Measurement of Field Variations Associated With Magnet Temperature Changes

A. M. El-Sharkawy[1], E. Atalar[1,2]

[1]Electrical and Computer Engineering, Johns Hopkins University, Baltimore, MD, United States, [2]Radiology, Johns Hopkins University, Baltimore, MD, United States

Introduction

MR thermometry [1] and fast EPI pulse sequences [2] used for functional magnetic resonance imaging (fMRI) are greatly affected by magnetic field inhomogeneities and variations. Such variations result in frequency and consequently phase variations. In proton resonance frequency (PRF) shift MR thermometry, changes in body temperature are detected via a linear relation between observed phase changes. A constant thermal coefficient of -0.01 PPM/^{0}C ($\Delta\Phi/\Delta T$) is used for the phase/temperature relation [3]. It has been previously shown that there are two major sources for frequency drifts [1]. First, oscillatory phase-drift behavior was observed and correlated to variations in the air-conditioning cycle of the electronic room. These oscillations have been dramatically reduced with advancements in the electronics of the receiver chain. Second, linear magnetic field drift has been attributed to normal magnet specifications. A correction method has been used by investigators to subtract the phase of a thermally insulated reference phantom. In this work we show that the changes in the field are not necessarily a simple uniform drift, but vary both spatially and temporally. The observed drift is directly correlated to changes in the temperature of the magnet resulting from gradient and RF heating. Such findings give a better understanding of the mechanism of field variation and enables better error correction strategies.

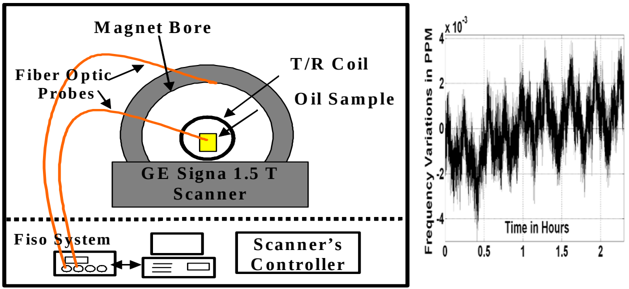

Figure 1: a. Experimental setup. **b.** Oscillating frequency variations determine the accuracy of measurements..

Materials and Methods

All experiments were performed on a GE Signa 1.5 T scanner with a Desc Conquest 1.5 T magnet manufactured in 1998. Figure 1a shows the experimental setup. A transmit/receive coil was used to avoid phase accumulations. Both the temperature of the bore of the magnet and the phantom were monitored using a fiberoptic sensor system (Fiso Inc.). Vegetable oil (100%) was used for all constructed phantoms because the resonance frequency of lipids is independent of their temperature [4]. This ensured that the detected frequency variations resulted solely from field changes.

To determine the accuracy of the scanner a cylindrical oil phantom 6cm in diameter and 6cm in height was placed at the iso-center of the magnet. The phantom and magnet were thermally stable and all of the gradients were shut off to avoid heating the magnet (we call this the "silent scan"). Spectral analysis was used to account for frequency variations. The detected accuracy of measurement was in the range of 0.005PPM (Figure 1b).

Using the same setup and by heating the phantom, the thermal coefficient of the oil was calculated as -0.001 PPM. This ensured that oil thermal variations did not contribute to observed field variations. To determine the relation between the temperature of the bore and the field changes, a gradient demanding pulse sequence was used to heat the scanner (Figure 2a). The pulse sequence was a balanced SSFP, 256x256, axial slice, TR/TE:5/1.8msec, ST: 3.5mm, FOV:28cm, FA:3^0, duration: 1hr. The scanner was left to cool and a silent scan was used to view the correlation between the temperature variations of the bore and field changes. Field drift direction was not directly correlated to the direction of the temperature drift in the first hour. This was attributed to the fact that the sensor's measuring point is located on a superficial point on the magnet. The total recorded variation was 0.7 PPM.

