

# Coil Sensitivity Maps for Sensitivity Encoding and Intensity Correction

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## INTRODUCTION

A variety of methods for the determination of coil sensitivity maps have been developed in the past in order to enable intensity correction of images acquired with a single surface coil or a coil array [1-3].

Recently, another application of sensitivity maps has emerged. Distinct spatial information contained in data acquired simultaneously with different receiver coils may be taken into account for image reconstruction, thus enabling the reduction of the number of phase encoding steps [4-6]. However, for image reconstruction from sensitivity encoded data, maps of particularly high quality are required. This is because even slight errors in sensitivity values result not only in shading deviations but also in residual foldover artifacts when sensitivity information is utilized for spatial signal separation. Therefore, known concepts like a priori map assessment on a phantom or straightforward low pass filtering are not applicable. In this work we present a method for highly accurate determination of coil sensitivity by means of a local polynomial fitting algorithm.

## METHODS

The proposed procedure is illustrated by Fig. 1. For a given surface coil a raw sensitivity map is obtained in a slice by division of a surface coil image and a body coil image, both of arbitrary yet identical contrast. A raw map is generally impaired by noise, in particular in regions of low or zero tissue signal. Straightforward elimination of noise by low pass filtering results in errors at object edges [1].

To overcome this problem, for each pixel a 2D polynomial is locally fit to the raw map. A refined sensitivity value is then obtained by evaluation of the fitting polynomial at the position of the respective pixel. Fitting is based on 'valuable' raw data only: the set of pixels to be taken into account is restricted by thresholding according to signal strength in the body coil image and subsequent exclusion of isolated pixels (minimum neighbourhood filtering). The remaining pixels plus a certain neighbourhood determined by region growing form the set for which refined sensitivity values are calculated by fitting.

An L-th order fitting polynomial for the position  $x_0, y_0$  is given by

$$s(x, y) = \sum_{i,j=0}^L c_{ij} (x - x_0)^i (y - y_0)^j \quad (1)$$

The complex coefficients  $c_{ij}$  are determined according to

$$\Delta = \sum_k w_k |s_k - s(x_k, y_k)|^2 = \min \quad (2)$$

where  $k$  counts the pixels taken into account,  $s_k$  denotes the raw sensitivity value of the  $k$ -th pixel,  $x_k, y_k$  its coordinates and  $w_k$  a weighting factor given by the product of a gaussian kernel centered at  $x_0, y_0$ , and the 'reliability' of  $s_k$ , derived from the signal strength in the body coil image. The width of the gaussian corresponds to the degree of smoothing. The minimum condition (2) yields  $L^2$  linear equations:

$$\frac{\partial \Delta}{\partial c_{ij}} = 0 \Rightarrow \sum_{i',j'=0}^L c_{i'j'} A_{ii'jj'} = b_{ij} \quad (3)$$

where

$$A_{ii'jj'} = \sum_k w_k (x_k - x_0)^{i+i'} (y_k - y_0)^{j+j'} \quad (4)$$

$$b_{ij} = \sum_k w_k s_k (x_k - x_0)^i (y_k - y_0)^j \quad (5)$$

Solving the equations (3) for  $c_{00}$  yields the desired refined sensitivity value at the position  $x_0, y_0$ .

The basic version of the fitting algorithm as described here would be unfavourably time-consuming. However, run time is reduced to a convenient range by considering only significant terms of the sums in (4),(5) and by restricting high order fitting to border regions.

## RESULTS

The discussed method has been used to determine sensitivity maps both for conventional intensity correction and for reconstruction of images from sensitivity encoded data. Fig.2 demonstrates intensity correction of

a gradient echo phantom image acquired with an array of five surface coils positioned around the object. Sensitivity maps were determined using low resolution references and first order fitting. The corrected image exhibits 'true' intensity according to comparison with body coil images. Despite of map smoothing no edge enhancement is observed.

Fig. 3 shows an example of image reconstruction making use of sensitivity information. Conventional reconstruction of three-fold undersampled data from five coils yielded the sum-of-squares image depicted in Fig.3a. According to the image domain formulation of aliasing [4,5] full FOV images were calculated using sensitivity maps of different fitting order. The need for highly accurate maps is illustrated by residual foldover artifacts in the image obtained with a zeroeth order fit (Fig.3b). Second order fitting eliminated aliasing (Fig.3c).

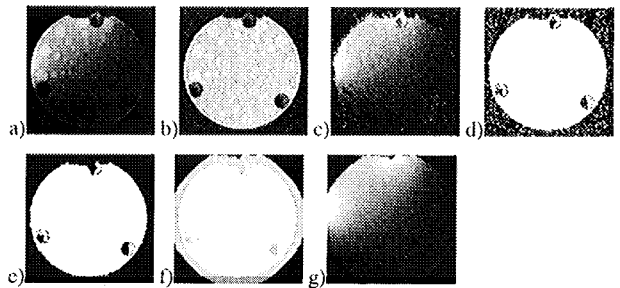


Fig.1 Sensitivity determination:

a) Surface coil image b) Body coil image c) Raw sensitivity map  
d) Thresholding e) 'Minimum neighbourhood' filtering  
f) Region growing g) Resulting sensitivity map

## DISCUSSION

It has been demonstrated that excellent intensity correction is obtained using the presented method for the determination of sensitivity maps. Nevertheless, the actual goal of this work was to provide highly accurate maps in order to enable sensitivity based image reconstruction. It has been shown that zeroeth order fitting is liable to cause residual foldover artifacts. Higher order fitting yielded sufficiently precise maps for reconstruction free of visible artifacts.

In conclusion, a crucial step in the processing of sensitivity encoded data is accomplished by the discussed local fitting procedure.

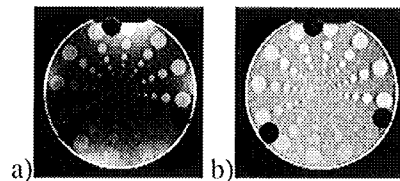


Fig.2 Intensity correction using first order fit

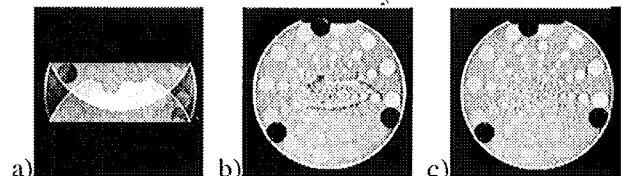


Fig.3 Reconstruction from sensitivity encoded data using  
a) zeroeth order fit b) second order fit

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