

Referenceless Thermometry using Bloch-Siegert Phase shift and Auto Regressive model

Manivannan Jayapalan¹

¹MR Pulse Sequence Applications and System Tools Engineering, GE Healthcare, Bangalore, Karnataka, India

Introduction: Thermal monitoring in Magnetic Resonance guided Focused Ultrasound (MRgFUS) treatments is a crucial step where the phase images from MR images are used to get thermal maps. One of the widely used techniques is proton resonance frequency (PRF) shift technique that involves some form of image subtraction using a baseline pre-treatment image. Subject motion and tissue deformation due to coagulation can severely distort these techniques. Self-referenced methods [1] help to overcome this hurdle which requires some area of tissue around the area of treatment, hot zone, for polynomial fitting to estimate the baseline phase. The accuracy of the temperature map from this method mainly depends on how close the estimated phase is with baseline phase. There are some recent works [2, 3] on Bloch-Siegert phase Shift, which is a function of applied off-resonance RF and that remains constant with no change in the environment. In this work, a new technique is described, where the equivalent-baseline phase values are generated/estimated by applying the current phase values to a model that is based out of Bloch-Siegert phase Shift obtained in run-time along the same location. This method not only eliminates the need for baseline subtraction but also produces better results as the model is generated in runtime against the known values.

Method: In this method, first, the baseline phase acquisition (ϕ_0) was performed using a normal gradient echo for the sake of comparison using GE Signa 1.5T MRI Scanner (GE Medical Systems, Milwaukee, WI, USA) and a water bottle phantom (figure 1). The temperature of the water was then raised and stopped heating at one point. Bloch-Siegert phase shift (ϕ_{BS}) was then obtained along the line of interest (LOI) as marked in figure 1.B, using an off-resonance RF of ± 4 KHz, 8 msec Fermi saturation pulse, as shown in figure 2A. Temperature variations between forward and reverse acquisition could be ignored as time lag is very minimal between them. Rate of change of Bloch-Siegert's phase shift was then modeled using an auto regressive (AR) model whose coefficients are determined using Levinson-Durbin algorithm and autocorrelation method. Phase values (ϕ) at each pixel along this line of interest were then acquired using a normal gradient echo with same prescription as in baseline acquisition. The rate of change of this phase (ϕ) was evaluated using the created model and this output gives the estimation of equivalent baseline phase (ϕ_{ref}). The difference between this estimated phase and the actual acquired phase ($\phi - \phi_{ref}$) would give us the temperature variations at this point as per equation in the figure 2B.

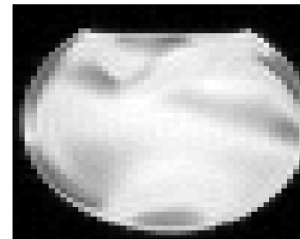


Figure 1.A : Baseline acquisition

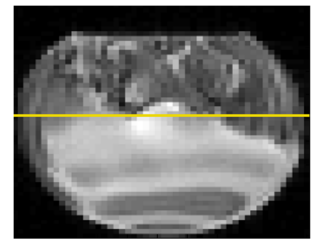


Figure 1.B : Acquisition during cooling

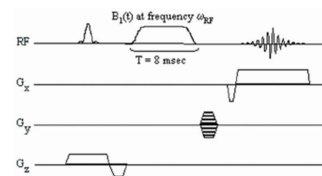


Figure 2A: Sequence with off-resonance RF

$$\Delta T(x, y, t) = \frac{\phi - \phi_{ref}}{\gamma \alpha B_0 TE}$$

$\Delta T(x, y, t)$: relative temperature change for a voxel at position (x, y) and time t
 ϕ : initial phase before heating
 γ : gyromagnetic ratio (42.58 MHz/Tesla)
 α : temperature sensitivity coefficient ($-0.01 \text{ ppm}/^\circ\text{C}$)
 B_0 : main magnetic field strength in Tesla
 TE : echo time in ms

Figure 2B: Relative temperature calculation

Results: Figure 3A shows the baseline reference phase (ϕ_0) and the modeled baseline phase (ϕ_{ref}). As shown, they are matching well, which proves the model efficiency in estimating baseline phase (ϕ_{ref}) from current phase (ϕ) with greater degree of closeness to the original baseline phase (ϕ_0). As shown in figure 3B, the difference in temperature along the line of interest obtained from proposed method ($\phi - \phi_{ref}$) and normal subtraction ($\phi_0 - \phi_{ref}$) method is also very less. This result shows that the model using rate of change of Bloch-Siegert phase shift could be used to calculate the baseline phase from the current phase values.

Conclusion: The proposed method eliminates the need for image subtraction and provides better results. In clinical scenario, temperature measurement at any location, at any point of treatment could be obtained without the baseline information by using the Bloch-Siegert phase shift from a known RF pulse and the current phase values. This new technique would be amenable for the MRgFUS treatments, in particular moving organs where subtraction method fails.

Reference: [1] Rieke V, Butts Pauly K. JMRI 27: 376-390 (2008), [2] Sacolick LI, et.al.,MRM 2010; 63: 1315-1322 [3] Bloch et al.,Phys Rev. 1940; 57:522-527

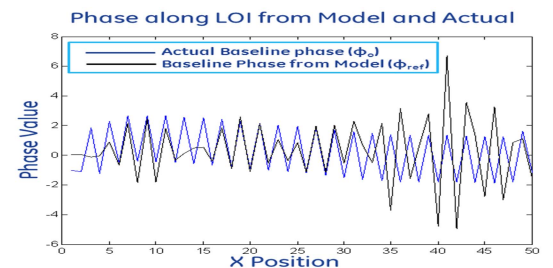


Figure 3A- Phase along LOI from Actual and Model

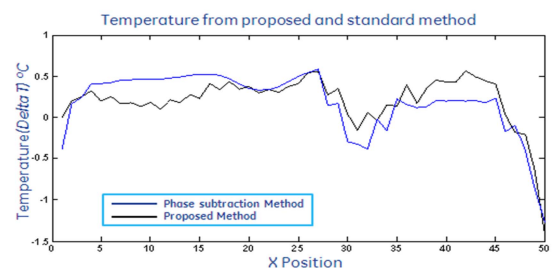


Figure 3B- Temperature variation