# Real-time temperature monitoring using line-scan phase measurement

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## Introduction

Real-time measurement of temperature during therapeutic procedures presents unique challenges with Magnetic Resonance. MR thermal measurement methods rely on high-speed imaging in which changes in temperature cause changes in either T1 or chemical shift. T1 thermal sensitivity has proven useful for qualitative measurement of temperature changes in tissues having both water and fat MR signals. Chemical shift sensitivity, on the other hand, has been demonstrated to be useful for the quantitative measurement of temperature changes in non-fatty tissue. For most non-fatty tissue, the change in chemical shift is approximately 0.01 PPM / °C.

Most thermal measurements with MR are performed with high-speed imaging sequences that are sensitive to changes in T1 or phase. We have developed a pulse sequence and user interface that permits high-speed measurement of temperature changes using a line-scan approach. Line-scan MR measurements collect only a single dimension of spatial information and thus are considerably faster than their 2D imaging counterparts. Line-scan methods for real-time temperature measurements have been proposed in the past, but have been used primarily for T1-sensitive temperature monitoring [1].

One of the major challenges of phase-sensitive temperature measurements with MR is that there many parameters that can affect MR signal phase. Some of these parameters (e.g. field inhomogeneity, eddy currents, resonance offset, etc.) are relatively constant during a therapeutic procedure and do not have a substantial effect on temperature measurements. Other parameters, such as patient motion and magnetic susceptibility changes due to inspiration, can cause variations in background phase during the procedure. We have developed a real-time method that corrects for these background phase changes during phase-sensitive temperature monitoring.

## Materials and Methods

Figure 1 shows a simplified pulse sequence diagram of the MR-tracking line-scan thermal measurement pulse sequence. The 90 degree excitation rf pulse is slice selective and creates transverse spin magnetization in a selected plane within the object or subject of interest. A second RF pulse refocuses spin magnetization. This pulse is applied in the presence of a magnetic field gradient that is orthogonal to the first. Thus, at the time of data acquisition, only the spins in the intersection of the two excitation slices retain coherent transverse spin magnetization. MR signals are detected in the presence of a read gradient that provides one dimension of spatial resolution. The spatial offsets of the 90 and 180 degree rf pulses are controlled in real-time and positioned with the help of a previously acquired reference MR image.

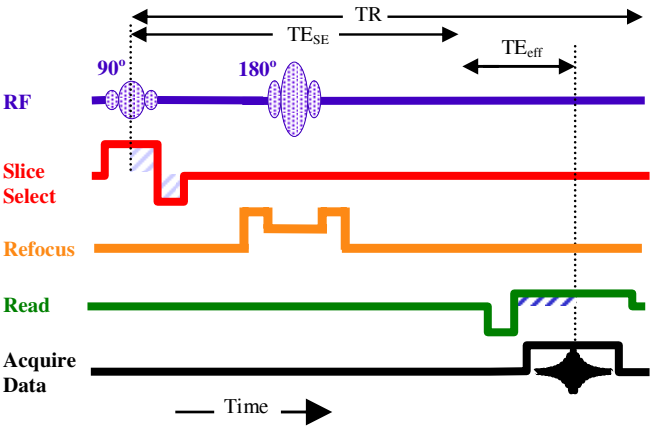


Figure 1.

The complex MR signals detected in response to the pulse sequence shown in Figure 1 are Fourier Transformed and sent to a custom built user interface (Figure 2) on the MR scanner (General Electric, Milwaukee, WI). The interface presents the data in both magnitude and phase. Manual and automatic algorithms permit zero and first order correction of phase in the data to correct for static phase shifts along the line of spin magnetization. Baseline phase measurements can also be used to correct the data.

The user interface permits the operator to define three zones of interest in regions having a sufficient signal-to-noise ratio (SNR). The two outer zones (delimited by blue markers) identify regions that are expected to be beyond the region of thermal therapy. The central zone (delimited by red markers) identifies the zone in which the thermal changes are to be monitored. Real-time correction of the phase between the two blue marker zones is performed to "lock in" the phase background of the monitored zone.

During a thermal therapy session, the application of heat in the central zone causes a change in the resonance offset of the spins that in turn causes a phase change in the detected MR signal. The phase change in the heated zone is presented as a rotation in an I/Q plot. The absolute temperature is computed by adding the measured temperature to a user defined reference temperature. Thermal dose is presented as a running plot of temperature as a function of time.

The thermal imaging system was validated in an agar gel phantom using a copper wire heater with a 30 second heating pulse (Fig. 2). Measured temperature changes were correlated with a Luxtron fiberoptic temperature system. The robustness of the system to changes in background phase was measured by perturbing the magnetic field near the phantom in a periodic fashion to simulate the susceptibility effects during breathing.

## Results and Discussion

The technique presented here is a one-dimensional analog of referenceless temperature monitoring proposed by Rieke et. al. [2]. Our method acquires a single dimension of data and permits faster data acquisition. This in turn enables real-time background correction algorithms that can compensate for phase changes other than those due to temperature changes (e.g. breathing). To date, the phase corrections that we have applied are derived from the two baseline regions on either side of the target zone and are linear in nature. Correction of higher order changes in the phase background using higher order polynomial fits is relatively straightforward.

The line-scan temperature monitoring system has been validated in phantoms that simulate the thermal monitoring conditions of HIFU and laser ablation in the liver and kidney. Although additional work is needed before this method will be ready for animal trials, we believe that it will be well suited to address background phase drifts and thus is a step towards more reliable measurement of temperature using magnetic resonance.

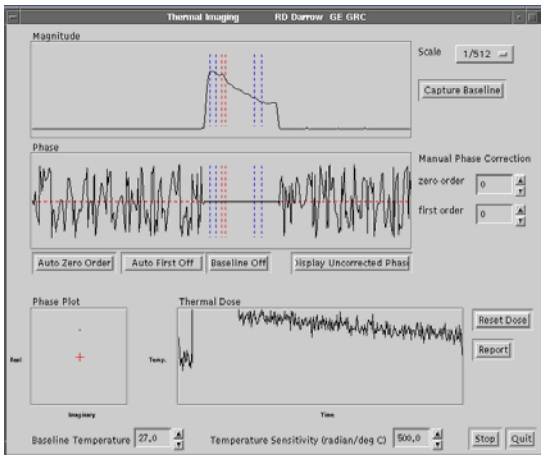


Figure 2.

## References

1. Hardy et. al., J. Compt. Asst. Tomog., 18(3): 476-83 (1994).
2. Rieke et. al., Magn Reson Med, 51(6): 1223-31 (2004).