Focal Position Determination in Breast MRgHIFU using 3 Tracking Coils

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Purpose

Rapidly finding the physical location of the ultrasound focus is critical to successful interventional treatments with MR-guided high intensity focused ultrasound (MRgHIFU). Typical methods of locating the focus include using scout images to identify the transducer location then using low power short duration heating or acoustic radiation force impulse (ARFI) imaging to verify the ultrasound focus location. These methods require extra scan time and multiple sonications with the transducer, and can be time consuming when transducers have multiple degrees of freedom, making the determination of the focal point more difficult than a vertically propagating system. Our proposed method uses 3 tracking coils rigidly mounted to the ultrasound transducer of a breast MRgHIFU system[1] to measure the transducer position and estimate the focus location in real time. This method provides reductions in both setup and total treatment time, minimizing the need for localizer heating or ARFI test shots.

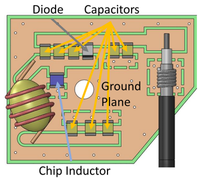

Figure 1. Circuit Design. Coil is rotated ~15° to give maximum signal possible for every transducer position.

Methods

Tracking Coils: The three tracker coils were made by tightly wrapping insulated 27 AWG wire four times around a benzonatate 100mg 6.75mm diameter spherical capsule. The wires were bonded to the capsule with super glue. The wire wrapped capsules were soldered to a circuit board made of FR4 material (Figure 1) forming the primary inductance of the tracker coil circuit. The match and tune capacitors were placed close together, and were mounted to the circuit board over a solid ground plane to reduce inductance from that part of the circuit. The circuit was tuned and matched to the ^1H resonant frequency of the scanner. The tracker coils were attached to Siemens 3T preamps with approximately 40cm of RG316 coax cable. The active and preamp decoupling were 34dB and 8dB respectively. The tracker coil circuit boards were rigidly attached to the posterior transducer support structure of the breast MRgHIFU system forming a triangle as shown in Figure 2b. A simple one dimensional readout sequence was used to obtain each tracker coil's approximate position within the bore[2] (Figure 3) (1 mm zero-filled to 0.1 mm, TR/TE = 9.4/4.6 ms, Flip Angle = 20°, FOV = 500 mm, BW = 250 Hz/Px). A gradient warp correction was then applied to calculate the true location[3]. The sequence repeats 6 times to readout in all 3 directions using both positive and negative readout gradients to be insensitive to resonance offset conditions[1].

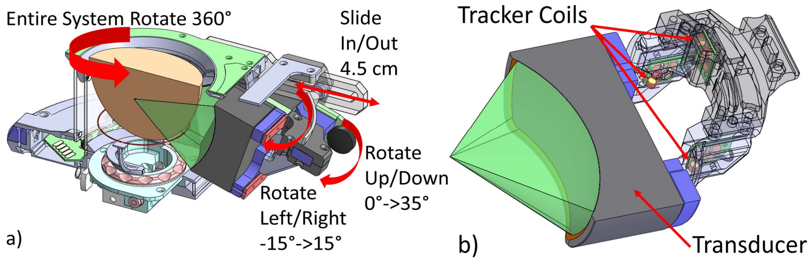

Figure 2. a) MRgHIFU Breast system cross section showing various degrees of freedom. b) Tracker coil arrangement. Transducer is cut in half to clearly show tracker coils

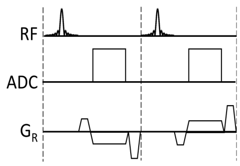

Figure 3. Locator Sequence for one readout direction G_R. This is repeated 3 times with the readout gradient switching direction each time.

