Removing Signal Intensity Inhomogeneity from Surface Coil MRI Using Discrete Wavelet Transform and Wavelet Packet

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Abstract- We evaluate a combined discrete wavelet transform (DWT) and wavelet packet algorithm to improve the homogeneity of magnetic resonance imaging when a surface coil is used for reception. The proposed algorithm estimates the spatial sensitivity profile of the surface coil from the original anatomical image and uses this information to normalize the image intensity variations. Estimation of the coil sensitivity profile based on the wavelet transform of the original image data is found to provide a robust method for removing the slowly varying spatial sensitivity pattern.

Keywords - MRI, wavelet packet, discrete wavelet transform, surface coil

I. INTRODUCTION

Surface coils offer the potential for a 2 to 5 fold increase in sensitivity compared to volume coils. Despite of this signal-to-noise advantage, surface coils are not used regularly for many applications because of their small region of coverage and their intrinsically inhomogeneous reception profile. The limited coverage of a single small surface coil can be extended by using a phased array of multiple coils [1]. The phased array technique also improves the homogeneity of the images in the plane of the array, but the image intensity is still significantly brighter near the coils than deeper in the brain. Thus, the surface coil detector has an inherently inhomogeneous reception profile that leads to a variation in intensity across the image. This significantly degrades the utility of the images for evaluation of pathology in the cortex.

To correct the inhomogeneity of the surface coil MRI due to the modulation of coil reception sensitivity profiles, several approaches have been studied to estimate the coil profile, which is used to correct the measured inhomogeneous MRI [1-12]. These methods use either a theoretically generated model [1, 3, 13] of the coil or the information in the image itself [2, 4, 6-8] to generate the expected coil sensitivity map. In the first case, knowledge of the location and orientation of each surface coil is required in addition to a B1 field map generated from the coil geometry. In the second case, the coil intensity profile can be approximated by a low-pass filtered version of the original image. The low pass filter based approximation of the surface coil profile requires a priori knowledge of the anatomy and coil fall-off in order to determine the appropriate cut-off spatial frequency which separates the low frequency variations due to coil fall off from the higher spatial frequency variations due to the anatomy.

Here we propose a solution to correcting surface coil image intensity variations using post-hoc processing of the original surface coil image. The method identifies edges in the image and uses this information to improve the estimation of the coil sensitivity map. The slowly varying intensity

II. METHODOLOGY

The images from a surface coil can be viewed as the product of the true anatomical image and a function representing the spatial modulation imposed on the image by the surface coil reception profile. Thus, the true homogeneous image, \( C[\vec{n}] \), is modulated by the coil sensitivity, \( S[\vec{n}] \), to generate the observed inhomogeneous image, \( Y[\vec{n}] \), where \( \vec{n} \) is the position vector in 3D space. Thus our goal is to get an estimate, \( \hat{S}[\vec{n}] \), of the true coil sensitivity profile, \( S[\vec{n}] \). The corrected reconstruction image, \( \hat{C}[\vec{n}] \), which represents an approximation of the true anatomical image is then expressed in terms of the ratio of the original data \( Y[\vec{n}] \) and the estimated coil sensitivity profile.

\[
\hat{C}[\vec{n}] = \frac{Y[\vec{n}]}{\hat{S}[\vec{n}]}, \vec{n} \in R^3
\]  

Estimation of coil sensitivity profile using discrete wavelet transform (DWT) has been reported in our previous publication [14] Figure (1) illustrates the algorithm. The advantage of this proposed algorithm is the automatic multiple-level coil sensitivity profile estimation adapted to different imaging protocols, since no prior knowledge about the coil position, orientation, and geometry is assumed in the algorithm. Also, we applied an iterative maximum projection on each level of coil sensitivity profile estimation in DWT to avoid the underestimation of coil sensitivity at the vicinity of high contrast brain-air boundary.

However, conventional DWT limits the spatial frequency resolution because only the low-pass bands are iteratively decomposed. On the other hand, wavelet packet algorithm can improve the frequency resolution by further decomposing other subbands. Our previous DWT algorithm can search the
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**Title and Subtitle**
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Boston University, MA

**Performing Organization Report Number**

**Sponsoring/Monitoring Agency Name(s) and Address(es)**
US Army Research, Development & Standardization Group
PSC 802 Box 15 FPO AE 09499-1500

**Sponsor/Monitor's Acronym(s)**

**Sponsor/Monitor's Report Number(s)**

**Distribution/Availability Statement**
Approved for public release, distribution unlimited

**Supplementary Notes**
Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.

**Abstract**

**Subject Terms**

**Report Classification**
unclassified

**Classification of Abstract**
unclassified

**Classification of this page**
unclassified

**Limitation of Abstract**
UU

**Number of Pages**
4
optimal level of DWT estimation. Therefore we increase the spatial frequency estimation using wavelet packet between one level above and one level below the optimal level determined by the DWT-based estimation. This combined DWT-wavelet packet approach can thus estimate the coil sensitivity profile with computational efficiency and with improved estimation accuracy.

