SNR Improvement by Modification of Wiener Filter for the Applications of Acquiring Multiple Similar Data: Application to Diffusion Tensor Imaging

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Introduction

Wiener filter (WF) is a filter which can control SNR optimally by using signal power Ps and noise power Pn of acquired data as defined ideally as Hw_i=Ps/(Ps+Pn) [1]. The Ps in the ideal type WF requires noise-free signal, though it's impossible to obtain ideal signal in practical medical imaging. To reduce noise effects on Ps, several techniques, such as threshold type WF (Hw_t=max(Ps-Pn,0)/Ps) [2] and the method of calculating Ps after smoothing, have been proposed. Here we proposed a modified WF method of further improving SNR for specific applications, in which multiple similar images are acquired. We assessed our proposed method on 1D simulation data and diffusion tensor imaging (DTI) data.

Theory and Methods

In general, lower frequency components cause little effects on the WF gain because of the ratio Ps/Pn is sufficiently larger, though, higher frequency components dominantly affect on the WF gain because the Ps/Pn reaches one or below. Consequently, reduction of noise effects on Ps is very important for improving SNR of subject data and for remaining higher frequency structure. Here SNR of data for calculating Ps was defined as PsSNR in distinguish from SNR of subject data. In our proposed method, for the purpose of improving PsSNR, Ps is calculated after averaging multiple data having similar characteristics, which we called 'mean-Ps' method. Methods for calculating Ps using just single subject data and using ideal data are called 'same-Ps' and 'ideal-Ps' methods, respectively.

Two types of gain control equations in WF, Ideal type Hw_i and threshold type Hw_t, and two types of filtering spaces, standard Fourier transformed space (FT-WF) and band split space after Fresnel transform (FR-WF) [2], totally four combinations, were evaluated. Compared with FT-WF, FR-WF has an advantage of de-nosing performance with minor reduction of higher frequency structures. Following indexes were used for quantitative comparison: SNR improvement ratio (SNRIR=$RMSE_{orig}/RMSE_{cor}$) as an index of including both noise and blur, and noise improvement ratio (NIR=SD_{orig}/SD_{cor} where SD_x was measured in no signal region) as an index of noise reduction.

a) 1D simulation using 1D rectangular profile added Gaussian noise:

For the purpose of assessing mean-Ps method, SNRIR was obtained as a function of PsSNRR (= $PsSNR_{cor}/PsSNR_{orig}$), where PsSNRR=1 corresponds to the same Ps method. The SNR of original data was set at 20.

b) Evaluation of DTI: One T2W and Six different DWI with b=1000[s/mm^2] brain images based on the 14-sided regular polyhedron method [3], which were acquired with single-shot SE-EPI with sufficiently higher SNR on 1.5T Excelart imager (Toshiba), were used. Gaussian noise set at SNR=20 was added before sinc interpolation from 128x128 to 256x256. The Ps data for mean-Ps method was obtained by averaging seven images. RMSE between filtered DWI and ideal DWI and each noise SD were compared. After filtering seven images, Fractional anisotropy (FA) maps were calculated and compared.

Results and Discussions

In 1D simulation (**Fig.1**), The SNRIR of Wi type particularly in FR-WF became larger than that of Wt type when PsSNRR was larger. The SNRIR were saturated when PsSNRR was over 5 in this data. Although those results may depend on the structure and SNR of subjects, those characteristics will be the same in any data. In the results of DTI data (**Fig.2** shows an example of DWI**, Table1** shows those SNRIR and NIR), the mean-Ps method improved SNRIR at the comparable level of the ideal-Ps method both for FT-WF and FR-WF. The FR-WF provided higher SNR than the FT-WF. Small reduction of SNRIR by the mean-Ps method from the ideal-Ps method was due to the difference of those two Ps, however, those effects were minor compared with the SNRIR by the same-Ps method. The higher the spatial resolution of subject image, the higher SNRIR improvements will be provided. We concluded that the proposed method of improving performance of the Wiener filter, by using higher SNR Ps data with averaging similar data, is very useful technique for DTI data as an example of acquiring multiple similar data. This technique can also be applied to another applications such as dynamic MRI and f-MRI.

Acknowledgements:

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References:

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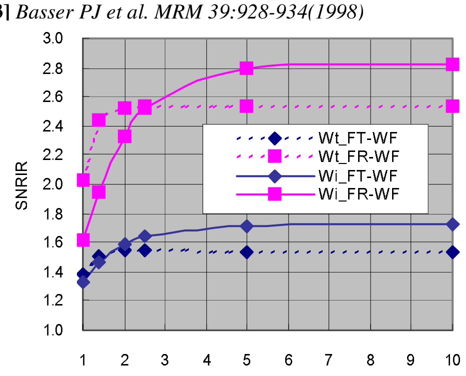

Fig.1 SNR improvement ratio (SNRIR) to the original of 1D noisy rectangular profile for four kinds of Wiener filter as a function of SNR ratio to the original of data for signal power Ps (PsSNRR).

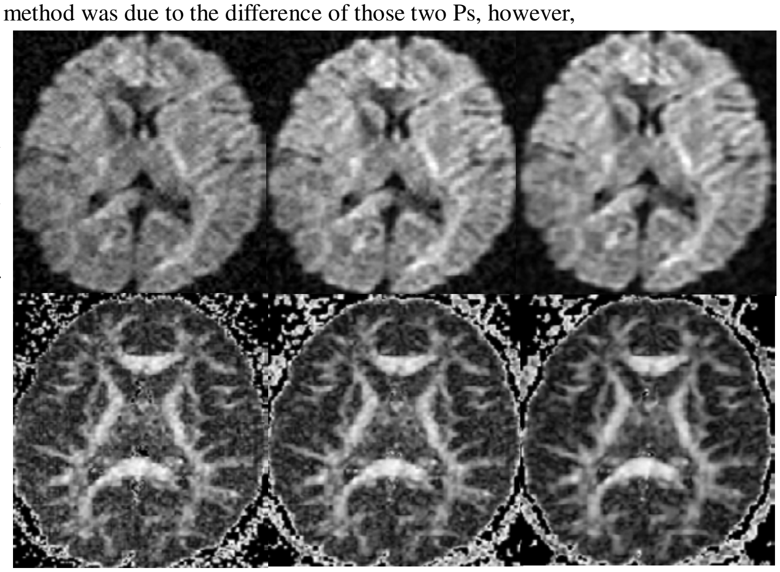

Fig.2 DWI (top) and FA maps (bottom) obtained by original, and filtered images using ideal type FR-WF with conventional method of same-Ps and proposed method of mean-Ps (left to right).

Table1. Improvement ratio of SNR and Noise for DWI image using deal type WF.

Index		original	FR-WF samePs	FR-WF meanPs	FR-WF idealPs	FT-WF samePs	FT-WF meanPs	FT-WF idealPs
SNRIR	to original	1.00	1.26	**1.54**	1.64	1.22	**1.42**	1.53
	to samePs	0.80	1.00	**1.23**	1.31	1.00	**1.17**	1.26
NIR	to original	1.00	1.35	**1.79**	1.79	1.32	**1.67**	1.68
	to samePs	0.74	1.00	**1.33**	1.33	1.00	**1.27**	1.27