Accuracy Verification: An MRgHIFU heating experiment (35 acoustic W, 30 seconds) was performed using a gelatin phantom to calibrate the location of the focus relative to the locations of the 3 tracker coils in a Siemens Trio 3T scanner. PRF temperature data was collected during heating using a 3D segmented EPI sequence (1x1x2 mm, Flip Angle = 20°, TR/TE = 20/8.9 ms, EPI Factor = 9, BW = 970 Hz/Px, 10 Slices with 16.7% oversampling). The temperature data was zero-fill interpolated to 0.5 mm isotropic resolution. To assess the accuracy of the predicted focus location, the locator sequence and ultrasound sonications were applied with the transducer in 9 total locations: 3 system angles around the vertical axis (parallel, 45°, and 90° to B0) and 3 transducer positions at each angle (max distance from phantom, 3cm closer, and rotated 35° down) (Figure 2a). The six degrees-of-freedom transform was calculated that realigns the calibrated tracker coil positions to the current positions. This transform was then applied to the calibration focus location to estimate the current focus position. The focal position estimates obtained from the tracker coil positions were compared to the center location of the focal spot obtained from the PRF temperature data.

Results, Discussion, and Conclusions

Figure 4 shows the signal from a tracker coil for all 6 readouts. The actual coil location is halfway between the peaks from positive and negative readouts[2]. Typical SNR of these coils was ~10,000. Table 1 shows the focus positions measured from temperature data, the estimates from the tracker coils and the distance between the two. The average distance between the measured and predicted locations was 3.35 mm with a standard deviation of 1.67 mm. The accuracy of the predicted location was very dependent on whether gradient warp corrections were applied to the locations of the coils. Without gradient warp correction, the average distance between the measured and predicted locations was 11.8 mm with a standard deviation of 5 mm. For each transducer position the ultrasound beam propagated through different distances in the phantom. These different amounts of attenuation would shift the focus location slightly, explaining the discrepancy between the heated and predicted focal spot location. The method shown here can accurately estimate the current focus position to within approximately 3 mm without the need to sonicate. This technique significantly shortens the scan time required to locate the focus and potentially reduces the total treatment time.

References: 1. Payne *et al.*, Med Phys 2012;39:1552-60. 2. Dumoulin *et al.*, MRM 1993;29:411-5. 3. Janke *et al.*, MRM 2004;52:115:22.

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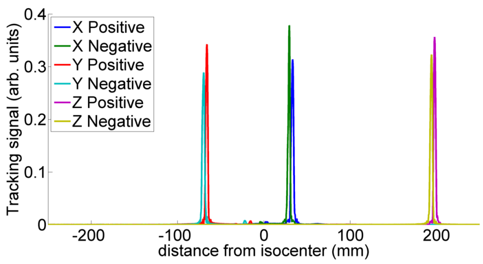

Figure 4. Tracker signal from a single coil for all 6 readout directions.

System Rotation	Trans-ducer position	Trans-ducer elevation	Heating Location vs Predicted Location (mm)						Dis-tance (mm)
			X	X	Y	Y	Z	Z	
0°	Max-3	0°	0.6	0.6	-81.6	-81.6	6.5	6.5	Calibration
0°	Max	0°	0.7	-0.2	-77.9	-78.1	34.1	35.8	1.9
0°	Max-3	35°	-0.2	-0.5	-18.9	-24.3	23.1	21.1	5.8
45°	Max-3	0°	1	1.3	-81.6	-81.4	7.5	6.4	1.2
45°	Max-3	35°	-11.2	-11.1	-17.3	-20.7	21	18.8	4.1
45°	Max	0°	-15.7	-19.1	-76.9	-77.1	27	26.6	3.4
90°	Max	0°	10	9.4	-76.4	-75.1	-0.4	0.1	1.5
90°	Max-3	0°	33.6	38.1	-79	-79.2	-0.8	1.1	4.9
90°	Max-3	35°	17.4	19.6	-16.9	-19.9	-1.3	0.3	4

Table 1. Focus locations measured from heating images (left: red) and the predicted locations from the tracker coils (right: blue), and the absolute distance between them. Max transducer position is the furthest distance out as shown in Figure 2a.