Absolute Thermal Mapping Using the MR Scanner

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Abstract

In this work, we use the MR scanner as a radiometer to passively measure noise emitted by bodies and detected by receiving coils. We develop a setup to calibrate the receiving chain of the MR system. Upon calibration, we show the ability of the scanner to measure absolute temperatures and generate absolute thermal maps.

Introduction

Previously we demonstrated the feasibility of using the MR scanner as a radiometer to measure absolute body temperatures [1]. Radiometry is a passive technique where a sensitive receiver is used to receive thermal noise radiation emitted directly by bodies. The equation governing this phenomenon in the microwave region is $P = 4GkBT+N$ (Equation 1) [2]. Where P is the radiated noise power, G is the available power gain of the receiver, k is the Boltzman constant, T is the temperature of the body, B is the system's bandwidth and N is the noise power added by the receiver. We have previously proved that the receiver chain of the MR scanner has a very high stable gain, low noise figure and thus capable of detecting body temperatures at small bandwidths within an accuracy of 1^0C [1] [3]. In this work we show that without knowing the detailed parameters of the receiver channel, we can obtain calibration curves for the relation between the received noise variance by the scanner and the average temperature of the medium within the sensitive region of the receiver coil. Once this relation is known, temperatures can be directly estimated from noise variance. We develop a setup to generate absolute thermal maps using this strategy.

Methods

A GE 1.5T scanner was used for all radiometric measurements. An MR compatible temperature controller was devised to accurately control temperatures of water pumped through phantoms under examination (Figure 1). A cubic plastic phantom (6x6x6cm) was constructed and continuously filled by the circulating water. Water conductivity was adjusted using salt to match that of the human body. A rectangular surface coil was constructed and it's matching and tuning was continuously adjusted during experiments to match 50Ω before each measurement. From Equation 1 it can be noted that G and N are functions of the reflection coefficient, Γ, which is consequently temperature dependent, thus by accurate matching and tuning we try to ensure the stability of the total gain of the system and reduce fluctuations due to changes in Γ. This setup was used to determine the relation between the noise variance ($\langle V_n^2 \rangle$) and the absolute temperature of the phantom (T_n). During acquisition the RF transmission and gradients of the scanner were turned off to guarantee no interference within the received frequency band. The bandwidth of the scanner was set to 125KHz and 25 million samples were acquired over an unusually long period (2 minutes) for each variance measurement to ensure that the statistical error in estimation was well below 0.1^0C. A thermal image is constructed using a two-dimensional phantom (Figure 1). The rectangular phantom (18x18cm) consists of two chambers. The middle chamber is connected to the temperature controller and is thermally insulated. The second compartment contains water at room temperature surrounding the middle chamber. The depth of all chambers is 6cm. The idea was to manually scan the temperature of a 3x3 non-overlapping voxels of the phantom by changing the position of the surface coil. The absolute temperature of each voxel was continuously monitored during experiments with an independent sensor.

Experiments and Results

An experiment was first conducted to acquire the calibration curve. Each data point on the curve is a measurement of the received noise variance at a certain temperature. Eleven data points were acquired to deduce the parameters of the linear relation, $\langle V_N^2 \rangle = aT_N + b$, where a is the lumped system gain and b is the noise added by the system. A least square fit was used to calculate the value of the coefficients a and b with a confidence interval of 99%, yielding values of 0.158 and 23.63 respectively. The resultant calibration curve is shown in Figure 2. A second experiment was conducted to acquire the thermal map of the 2-D thermal phantom. The temperature of the center voxel was adjusted to 38°C and the surrounding voxels were maintained at 28°C. The noise variance received from each voxel was measured and converted to its corresponding temperature value using the calibration curve. The reconstructed thermal map is shown in Figure 3. Note that some voxels deviate from the real temperature value by approximately 2^0C and that the standard deviation of measurements is 0.92^0C. This error is by far greater than the statistical estimation error and is attributable to inaccuracies in exact tuning and matching as well as quality factor variations of the receiver coil.

Discussion and Conclusion

We have successfully demonstrated the ability of MR Radiometry to generate thermal maps. This is a new method that shows a promising potential for absolute thermal imaging in the MR scanners. We are currently working on developing more accurate tuning and matching strategies to increase the accuracy of measurements. Phased arrays are being investigated to parallelize acquisition and increase spatial resolution.

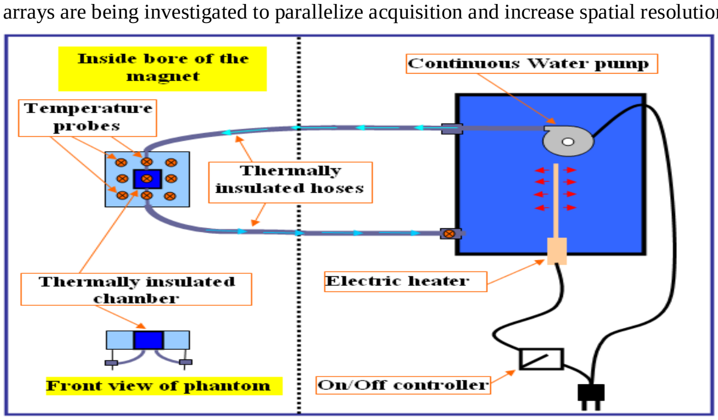

Figure 1: Cartoon showing the experimental setup used during experiments. Water's temperature is controlled in a thermally insulated box, placed by the side of the scanner's table, and pumped to circulate through the plastic phantom placed inside the bore of the magnet.

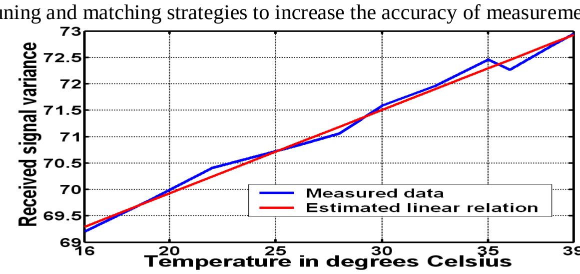

Figure 2: Calibration curve acquired by calculating the received signal variance at different temperatures of the phantom.

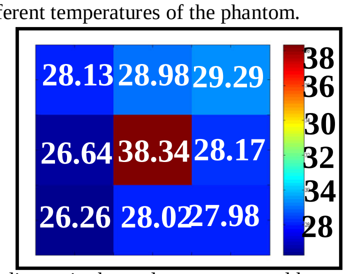

Figure 3: A radiometric thermal map generated by scanning the phantom with a surface coil. The measured independent absolute temperature of the middle chamber was measured to be 38^0C. The surrounding compartment was at 28^0C.

Acknowledgments:

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References:

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2. J.B.Johnson, Physical Review V.32: 97-109; 1928 July. **3.** A. El-Sharkawy & E. Atalar, US2004021642, Assignee: Johns Hopkins University