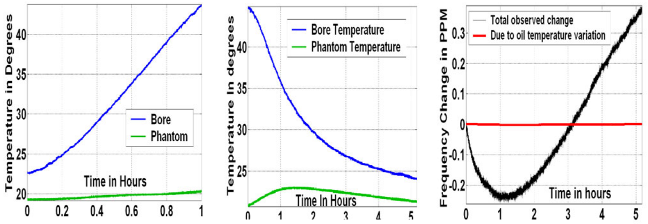

Figure 2: a. Sensor measurements for the heating of the bore of the magnet. **b.** Sensor measurements monitor the cooling of the bore of the magnet. **c.** Observed frequency variations.

Results

To view the spatial field variation, phase difference imaging (PDI), similar to PRF thermometry, was used. The scanner was first heated, then the field strength variations were monitored by PDI as the scanner was cooling using a very low heat generating pulse sequence. The sequence was an FGRE, 256x256, TR/TE:1000/1.8msec, FOV:32cm. The slice thickness (ST) gradient was shut off and ST was set by the phantom thickness to be 5mm. To monitor variations in the X-Z plane a 15X25 cm oil phantom was used (Figure 3). The field at each spatial location linearly drifted as the scanner cooled down. After 4 hours an almost linear spatial field variation of 0.05 PPM developed in the Z direction. Similarly, a circular oil phantom of 15cm in diameter was used to monitor variations in the X-Y plane (Figure 4). Again, the field at each spatial location linearly drifted with time and after 4 hours a linear spatial field variation of 0.05 PPM developed in the Y direction. No significant field variations were detected in the X direction. In Figure 4a some spatial nonlinearities are evident, resulting from non-uniformities in the constructed phantom.

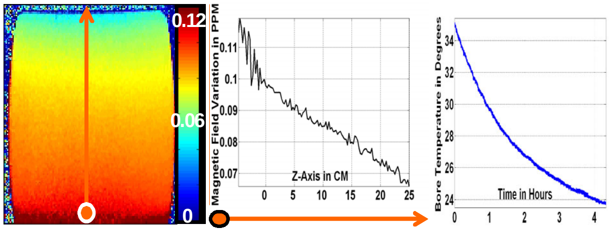

Figure 3: a. Magnetic field changes in the X-Z (coronal) plane after 4 hours. **b.** Plot showing variations in the Z direction at the middle of the phantom. **c.** The temperature of the bore of the magnet.

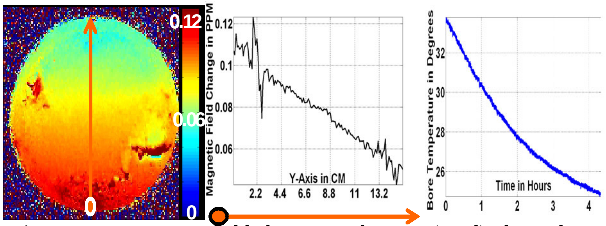

Figure 4: a. Magnetic field changes in the X-Y (axial) plane after 4 hours. **b.** Plot showing variations in the Y direction at the middle of the phantom. **c.** The temperature of the bore of the magnet

Discussion and Conclusion

The detailed mechanism behind the spatial and temporal field variations associated with magnet temperature changes depend on many engineering factors. We strongly believe that this mechanism is associated with the dimensional and magnetic property variations of passive metal shim parts. Therefore, in newer magnet designs, used in fMRI, passive shim trays should be avoided as much as possible [5]. The spatial characteristics of the field changes reveal the necessity for using at least 3 non-collinear phase references in the correction procedure for PRF thermometry (Y and Z direction). Further consideration is also necessary while using prolonged fMRI EPI pulse sequences on magnets that experience field variations from changes in the magnet temperature. Since the scanner heats up during daily procedures the magnetic field can vary depending on the scanner's thermal status. We believe that predetermining the nature of the field variations for magnets allows for devising the appropriate correction methods in phase sensitive pulse sequences.

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