Validation and Application of a Perceptual Difference Model for Keyhole MR Imaging

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Purpose

The purpose of this study was to develop a method, based on the characteristics of the human visual system (HVS), for the evaluation and optimization of keyhole MRI and other fast imaging sequences.

Introduction

In keyhole imaging one starts with a full k-space acquisition and applies a Fourier transform to create an initial output image. Only a portion of k-space is sampled and updated prior to the inverse Fourier transform that creates subsequent output images. Variables in keyhole imaging include the number of k-space samples to acquire, the locations to sample, potential averaging with previous k-space samples, etc. In keyhole imaging there is a variety of parameter values to be optimized or adjusted. Since human perception experiments are very costly, computer evaluation is not only desirable, but also necessary. One criterion for optimality is a minimum visual difference between a fast technique and a very slow, high quality MR image. To determine visual differences, we validated and applied a mechanistic perceptual difference model (PDM), which mimics the processes that occur in the HVS. The output of this model provides a method for finding the optimal keyhole imaging parameters, giving the best possible image quality for a given acquisition time.

Methods

A series of images was acquired during the insertion of an MR-compatible biopsy needle into ex vivo bovine liver. To validate the PDM, these images were degraded by one of two processes that decrease image quality in fast MRI, noise and blur. In the case of noise, Rician MR noise was added to a "perceptually noise-free" image. For blur, an ideal low pass filter in the Fourier domain was used to simulate the image degradation that can occur in keyhole imaging. Four observers were asked to score the level of image degradation present in these images, with reference to the original, unaltered image. The PDM and a mean squared error metric were also applied to the original and degraded images. The human observer scores were plotted against the PDM output to develop an appropriate linear calibration curve and the R^2 value, a measure of the quality of the fit, was obtained. In a second experiment, six static keyhole sequences were simulated with data sampled as shown in Figure 1. The keyhole images were compared, using the PDM, to their corresponding reference images over both the entire image and in a region of interest (ROI) around the needle tip.

Results

The validation of the PDM shows that it very accurately reflects the image quality judgements of human observers for degradation due to both noise and blur. A linear fit of the noise and blur data show high R^2 values, 0.868 and 0.945, respectively. While the mean squared error metric correlated well with the noise validation results, it failed to agree with the blur responses. The keyhole simulations produced a number of visible image artifacts, and in all cases the keyhole simulations decreased the conspicuity of the true needle in the images. By examining the perceptual difference output maps, the areas of image quality degradation could be easily identified, as shown in Figure 2. For keyhole stripes larger than 1/4th of k-space, the perceptual model selected a keyhole stripe parallel to the insertion as having the best whole image quality and a perpendicular stripe from ROI analysis. As the amount of sampled k-space was decreased, the cross patterns produced smaller perceptual error by as much as a factor of two.

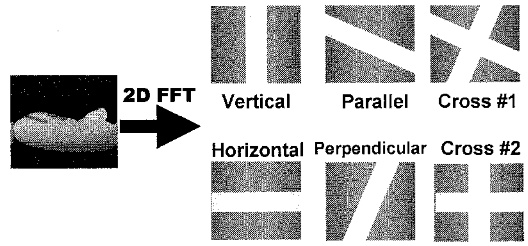

Figure 1. Keyhole stripes were simulated in six different orientations as shown above. Rotated stripes used a rotated coordinate system and were gridded and density compensated. To fix the sampling time for each frame, the individual stripes in the cross orientations are one half of the width of the stripes for the other acquisition methods.

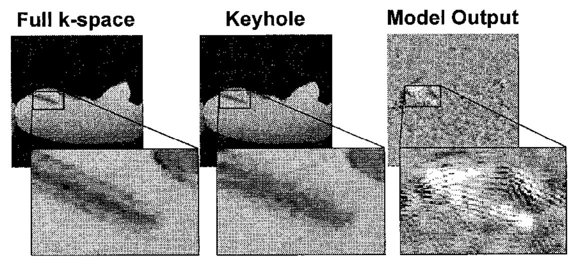

Figure 2. The Perceptual Difference Model creates a map of the likelihood that a human observer will perceive a difference between two images at that location. The analysis of these maps can provide both the magnitude of distortion due to a fast MR technique and the location of the degradation. This type of analysis is important because changes far from the objects of interest in iMRI can be inconsequential.

Discussion

The usefulness of perceptual difference modeling of the HVS is evidenced by its ability to agree with human observer inspection. It allows for the evaluation of a number of different possible fast MRI sequences in a relatively quick and inexpensive manner. This type of study provides the information necessary for that design process. Additionally, the perceptual difference map provided quantitative results allowing the identification and localization of areas change in images. This work is probably the first in which quantitative image quality modeling has been applied to fast MR imaging, and shows that the HVS model is an objective, promising tool for the automated evaluation and optimization of keyhole imaging sequences. This model is the first of its kind to provide an objective method for optimization of the large number of potential techniques available in the development of fast MR imaging.

Acknowledgments

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