MR-Noise Tomography: extracting information from noise

S. Reza[1,2], F. Huang[1], G. Bosman[2], G. R. Duensing[1], M. K. Limkeman[1], C. Saylor[1]

[1]Diagnostic Imaging, Invivo Corporation, Gainesville, Florida, United States, [2]Department of Electrical and Computer Engineering, University of Florida, Gainesville, Florida, United States

Introduction:

A method for increasing specificity of the MR Image from noise correlation and measurement results in two dimensions is presented. This technique utilizes the MRI image as a guiding image. Using a segmentation algorithm, different regions within the body are identified based on contrast. The noise signals measured at the ports are functions of the conductivity at each region and the sensitivity map of the field probes. For a known sensitivity map, from the measured noise correlation at the ports, the conductivity of different regions is determined. One potential application of this method is breast cancer detection. Studies have shown that the conductivity of a malignant tumor can be an order of magnitude higher than the conductivity of a benign tumor or that of breast tissue [1,2]. So by identifying the suspicious region using a MRI scan and then determining the conductivity of the region by noise correlation measurement, a malignant tumor can potentially be differentiated from benign lesions.

Methods:

The thermal noise is caused by the random fluctuation of electrons due to thermal excitation. The noise current at a grid point in the body J obeys a Gaussian distribution with mean $\bar{J} = 0$ and variance $\overline{J^2} = 4k_B T \Delta f \sigma$ [3], where k_B is the Boltzmann constant, T is the temperature and Δf is the system bandwidth. The noise voltage measured by j-th coil in an array of RF coils is equal to: $c \cdot \int J(\vec{r})\vec{E}_j(\vec{r})dV$, where c is proportionality constant. This follows from the Reciprocity Theorem, assuming a linear system, where $\vec{E}_j(\vec{r})$ is the electric field at a point inside the body due to a unit current in the j-th coil. The noise correlation between coils j and k, $CV_{jk} = \overline{\left[\int J(\vec{r})\vec{E}_j(\vec{r})dV\right] \cdot \left[\int J(\vec{r})\vec{E}_k(\vec{r})dV\right]^*}$ is reduced to $\int \overline{J^2(\vec{r})} \cdot \vec{E}_j(\vec{r}) \cdot \vec{E}^*_k(\vec{r})dV$ (The proportionality constant is dropped for simplicity), because of the fact that $\overline{J(r_1) \cdot J^*(r_2)} = 0$, for $r_1 \neq r_2$. Now the measured correlation can be written in terms of conductivity and assuming the conductivity in a volume segment is constant, the integral can be written as a sum of integral over each segment, $CV_{jk} = 4k_B T \Delta f \int \sigma(\vec{r})\vec{E}_j(\vec{r}) \cdot \vec{E}^*_k(\vec{r})dV = 4k_B T \Delta f \sum_{Segment=1}^{N} \sigma_{segment} \int_{segment} \vec{E}_j(\vec{r}) \cdot \vec{E}^*_k(\vec{r})dV$. For a digitized and segmented image this integral equation becomes a matrix equation; $\left[CV_{jk}\right] = 4k_B T \Delta f \cdot \left[\int_{segment} \vec{E}_j(\vec{r}) \cdot \vec{E}^*_k(\vec{r})dV\right] \cdot \left[\sigma_{segment}\right]$. The Electric field map can be calculated or simulated. Then the conductivity of different regions can be obtained by inverting the matrix equation [4].

Results:

Measurements were done on a two-dimensional system. The phantom (fig 1.a) is constructed of a 7.75″ diameter and 7″ long acrylic tube. One larger (3″ dia) and two smaller acrylic tubes, each of which is 7″ long, are contained within the phantom. The phantom was designed for translational symmetry over its length, producing an effective two-dimensional system. The 3″ diameter tube is filled with distilled water; the rest of the phantom is filled with a saline solution $(\sigma = 0.8 \cdot S/m)$ containing Cu_2SO_4 (2.0 g/L) and NaCl (4.5 g/L). An MRI image (fig. 1.b, d) was obtained with an 8-channel head coil at 63.86 MHz, 15 kHz bandwidth and 1.38 min. acquisition time. Then the noise acquisition was made with the same settings with the transmitter disconnected. A total of 16 data sets were collected by rotating the phantom in 5° steps and repeating this procedure. The calibration data set was acquired by replacing the water in the 3″ tube with the saline solution. The calculated values for the conductivity are 0.984, 0.285 and 0 S/m for the saline solution, distilled water and acrylic respectively. The most accurate values were obtained when the cylinder containing distilled water was furthest from the center of a coil.

Discussion:

The coil array used is optimum for MRI scans but not for noise scans. The simulated Electric field plot (fig 1.c) shows a zero field region that extends from the middle of the coil excited and covers a large area including the middle of the phantom. This zero field is translated into zero sensitivity regions in the correlation sensitivity maps (fig. 1.e, f) and results in a loss of accuracy near the center of a coil and in the middle of the phantom. The accuracy of measurement is also a function of bandwidth and data acquisition time [5]. The results clearly demonstrate the merit for continuing research on the proposed method. Work is progress to determine an optimum system design for noise scanning.

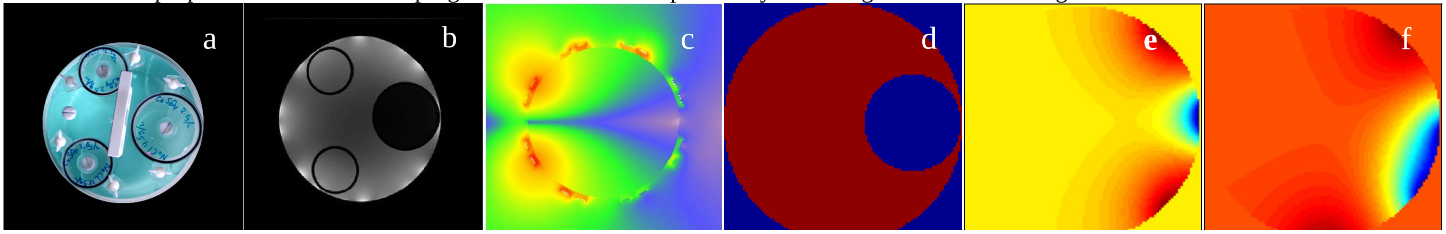

Figure 1.a) Phantom b) MRI Image c) Simulated E-field d) Digitized MR Image, and Sensitivity maps e) adjacent coils f) 1 coil in between

References:

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