Reconstruction in Image Space using Basis Functions (RIB): Eigenmode Analysis Method

Y. Li[1], S. Vijayakumar[1], and F. Huang[1]
[1]Advanced Concept Development, Invivo Diagnostic Imaging, Gainesville, FL, United States

Introduction: Theoretically, SENSE reconstruction is optimal for partially parallel imaging (PPI). Practically, however, the clinical applications of SENSE are significantly limited by two factors: 1) unavailability of an accurate sensitivity map; 2) g-factor noise. In this study, these limitations are overcome by introducing a new image-space reconstruction method, Reconstruction in Image space using Basis functions (RIB). Unlike SENSE, RIB does not rely on the accuracy of sensitivity maps, but requires the design of a set of basis functions to optimize the reconstruction matrix. An Eigenmode analysis method is developed to automatically generate the basis functions from the calibration data [1]. Using a least square method, RIB can optimize the reconstruction matrix for every local region in the image space and a full image can be reconstructed region by region. From experiments, it is observed that the Eigenmode-based RIB can effectively reduce the noise and artifacts in SENSE reconstruction when the same set of sensitivity maps is used.

Theory and methods: An image reconstruction using RIB can be represented in matrix form by:

$$Y(\vec{r}) = \left[F(\vec{r})\right]\left[A\right]\left[S(\vec{r})\right] \qquad (1),$$

where $\vec{r}$ is a space vector in image space, $Y(\vec{r})$ is the reconstructed image, $\left[S(\vec{r})\right]$ ($N\times1$ matrix) represents the N images reconstructed from N-channel undersampled data, $\left[A\right]$ ($M\times N$ matrix) is an unknown coefficient matrix, and $\left[F(\vec{r})\right]$ ($1\times M$ matrix) is a set of pre-defined basis functions. A set of calibration data, acquired at an adequate sampling rate and with a low spatial resolution, can be used to find the optimal coefficient matrix by minimizing the sum of square error:

$$\left[A^*\right] = \underset{\forall[A]}{\arg\min}\left\{\int_{ROI}\left(\left[F(\vec{r})\right]\left[A\right]\left[S_x(\vec{r})\right] - X(\vec{r})\right)^2 d\vec{r}\right\} \qquad (2),$$

where $X(\vec{r})$ is a low-resolution image reconstructed from the calibration data, $\left[S_x(\vec{r})\right]$ is the images reconstructed from an undersampled version of the calibration data, and *ROI* represents the region of interest. By comparing RIB and SENSE, it is found that a solution to the basis functions in Eq. (1) can be the Eigenvectors of the sensitivity matrix. This provides a means for RIB to automatically generate the basis functions. Physically, the Eigenvectors of the sensitivity matrix correspond to the Eigenmodes of the RF coil array and hence; this method is termed as Eigenmode analysis in this work. [1]. Sensitivity maps are calculated from the calibration data. Eigenmode analysis is applied to the sensitivity-map data. The stronger Eigenmodes are used as the basis functions in RIB reconstruction. An optimal coefficient matrix is estimated using Eq. (2). The image is reconstructed using Eq. (1). RIB images are compared with SENSE images.

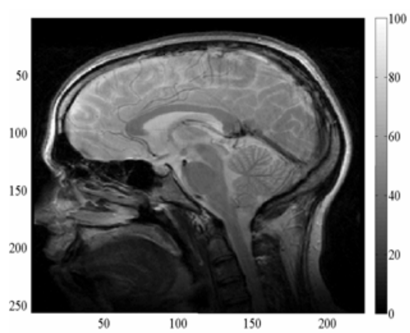
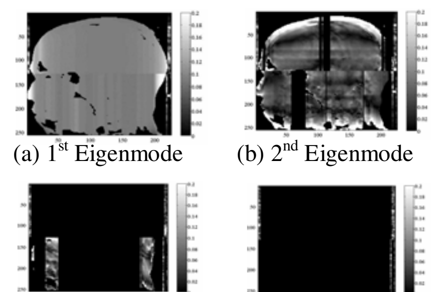


Fig. 1 High-resolution image.



(a) 1st Eigenmode (b) 2nd Eigenmode (c) 3rd Eigenmode (d) 4th Eigenmode

Fig. 2 Basis functions for RIB.

Results and Discussion: Fig. (1) shows a high-resolution brain image acquired using a 4-ch head coil with an adequate sampling rate. This set of data was downsampled to generate the PPI data needed for this study. Fig. (2) shows the basis functions generated from the calibration data by Eigenmode analysis. A black region means that the corresponding Eigenmode is discarded in that region. It can be seen that only two low-order Eigenmodes remain in most regions. In high-order Eigenmodes, noise dominates the signal and hence; the noise level in reconstruction can be reduced if only low-order Eigenmodes are used. Fig. (3) shows the reconstruction results from a set of PPI data with a reduction factor of 3. Figs. 3(a) and 3(b) are the SENSE image and relative error image. Strong noise and artifacts, caused by inaccurate sensitivity maps and/or high g-factor, can be clearly seen in the relative error image. Figs. 3(c) and 3(d) are the RIB-reconstructed image and corresponding relative error image. It can be seen that the noise and artifacts are significantly reduced.

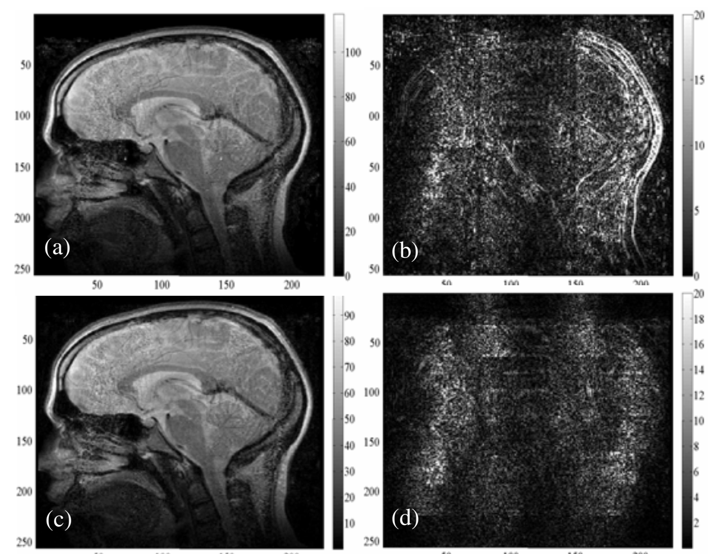


Fig. 3 Reconstruction results using SENSE and RIB.

Conclusions: In this study, an Eigenmode analysis method is developed for RIB reconstruction. This method can automatically generate a set of basis functions and provide a means to denoise the reconstructed image. Because a least square method is used to estimate the reconstruction matrix, the accuracy of sensitivity maps is not critical in RIB. Compared with SENSE, Eigenmode-based RIB can effectively suppress the noise due to g-factor and the artifacts due to inaccurate sensitivity map, which enables further acceleration in clinical PPI using this technique.

Reference: 1). King S.B. et al. Pro c. ISMRM, p.712, 2003. 2). Prussmann , K.P. et. al., MRM 42: 952-962 (1999).