Simplified and Higher Degree-of-freedom Correction Method of Spatially Inhomogeneous Noise on Parallel MR Images obtained with Surface Array Coils

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Introduction

Parallel imaging (PI) [1] and standard surface-coil imaging suffer from degradation of image quality due to spatially inhomogeneous noise distribution attributable to inhomogeneous coil sensitivity. Generally, spatially variant filters depending on signal sensitivity distribution can be used to improve such images. However, it requires specific implementations and is difficult to apply generally developed image filters. The purpose of this study is to propose a simplified and higher degree-of-freedom correction method to improve spatially inhomogeneous noise by using standard spatial filters, including adaptive type filters as well as linear space invariant (LSI), which were developed to apply on homogeneous noisy images.

Theory and Methods

Theory: Schematic of flow chart of our proposed correction method is shown in **Fig.1**. First, sensitivity corrected image S_{scor} is obtained from original S_{orig} using normalized sensitivity map I_{sens}. Second, SNR weighted window function W_{snr} is calculated using I_{sens}. If SNR depends only on the coil sensitivity, window becomes $W_{snr}=I_{sens}$. In parallel imaging in which noise distribution is characterized by g-factor I_g [1], windows becomes $W_{snr}=1/I_g$. Third, filtered image $S_{scor.fil}$ is obtained by processing S_{scor} with smoothing type uniform filtering operator H as $S_{scor.fil}=H[S_{scor}]$, where 'uniform filter' was defined as a filter which doesn't require sensitivity map while filtering process.

Therefore various kinds of filters designed regarded as homogeneous noise distribution, for example, LSI type, and adaptive type, can be used. Finally, weighted summation of S_{scor} and $S_{scor.fil}$ is performed using W_{snr} so that the weight on the filtered components is made larger as the SNR of the portion of S_{scor} is lower shown as $S_{nonuni\_fil}= W_{snr} S_{scor} + (1-W_{snr}) S_{scor.fil}$. It is possible to apply extra uniform filtering after this process if necessary. Here each notation except for filter operator H is a function of spatial distribution (x,y,z).

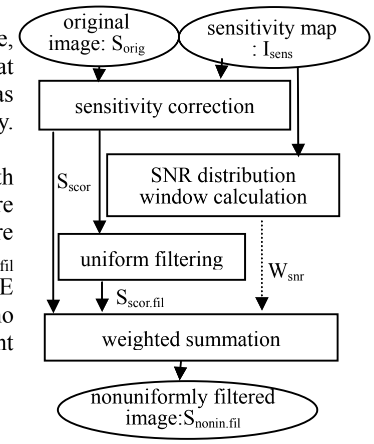

Fig.1 Flow chart of nonuniform filtering

Experiments: S_{orig} was obtained by adding Gaussian noise on the abdominal axial T1 weighted image with sufficiently higher SNR PI before sensitivity correction. Then sensitivity was corrected by $S_{scor}=I_{sens} S_{orig}$. Here W_{snr} was calculated as $W_{snr}=\{I_{sens} - min(I_{sens})\}/\{max(I_{sens}) - min(I_{sens})\}$. Two types of filters, LSI and structure adaptive filter [2], were used for H. Uniformly filtered image $S_{scor.fil}$ and nonuniformly filtered image $S_{nonuni.fil}$ with two types of filters were compared. Smoothing strengths of both types of filters were varied, then RMSE between every filtered image and ideal image for whole pixels was calculated as a function of noise SD in no signal region, where noise SD in no signal region was regarded as indexes of smoothing strength of different type filters.

