TOTAL CURRENT REDUCED DESIGN FOR BRAIN B_0 SHIM COIL USING SINGULAR VALUE DECOMPOSITION

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Introduction

Local B_0 shim coils placed close to the head have been shown to greatly reduce the B_0 inhomogeneity of the human brain [1-4]. Generally, large currents or complex current patterns are needed to compensate strong and localized B_0 inhomogeneity as such in the prefrontal cortex. For multi-coil array approaches [1,4], complex patterns are made by placing large number of channels, generally 32 or more. However, the total current increases according to the number of channels. Recently, singular value decomposition (SVD) has been shown to be a powerful tool to analyze current efficiency, and has been applied to design of and assessment for gradient coils [5,6]. Here, we applied SVD to design a total current reduced brain B_0 shim coil. This abstract aims for MR engineers interested in B_0 shim coil design.

Methods

Coil design: An 18ch B_0 shim coil was designed by reducing the number of channels from an initial state of 50ch (100 turn loop each) using SVD. The initial state consisted of a 48ch multi-coil array (MCA) as in ref. [1] and 2 concentric coils above the head targeted for the prefrontal cortex. The magnetic field B_z of each channel per unit current was calculated and stored as a real valued matrix A with a size of the number of channels by the number of voxels of the region of interest (ROI). ROI was set to an axial slice close to the ethmoid sinus, where the total current tends to increase because of the strong and localized B_0 inhomogeneity. Applying SVD to matrix A gives $A = USV^*$, where U describes the eigen modes (orthogonal magnetic fields), S is the singular values, and V is the current distribution of the eigen modes. The eigen mode strength [5], which describes how close each eigen mode is to the target map, is given by $D = U^*B$, where B is the target B_0 map of the ROI. By selecting modes in descending order of $|D|$, the maximum current among the 50ch increased as shown in Figure 1 (a). Limitation current of 1 A was set as a threshold for truncation. Truncating higher order eigen modes which require larger currents is the key to reduce the total current. Fig. 1 (b) shows shim currents using the top 7 modes in descending order of $|D|$. Elements with similar currents were combined, forming an 18ch B_0 shim coil as shown in Fig. 2 (A) (hereafter, shim coil (A)).

Evaluation: Shim coil performance was simulated by shimming experimental B_0 maps of 3 human brains acquired at 1.5 T (ECHELON Vega®, Hitachi Medical Corporation, Japan) without any shimming. We compared spherical harmonic (SH) shimming and 3 local shim coils (Fig. 2). Fig. 2 (B), (C) show schematic diagrams of conventional local shim coils of a 48ch MCA (100 turn loop each) [1] and a 32ch RF-shim array (1 turn loop each) [4], respectively (hereafter, shim coils (B) and (C)). SH shimming was simulated off-line with 1st and 2nd order B_0 maps of the scanner. All local shim coils used Biot-Savart-generated field maps and the shim currents were optimized with the scanner's SH shimming used at the same time. Shim currents were calculated with constrained optimization of <1 A per channel for shim coils (A), (B) as in ref. [1], and <2.5 A per channel for shim coil (C) as in ref. [4]. ROI was set to a challenging slice 5 mm from the edge of the ethmoid sinus for all 3 human cases. Residual B_0 maps were analyzed for shimming performance and the shim currents were analyzed for total current comparison. All simulations were performed in Matlab (Mathworks, Natick, USA). Experimental data were obtained according to the regulations of our institutional review board.

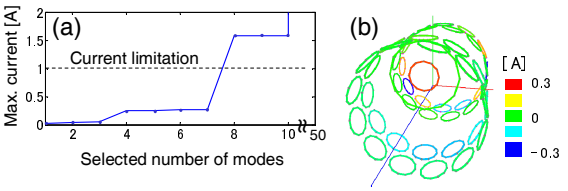

Fig. 1. B_0 shim coil design using SVD. (a) Maximum current of the 50ch initial state versus selected number of eigen modes. (b) Referred shim currents using top 7 eigen modes.

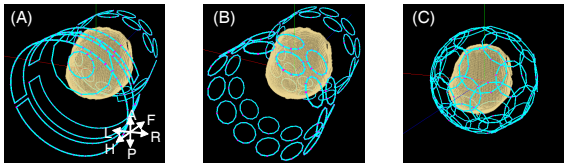

Fig. 2. Configuration of B_0 shim coils and the brain. (A) Proposed 18ch shim coil designed using SVD, and reference coils of (B) 48ch MCA, and (C) 32ch RF-shim.

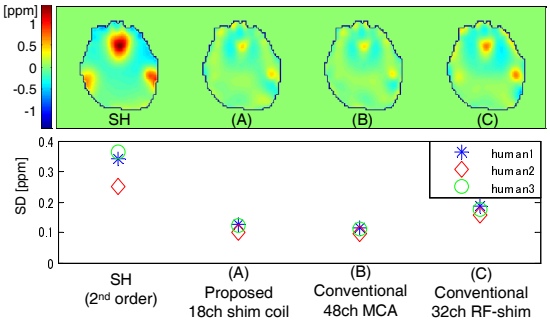

Fig. 3. Simulated B_0 shimming performance. (Top) Residual B_0 maps for human1. (Bottom) Standard deviation of single slice shimming for 3 human cases of each shim coil.

Results and Discussion

Fig. 3 shows simulated B_0 shimming performance. Compared to 2nd order SH shimming, all local shim coils (A), (B) or (C) improved B_0 homogeneity for all cases. The proposed shim coil (A) reduced the standard deviation more than shim coil (C), and as much as shim coil (B) for all cases despite of having fewer channels. Fig. 4 shows the total current of the 3 local shim coils. Shim coil (A) had the least total current. The total current of shim coil (C) increased because single loop coils need more current for adequate B_0 shimming performance for a slice close to the sinus. The total current of (A) to (B) was reduced by a quarter which is more than the decrease of the number of channels. This was because the efficiency increased by reducing compensating currents running in opposite direction in neighbor coils of the array.

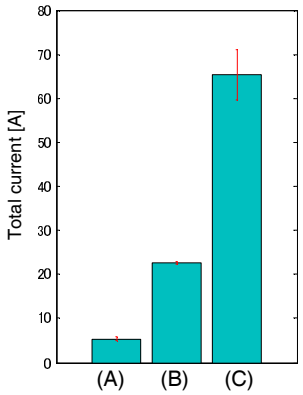

Fig. 4. Total current of 3 local shim coils, (A) Proposed 18ch shim coil, (B) 48ch MCA, (C) 32ch RF-shim. Plots show mean values and error bars for 3 human cases.

Conclusion

We applied SVD to design a total current reduced brain B_0 shim coil. Simulated B_0 shimming comparison showed that the proposed shim coil designed using SVD can greatly reduce the total current compared to conventional local shim coils while maintaining the B_0 shimming performance.

Reference

[1] Juchem C, JMR 212, 280 (2011). [2] Pan JW, MRM 68, 1007 (2012). [3] Harris CT, ISMRM, 11 (2013). [4] Stockmann JP, ISMRM, 400 (2014). [5] Abe M, ISMRM, 3794 (2011). [6] Littin S, ISMRM, 1471 (2014).