Inpainting for Sensitivity Maps

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Introduction

Highly accurate knowledge of the spatial receiver sensitivity is required by some reconstruction algorithms [1]. Sensitivity maps are also crucial to correcting the inhomogeneities of MRI surface coils. Accurate sensitively information can only be obtained where an MR signal is present, however some data contain large areas where little or no signal is present. When this is the case sensitivity map interpolation techniques are required to fix theses holes. To deal with slightly varying tissue configurations and motion, extrapolation over a limited range may also be necessary. There are some existing techniques for these purposes, such as the polynomial fit procedure [1], thin-plate splines [2], wavelets, and Gaussian kernel smoothing [3]. These methods are based on the assumption that the sensitivity map is sufficiently smooth (i..e., containing no sharp variations). Based on our experiments this assumption is seen to not always hold. The PDE based inpainting model [4] proposed here is a technique to handle both interpolation and extrapolation for the more general case of piecewise smooth maps .

Methods

For each probe coil j there will be a sensitivity map u_j. Let I_j be the image generated by coil j, and let I be the homogeneous sum-of –squares image. In our model the raw sensitivity map u_j^0 will be defined as I_j / I. Let Ω be the image domain and let D be the low intensity regions in I (i.e. hole regions). Hence $\Omega \setminus D$ is the area where image information is contained, which will be referred to as "known locations." The new inpainting model for sensitivity maps is defined by Eq. 3. The first term is called the fidelity term, which mininizes the difference between u_j and u_j^0 at "known locations".

The second term is called the smoothing term which is used to smooth and extend the image along the intensity level set. The last term insures that the sum-of-squares of every coil's sensitivity map will be unity at each pixel. Given both u_j^0 and D, the u_j which minimizes the energy functional in Eq. 3 will be the inpainting result we seek. β, σ, γ and μ are parameters. β is used to accentuate the edges between regions of different intensities, σ is the standard deviation of the Gaussian smoothing function. γ and μ are used to balance the terms in energy functional. Eqs. 1 and 2 define terms used in Eq. 3.

$$\lambda_D(x) = \begin{cases} 0 & , x \in D \\ 1 & , x \in \Omega \setminus D \end{cases}, G_\sigma = \frac{\exp\left(-|x|^2 / \left(4\sigma^2\right)\right)}{\sigma} \quad (1)$$

$$P(x, |\nabla u|) = \begin{cases} 1 + \dfrac{1}{1 + \beta |\nabla G_\sigma * u|^2} & , |\nabla \lambda_D| = 0 \\ 2 & , |\nabla \lambda_D| > 0 \end{cases} \quad (2)$$

$$E[u_j \mid u_j^0, D] = \frac{1}{2} \sum_j \int_\Omega \lambda_{D_j}(x)(u_j I - I_j)^2 \, dx +$$

$$+ \gamma \sum_j \int_\Omega |\nabla u_j|^{P(x, |\nabla u_j|)} \, dx + \frac{\mu}{2} \int_\Omega \left(\sqrt{\sum_j u_j^2} - 1\right)^2 \, dx \quad (3)$$

Results

The proposed method was applied to both artificially contructed and experimental holes. Fig. 1 shows the inpainted result for a phantom, data acquired in SIEMENS 1.5 T system with 8-channel phased array coil (MRI Devices Corporation, Waukesha, WI, USA) . Table 1 shows the accuracy of inpainted sensitivity maps for SENSE. Raw sensitivity maps in Table 1 are generated by using low resolution images reconstructed with the 31 fully sampled central rows of K-space. Then we applied the inpainted sensitivity maps to reconstruct an MR image by using SENSE and then compare the reconstructed image with the reference image (which is generated by using all of K-space). The reduce factor of K-space in all experiments is 2. Let the phrase "intensity difference" refer to the difference in magnitudes between the reconstructed and reference-images at each pixel. We define the "ghost ratio" as the magnitude of the "intensity difference" (at each pixel) summed over every pixel in the image divided by the sum of the absolute value of each pixel in the reference image. The "ghost ratio" here is a measure of relative error. In all of our experiments, MATLAB codes are run on a COMPAQ PC with a 1G Hz CPU and 1G RAM.

Discussion

A novel inpainting model was proposed and applied to the correction of sensitivity maps. From Fig 1 it can be concluded that the holes were fixed with almost no distortion of local texture. From Table 1, it is further concluded that inpainted sensitivity maps produce better results than raw sensitivity maps for sensitivity maps generated through different types of imaging. The inpainting technique is fast. The average process time for a 256×256 image is less than 2 seconds.
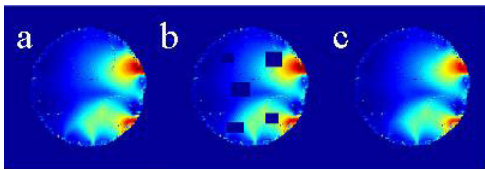
Fig 1. Results for the artificially contructed holes a) magnitude of the reference sensitivity map b) magnitude of the sensitivity map with 5 randomly constructed holes c) magnitude of the inpainted sensitivity map by the proposed method

References

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Table 1 Ghost ratio by using Inpainted and Raw sensitiviry maps for different Images			
	Coronal Phantom	Neurovascular Images	Cardiac Images
Inpainted	2.03%	6.61%	10.58%
Raw	6.7%	15.07%	17.56%