Global 2D Polynomial Fit Method for Efficient Filling of Coil Sensitivity Profile Gaps

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Introduction

Reconstruction of MR images acquired with a parallel array using methods such as SENSE [1] requires proper determination of coil sensitivities to ensure accurate unfolding. An initial estimate of the profile can be obtained by dividing a single surface coil image by a sum of squares of the complete set of images captured by such an array. Removal of map noise produced by low-signal regions for optimal SENSE reconstructions can produce gaps in the sensitivity profile. In subsequent reduced data acquisitions, object motion into these regions or beyond map boundaries necessitates missing information be obtained for proper reconstruction. Techniques for accomplishing this task include a local 2D polynomial fit using gaussian weighting of neighboring points [1,2]. To produce a successful fit, this method requires proper definition of the local fit neighborhood and the gaussian weighting profile. Such parameters can be difficult to define for larger gaps in the map, and the method can be computationally slow due to determination of unique fit parameters for each point. In this abstract, we demonstrate an adaptation of this method that replaces the local gaussian weighting with a single global determination of the 2D polynomial fit parameters that can be applied for fitting of all gaps and extrapolation points. This adapted method has been demonstrated to be both efficient and accurate, with the order of the polynomial the only parameter to be optimized.

Methods

Map Noise Removal – The process demonstrated in figure 1 was developed and tested using Matlab (MathWorks). First, a complex single coil image (A) was divided by a sum of squares of images collected by each coil in a multi-channel array (B), with object phase contrast reduced as described by de Zwart [2]. Background map noise was removed from the map (C) using a high and low threshold (D). Remaining median noise clusters were identified and labeled using a connected components algorithm (E), with only the largest cluster maintained. Any residual noise not captured by these steps was manually identified for exclusion in subsequent steps (F). Map edges prone to noise were removed by edge erosion, and extrapolation regions were defined by dilation of the original object boundary, both using a disk kernel. A final mask was then generated that identified map points, gaps, eroded edges, extrapolation regions, and background (G).

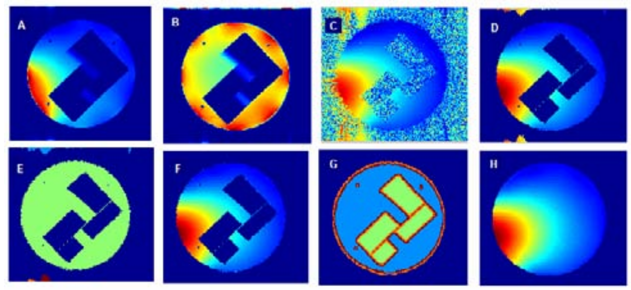


Figure 1: A.) Single coil image, B.) sum of squares, C.) original map, D.) after noise threshold, E.) connected components labeled mask, F.) map with gaps, G.) gap and extrapolation mask, H.) final fit map.

Map Polynomial Fit – To fit gaps, edges, and provide general smoothing, an N^{th} order 2D polynomial was used, where the fit value at location (x_0,y_0) was defined by:

$$f(x_0,y_0)=\sum_{n=1,m=1}^{N} p_{m,n}(x-x_0)^m(y-y_0)^n \quad \text{where } p=(X^TX)^{-1}X^TF$$

Here, F is a vector containing the value of all map points used for the fit. X corresponds to a matrix of their positions applied to $(x-x_0)^m(y-y_0)^n$ for all n and m combinations from 1 to order N. In this application, all non-zero map points were used to calculate polynomial coefficients with equal weighting rather than a limited neighborhood of points weighted by a gaussian centered on (x_0,y_0). As such, for every gap or extrapolation point that required a fit solution, the same set of p values was used to define the polynomial. Fitting was performed on the complex sensitivity map, with a final magnitude (H) and phase representation of the profile generated for subsequent analysis of the fit process.