Figure 2 illustrates the details about incorporating wavelet packet analysis in DWT estimation of the coil sensitivity profile. Here we assume that level 2, which has an equivalent cut-off frequency at pi/4, is the given optimal level from the DWT estimation. To search a possibly better solution than the one found in DWT, we decompose one level above and below the optimal level into subbands (between thin dashed lines) for finer spatial frequency resolution, which is implemented by wavelet decomposition on both high-pass and low-pass bands of signal in each dimension. After zeroing out the high-pass information, spatially slowly varying coil profiles are reconstructed from the wavelet packets coefficients (the light gray area), in addition to the DWT decomposition coefficients (the dark gray area).

Daubechies 9/7 filter banks [15] were used in the estimation of the coil sensitivity map using wavelet packets. This filter bank has three vanishing moments to provide smooth cubic polynomial approximation of the input signal. Intel Pentium® III processor (Santa Clara, CA) and Matlab (Natick, MA) were used in implementation environment.

III. RESULTS

Image acquisition

Images were acquired using a General Electric Signa 1.5T scanner (Milwaukee WI) with a home built four-element bilateral surface coil array. The array elements consisted of overlapping 8cm diameter surface coils. The imaging pulse sequence was either a spoiled gradient echo (SPGR) 3D volume exam (TR/TE/flip = 40ms/6ms/30°), partition thickness = 1.5mm, matrix = 256 x 256, 124 partitions, Field of View = 18cm. The array elements were placed over the subject’s temporal lobes.

Image inhomogeneity correction

Our previous DWT-based results revealed that for the input image acquired from the bilateral phased array with image matrix of 256 X 256 pixels, level 5 gives the optimal estimation of the coil sensitivity profile in terms of the most homogeneous reconstructed image. This DWT estimation of coil sensitivity profiles and the associated corrected images are shown in Figure 3.

Given level 5 being the optimal level of reconstruction from DWT, we decomposed the images between level 4 and level 6 using Daub 9/7 filter bank for finer spatial resolution. 2 levels of wavelet packets were performed between level 5 and level 6 to generate 4 frequency bands between pi/16 and pi/32. Additionally 3 levels of wavelet packets were performed between level 4 and level 5 to generate 8 equal bandwidth analyses between pi/8 and pi/16. Totally 13 reconstructions were obtained with equivalent cut-off frequency between pi/32 and pi/8, and they are shown in Figure 4.

After correction, visualization of the temporal and frontal cortex and deep sub-cortical structures including putamen and caudate body is considerably improved. To numerically assess the improvement in homogeneity, the image intensity before and after correction was scaled so that the mean pixel value in the caudate nucleus was 70.0. Frontal white matter near the caudate then had a mean pixel value of 100.0 in both images. With the before and after images scaled to provide the same caudate to white matter contrast, the image correction method was found to reduce the peak to peak
variance in the brain parenchyma by a factor of 17. Also, we created a brain parenchyma mask excluding the background, scalp, skull and cerebrospinal fluid space to quantify the variance change after the correction. The image with smaller variance inside the brain parenchyma mask is considered to be more homogeneous. The 6th wavelet packet reconstruction, which has an equivalent cut-off frequency of $21 \cdot \pi / 128$, provides a more homogeneous image than the DWT optimal level 5, which has a cut-off frequency of $\pi / 16$. This is shown in Figure 5.

Fig. 3 Estimated sensitivity profiles of 8 levels of DWT decomposition and reconstruction. Level 5 is the optimal estimation in that the corrected image has minimum image variance.

IV. CONCLUSION

In this paper, we propose an automatic method to correct the inhomogeneity of surface coil MRI using a combined discrete wavelet transform and wavelet packet analysis for finer spatial resolution as we estimation the coil sensitivity profile. The Daubechies 9/7 filter bank was found to have good computational efficiency and approximation of coil sensitivity map. The method uses neither prior physiological knowledge nor knowledge of the electro-magnetic properties or locations of the RF coil. Reconstructed images show improved visibility, which allows region near the coils to be viewed with the same window and level settings as regions far from the coil. This improves visualization of the cortical areas and deep gray structures in the basal ganglia.

Fig. 4 Eight levels of correction by Daub97 filter bank using DWT. Reconstruction at level 5 (cut-off frequency $\pi / 16$) provides the optimal reconstruction in terms of user-defined ROI homogeneity.

Fig. 5 Thirteen inhomogeneity-corrected images by wavelet packet estimation of coil sensitivity profile using Daub97 filter bank between DWT level 4 (cut-off frequency $\pi / 8$) and DWT level 6 (cut-off frequency $\pi / 32$). The 6th wavelet packet reconstruction (in solid frame; cut-off frequency $21 \cdot \pi / 128$) provides better coil sensitivity profile estimation than the DWT optimal level 5 (in dashed frame) in terms of smaller brain parenchyma variance.
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