaging methods acquire each of these images independently, leading to a compromise between image spatial resolution and temporal resolution.

To overcome this problem, several constrained imaging methods have been proposed in the last few years [1; 2; 3; 4; 5; 6; 7; 8]. A common feature of these methods is that a high-resolution reference image is obtained prior to the dynamic imaging period so that subsequent dynamic images can be obtained with a reduced set of encodings. An desirable advantage of these methods is that significant improvement in both imaging efficiency and temporal resolution can be obtained. However, when the number of dynamic encodings collected is too small, data truncation artifacts will result. In RIGR (Reduced-encoding by Generalized-series Reconstruction) [1; 2], for example, these artifacts manifest themselves as a loss of spatial resolution for the dynamic features. But with the SVD based imaging methods, data truncation can result in significant blurring as well as spatial displacement of dynamic features. Therefore, caution needs to be exercised in interpreting the results from such imaging methods.

Another more radically different approach to dynamic imaging, called DIME (Dynamic Imaging by Motion Estimation), treats it as a higher-dimensional image reconstruction problem [10]. Specifically, this method describes dynamic data acquisition using a (k, t)-space formalism [11], revealing that motion artifacts are fundamentally a temporal undersampling problem. By properly imposing a temporal generalized harmonic model, this undersampling problem is overcome, making it possible to obtain high spatial and temporal resolution simultaneously.

One set of representative results from a simulation study of this method is presented in Fig. 1. Because the cardiac and respiratory motion in the simulation are asynchronous and of non-rigid-body type, it is basically impossible to obtain motion-artifact-free dynamic images using traditional methods. However, with DIME the motion artifacts are significantly reduced and the time course of the dynamic variation is also very well reproduced. This result demonstrates the great potential of temporal modeling in dynamic imaging.

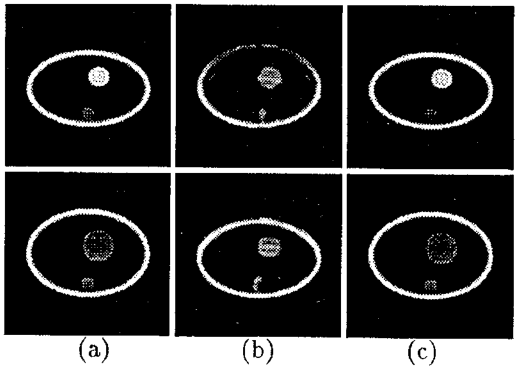
(a) (b) (c)

Fig. 1. Simulation results of an upper chest model: (a) the ideal snapshot images and (b-c) reconstructed snapshot images using the Fourier method and the proposed method, respectively.

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III. SPECTROSCOPIC IMAGING

As compared to the conventional anatomical imaging, spectroscopic imaging provides an additional dimension of spectral information to reveal the biochemical properties of localized tissues. However, in order to obtain this new dimension of information, we now lose the freedom to use the time evolution of the MR signals to encode spatial information. Therefore, all positional information has to be encoded by properly incrementing the magnetic field gradients. For example, if a spatial resolution of $N_x \times N_y \times N_z$ voxels is required, $N_xN_yN_z$ phase or frequency encoding experiments will be necessary with the conventional chemical shift imaging (CSI) methods. This means that the data acquisition time for obtaining adequate spatial resolution can be prohibitively long in practice. To reduce data acquisition times, the usual approach is to reduce the number of encoding steps used. However, if no other constraints (or *a priori* information) are available to compensate for the lack of high spatial frequency measurements, this limited k-space coverage will lead to degraded spatial resolution and possible reconstruction artifacts, as is often the case with the conventional Fourier series spectroscopic imaging methods. To overcome this problem, various volume-selective methods have been proposed to obtain single-voxel spectra from a small number of voxels with rather short data acquisition times. These volume-selective methods suffer from various problems, notably, geometric inflexibility, possible mis-registration of spectral information, and spectral contamination from incomplete suppression of unwanted signals, which limit their practical utility. More importantly, since these techniques usually do not have full spatial-multiplexing capability, they are often considered as localization rather than imaging methods.

To overcome this problem, another more efficient multi-voxel spectral localization technique, called SLIM (Spectral Localization by IMaging) [12], was developed. This method makes use of the structural information available from pilot proton images to model the object being imaged by a set of homogeneous compartments with arbitrary shapes defined by the geometric information. With this technique, localized spectra from these compartments can be derived from a minimal set of phase or frequency encoding measurements and, therefore, optimal efficiency is obtained. However, when the homogeneity assumption is violated by, for example, the presence of magnetic field inhomogeneities or chemical concentration gradients, new localization errors may occur [13]. This problem is overcome by a generalized SLIM technique [14], which uses a generalized series model to represent the spatial-spectral function.

IV. CONCLUSION

Prior information exists in many practical imaging applications. Much work has been carried out to establish new imaging formalisms to effectively utilize this information for improving imaging speed, efficiency and accuracy. Preliminary results from various research groups indicate that these methods are potentially very useful, but much work remains to be done to bring these methods to the level of maturity needed for general practical applications.

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