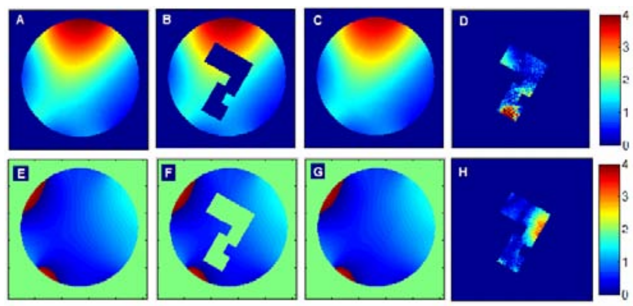
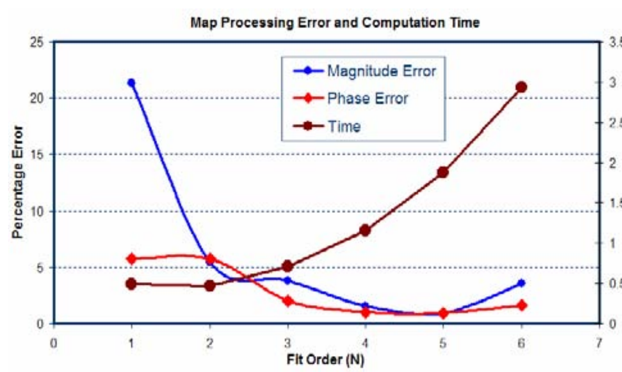


Figure 2: A.) Sensitivity map B) marked with gaps, C) after global 2D polynomial fit (N =4), and D) % difference between A and C. E-H.) Corresponding fitting test of map phase image.

Map Processing Test - 256x256 images were collected of a uniform phantom with a 6 channel SENSE array and Philips 3T Intera Achieva system. Image gaps were created using Matlab and sensitivity maps calculated using the original and gapped images. A comparison of the magnitude and phase images for the two sets of sensitivity maps yielded a measure of the fitting error for orders of 1 to 6 (figure 2). The computation time required to generate and process the maps was also recorded. Measurements were obtained using the described and local weighted fit methods. To demonstrate SENSE reconstruction performance, additional full-FOV images were collected of a non-uniform phantom and its k-space reduced by an R of 2. Sensitivity maps were generated with the global fit processing, the aliased images reconstructed, and a g-factor map calculated.

Results

Using a global fit with an N of 5, a mean error of less than 1% was observed in the magnitude and phase images, with a computation time less than 2 seconds to denoise and fit a single complex map (figure 3). The observed increase in error from order 5 to 6 was caused by impairment of the matrix inversion due to poor scaling, which was eliminated below N = 4 by scaling fit positions. Using the local fit method, comparable magnitude and phase errors of 0.9% and 0.4% were observed respectively at N = 2, with a process time of 167 seconds with a 40x40 neighborhood. Reconstructions at R = 2 using the global fit produced images without appreciable artifacts and a mean g of 1.06 (figure 3).



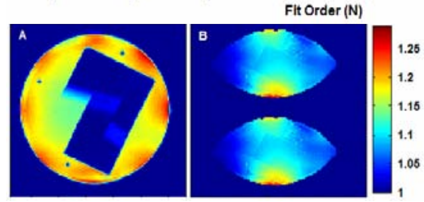


Figure 3: Global fit Magnitude and phase error, fit computation time. A.) Reconstructed image (N = 4, R = 2), B.) g-factor map.

Discussion

The described method for fitting map gaps, edge extrapolation, and map smoothing is 89 to 145 times faster than a local fit, and produces comparable errors in both map magnitude and phase images. The efficiency is due to only a single computation to determine fit coefficients for each point with no weighting. In addition, by eliminating the need to define a fit neighborhood, the global approach is robust for various gap sizes and patterns, optimal at an N of 4 or 5 to minimize error. Future studies will confirm these results using various degrees of uniformity in the B_1 profile.

References [1] Pruessmann, KP, et. al., MRM 42: 952-962 (1999), [2] de Zwart, JA, et. al., MRM 48: 1011-1020 (2002)