Impact of Gradient Nonlinearity on the Accuracy of NMR Field Camera Readouts

Paul Chang[1,2], Martin Eschelbach[1], Roland Syha[3], Klaus Scheffler[1], and Anke Henning[1,4]

[1]*Max Planck Institute for Biological Cybernetics, Tuebingen, Baden-Wuerttemberg, Germany,* [2]*Graduate School of Neural & Behavioural Sciences, University of Tuebingen, Tuebingen, Baden-Wuerttemberg, Germany,* [3]*Diagnostic and Interventional Radiology, University Hospital Tuebingen, Tuebingen, Baden-Wuerttemberg, Germany,* [4]*Institute for Biomedical Engineering, UZH and ETH Zurich, Zurich, Switzerland*

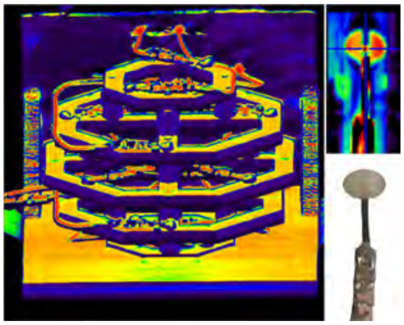

Fig. 1: Left: CT scan of a NMR field camera (16 field probes on a 125mm radius spherical mount). Right: CT scan and photo of field probe.

Introduction: Field monitoring using NMR field cameras has been used to improve MR imaging and spectroscopy. In imaging, imperfect gradient trajectories can be corrected for in the reconstruction; field perturbations can also be accounted for [1]. NMR field cameras try to characterise field imperfections using a set of basis functions, typically spherical harmonic functions [2,3]. A field camera is simply an array of NMR field probes [4] that measure FIDs at distinct spatial positions to calculate the measured magnetic field. However, these calculations require the positions of the probes relative to the isocentre of the scanner. The positions are typically acquired in a calibration step where the gradients are used to estimate the positions [2,3]. This method is simple and does not require one to physically measure the distances, which is beneficial since the exact isocentre of the scanner is not easy to determine. However, this calibration is based on the assumption that the gradient coils generate perfectly spatially linear fields which usually have small deviations. The inaccuracy is not a problem when only (zero and) linear spherical harmonics are being measured since the inhomogeneity is reversed when estimating the fields. However, the imperfect gradient linearity may play a significant role in the estimation of higher order spherical harmonics i.e. shim fields and physiologically induced higher order field distortions.

We attempt to analyse the effects of these nonlinearities and probe positions on field monitoring on a 9.4T Siemens Magnetom scanner (Erlangen, Germany).

Method: An NMR field camera consisting of sixteen probes mounted on a 125mm radius sphere was used. The actual relative positions of the probes needed to be measured independently of the MR scanner and were thus measured using a computer-tomography (CT) scanner for cross-validation and correction of the probe positions. The resolution was 0.6386mm in the x- and y-direction and 1mm resolution in the z-direction (fig. 1).

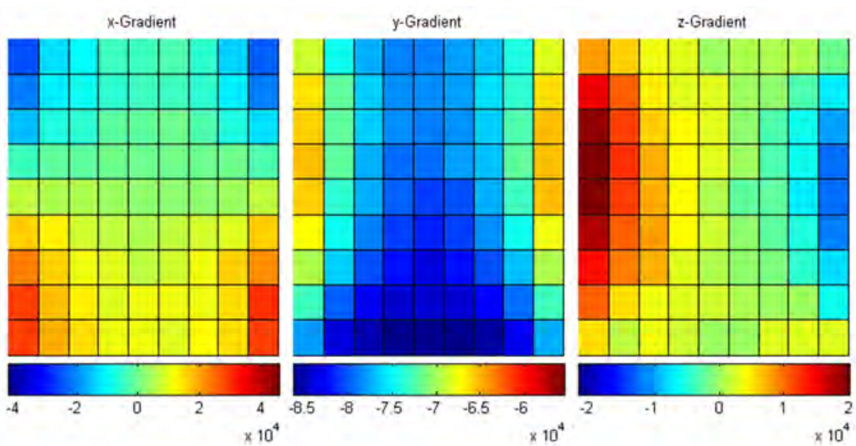

Fig. 2: Gradient field nonlinearities for a single slice (y = -56mm). Scaled in Hz.

The gradient field nonlinearities were calculated using a single field probe measuring the frequencies at different spatial locations. These points were spaced at 32mm on a 9x7x9 mesh grid (in the x-, y- and z-directions respectively). Fig. 2 shows the the deviations of the actual gradient fields from a perfectly linear fields. The measured fields of the x-, y- and z-gradients were used to estimate the error between actual probe positions and probe positions calculated given the imperfect gradient fields. The distance errors varied between 0.8 mm and 18 mm, which is a significant difference (fig. 3).

The field camera was placed in the scanner and the initial estimates of the probe positions were made using the method with the gradient fields. The probe positions were then corrected by constraining the relative positions to using the measurements from the CT scan. The optimisation was performed by minimising the difference between measured x-, y-, z-frequencies and the frequencies generated by the measured gradient fields (previous paragraph) for each probe .

For completeness, the amplitude nonlinearities were also investigated; that is, as the gradient amplitude increases this should correspond to a proportional increase in the field strength. The amplitude nonlinearities were measured by placing a single NMR field probe slightly off the isocentre.

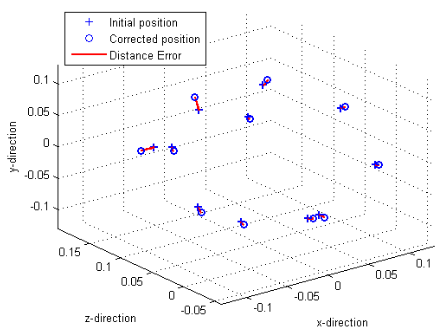

Fig. 3: Initial vs corrected probe positions by acounting for relative position constraints.

Table I: Actual vs measured spherical harmonic term

Sph. Har.	Actual	Measured
F0	0	0.001
X	0	-0.010
Y	0	0.017
Z	0	-0.025
XY	0	-0.737
YZ	0	-0.537
XZ	0	0.757
X2 – Y2	0	0.166
Z2	1	1.212

Results: The initial estimate and corrected estimate of the positions are shown in fig. 3. To see the effect of incorrect positions on the estimated higher-order spherical harmonics, the initial and corrected position estimates were used. The corrected positions were assumed to be the actual positions. Table I shows the difference in the measured spherical harmonic terms when a Z2 term is applied with $1mT/m^2$. The measured spherical harmonic differs from the actual amplitude by 20% and the presence of other harmonic terms is monitored when they should not be (non-Z2 terms are not zero). The correction was also performed on measurements by applying second-order shim terms and the corrected position makes a significant difference on all second-order harmonics of the measured field.

For the amplitude linearity analysis, a gradient was applied with amplitudes at 1mT/m intervals and the corresponding frequencies were also found to be linear.

Conclusion: The spatial nonlinearities in the gradient fields were measured. These measurements were used to show that nonlinearities have a significant effect on estimating probe positions, up to 18mm (assuming the camera is more or less in the isocentre).

It was also shown that small differences in the positions of the probes can lead to significant differences when monitoring higher order terms in the static field. Therefore more accurate position estimates need to be acquired by correcting for the gradient nonlinearities.

References

[1] C. Barmet et al., MRM 2008, 60:187-197; [2] S. J. Vannesjo et al., MRM 2013, 69:583-593; [3] D. Giese et al., MRM 2012, 67:1294-1302; [4] N. De Zanche et al., MRM 2008, 60:176-186.