Results and Discussions

Typical results of images are shown in **Fig.2**. Smoothing strengths of those uniform filters were nearly same by coincided both the noise SD of $S_{scor.fil}$. In LSI filters (**b**,**c**), although uniform filter (**b**) improved SNR but caused blur in the higher SNR portion compared with the proposed method (**c**). Structure adaptive filter **(e,f)** reduced blur compared with the results of LSI filters even in the uniform filtering (**e**), however, strong smoothing caused blur in the higher SNR portion such as abdominal and back wall. On the other hand, the proposed method (**f**) could preserve those edge informations and resulted in the best among those four images. In comparison with smoothing strength shown in **Fig.3**, RMSE of the nonuniform filtering was smaller than that of uniform filtering for both LSI and adaptive type. Minimum error was almost the same for both types, however, the adaptive filter showed robustness against the variation of smoothing strength. In conclusion, we confirmed that our proposed method could improve spatially inhomogeneous noise with preserving higher frequency information on PI, and LSI as well as adaptive filters could be applied. Proposed method has easy and higher degree-of-freedom implementations on commercial MRI, because general-purpose de-noising filters can be used without any specific modification and it can be implemented on real-space as well as k-space. Faster processing is also expected.

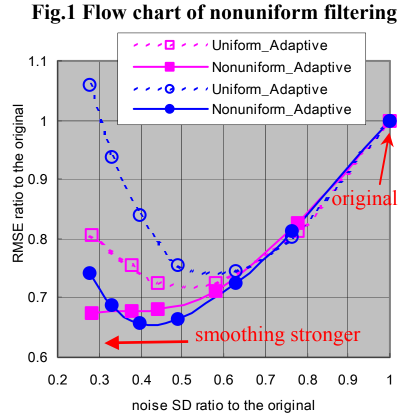

Fig.3 RMSE as a function of smoothing strength

References:

[1] *Pruessmann KP et al. MRM 42:952-962 (1999)* , [2] *Chen H et al. MRM. 33:534-540 (1995)*

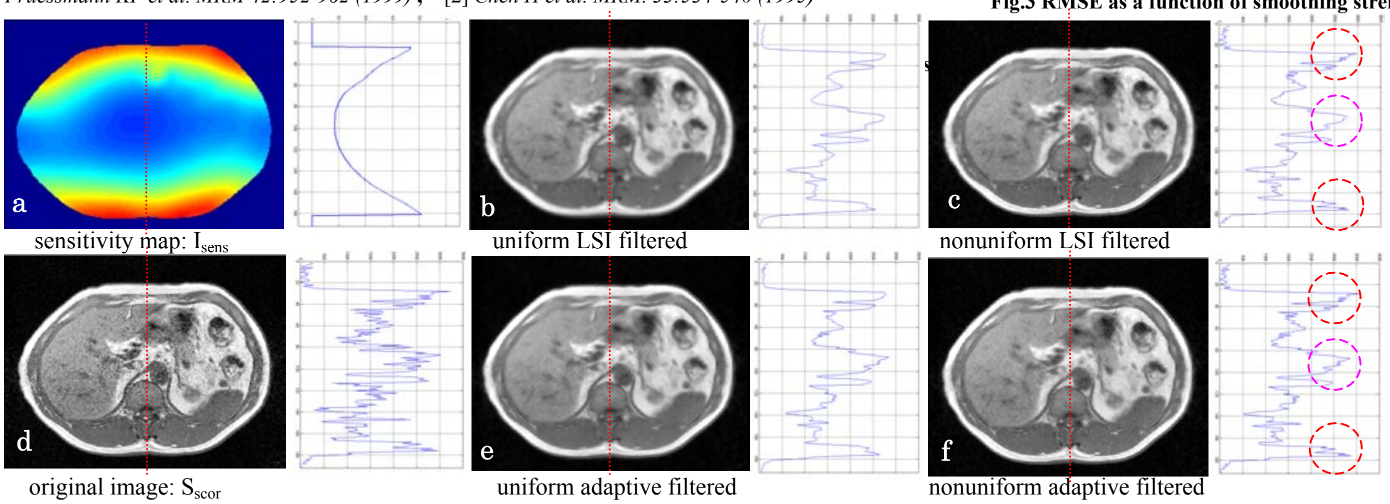

Fig.2 Example of correction results for PI. The images **c** and **f** obtained by proposed method resulted in better performance than **b** and **e**, respectively, because noise was reduced in the lower SNR portion (center of body) (pink dotted circle) with preserving edge information on the higher SNR portion (abdominal and back wall) (red dotted circle) of image. Blurring in lower SNR portion in **f** was minimized compared with **c**.