Realization of a synergistic passive and active shimming system to optimize B_0 field homogeneity in micro MR imaging

Rahul Dewal[1], Zhipeng Cao[2], Sebastian Rupprecht[3], and Qing X. Yang[1,3]
[1]*Bioengineering, Penn State College of Medicine, Hershey, PA, United States,* [2]*Institute of Imaging Science, Vanderbilt University, Nashville, TN, United States,* [3]*Radiology, Penn State College of Medicine, Hershey, PA, United States*

Introduction: The spherical harmonics-based B_0 active shimming methods developed for NMR spectroscopy in a uniform sample are known to be less effective for high-field *in vivo* MR imaging studies due to the localized, higher-order gradients present in regions near air-tissue interfaces, such as the paranasal sinuses and ear canals. Attempts have been made to address this issue with a passive shimming or localized active shimming approach, but current methods have lengthy calibration experiment requirements[1] or expensive hardware requirements[2]. Here, we present a synergistic shimming system that simultaneously optimizes the linear active shim coil settings and the passive shim element configuration for a specific subject. The shim configuration is implemented using a shim frame that fits to the animal bed and validated by demonstrating improved shimming in an *in vivo* mouse brain. This synergistic shimming approach is expected to be extensible to standard high-field MRI systems for both animal and human studies.

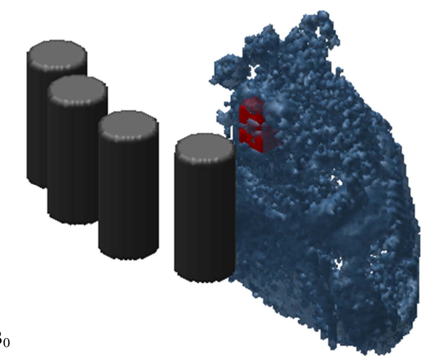

Figure 1. A stylized 3D rendering of the mouse geometry (blue), VOI (red), and shim elements. In this particular optimized shim configuration, all shim elements are graphite.

Methods: The synergistic shimming system optimizes the B_0 homogeneity within the desired volume of interest (VOI) by simultaneously varying the placement of cylindrical passive shim elements of varying lengths and the currents in the linear active shim coils. The two passive shim element types used in this study were graphite and titanium, experimentally measured to have effective magnetic susceptibility values of approximately -144 ppm and +175 ppm, respectively. The optimization method is comprised of two steps: In the first step, a novel VOI-based Fourier Transform method[3] is used to pre-calculate the shim fields of single passive shim elements of various sizes, positions, and magnetic susceptibility values. These shim fields are stored in a library that can be reused across multiple subjects. In the second step, the optimal combination of passive shim elements and active shim coil settings for the current subject is determined via linear superposition of the individual shim fields and evaluation of the variance of the resultant shimmed ΔB_0 field. The synergistic shim combination with the lowest variance within the VOI of the subject is considered to be optimal. All simulation and optimization experiments are performed using MATLAB (The MathWorks, Inc., Natick, MA).

In this study, the number of shim elements was limited to 4 for ease of implementation. The frontal region of an *in vivo* mouse brain was chosen as the VOI to be optimized. The optimized passive shim configuration as determined above was implemented using a home-made plastic shim frame that fits to the animal bed. It features plastic mounting rings and rods that may be used to precisely position the shim elements as well as fiducial markers to ensure correspondence between the simulated and experimental setups. Finally, the linear active shim settings of the MR system were set in accordance with those determined by the synergistic optimization. A 7 T Bruker animal MR scanner was used to acquire the ΔB_0 map data.

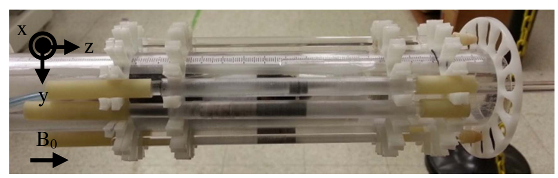

Figure 2. The shim frame used to implement passive shim configurations. Shim elements are positioned using hollow plastic rods mounted onto the frame.

Results: Figure 1 shows the optimized configuration of the passive shim elements with respect to the mouse brain. Figure 2 shows the passive shim frame attached to the animal bed, with passive shim elements and fiducial markers mounted. Figure 3 shows ΔB_0 maps of the mouse with active shimming alone and with synergistic combined passive and active shimming. With linear active shimming alone, the B_0 field in the mouse brain remained inhomogeneous. Our algorithm was able to find simultaneous configurations of linear active shims and passive shim elements that reduced the overall B_0 inhomogeneity variance in the VOI by 25%.

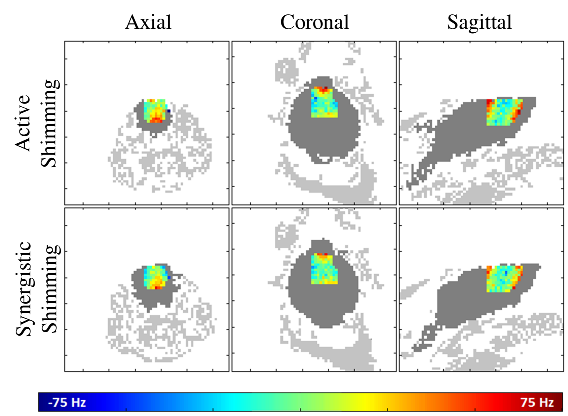

Figure 3. Synergistic passive and active shimming results in markedly reduced B_0 field inhomogeneity within the VOI, with a reduction in variance of 25%.

Discussion: We have developed a software and hardware system for synergistic passive and active shimming that can significantly improve B_0 homogeneity as compared to conventional active shimming. In practice, this should allow for more effective imaging artifact reduction and narrower MRS line widths in brain regions near air-tissue interfaces at high field. The initial B_0 map acquisition, optimization, and shim element placement can be performed within 20 minutes or less using a modern multi-core workstation, which should be adequate for most animal studies. For human studies, further speed improvement may be necessary, or the computation time can be offset by performing the computation while anatomical scans are being acquired.

An important advantage of the synergistic shim system is that, excluding the computer workstation, the hardware costs are low, as the plastics, tubing, and graphite and titanium rods are all widely available and inexpensive. This makes the system more accessible than high-performance active shimming systems that can cost tens to hundreds of thousands of US dollars.

Acknowledgments: Funding has been provided in part through NIH R01 AG027771, NIH R01 EB000454, and the Pennsylvania Department of Health.

References: 1. Koch et al. JMR 182 (2006) 66–74 2. Juchem et al. MRM 66 (2011) 893–900 3. Dewal et al., Proc. ISMRM (2013), p. 5145