Online Local SAR Supervision for Transmit Arrays at 7T

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Target audience: RF engineers and MR physicists

Purpose: Local SAR and its safe supervision are dominant limiting factors for high performance pTX applications. Safety concepts typically provide a SAR prediction strategy based on numerical simulations using generic body models [1]. Only sequences that will not exceed SAR limits are allowed to be executed. To capture operation errors or system fault during runtime, an additional online supervision was proposed to ensure the correct execution of the RF pulses as considered in the simulations [2,3]. To function properly, both look-ahead and online supervision must give valid results. Additionally, these systems need to know the exact sequence timing of all executed sequences to function properly. In this study, an online local SAR calculation and supervision system using measured complex transmit array RF pulse shapes was built. Local SAR is calculated in near real-time based on a compressed [4] electric field model of the current RF coil and patient.

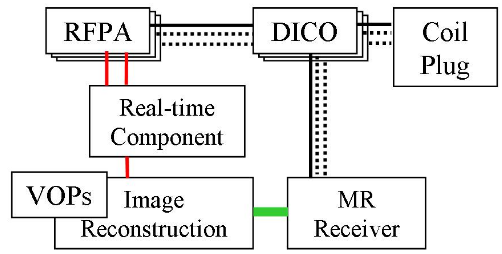

Fig. 1: Schematic architecture of local SAR super-vision system. RF paths are shown in black, digital data paths in green and 1-bit digital control lines in red

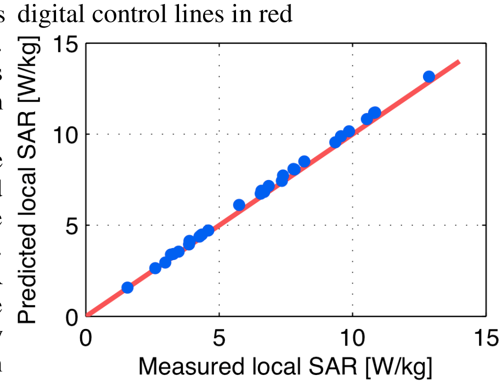

Fig. 2: Online calculated local SAR vs. predicted local SAR for several arbitrary TX Array RF pulses

Methods: Figure 1 shows the hardware architecture of the online local SAR supervision system. The RF transmitted by the RF power amplifiers (RFPA) to the RF coil is monitored using directional couplers (DICO). The directional couplers are located at the rear of the magnet. Measured forward and reflected RF signals are digitized by the standard MR receiver components at a dwell time of 1us. The digitized signals are processed by the standard image reconstruction system. There, the incoming digitized RF waveforms are calibrated to reflect the situation at the coil plug. The local SAR calculation and supervision is done based on electrical field models for a specific coil including cabling and patient. Electrical field models are provided in a compressed form using virtual observation points (VOP) [4]. This reduces the model size at the cost of a slight local SAR overestimation. Local SAR is calculated and limited for a 10 second and 6 minute sliding window as required by IEC regulations. If local SAR is exceeded, the image reconstruction system stops the measurement control unit.

A simple real-time logic implemented on a FPGA supervises the SAR calculation because data processing needs a short and not exactly known amount of time. In case of delayed processing by or misconfiguration of the image reconstruction system, the real-time component turns off the RFPA if more than 10ms of unchecked RF was transmitted. Within this 10ms window of possibly unknown applied local SAR, a worst case local SAR scenario is assumed and enforced by the standard global SAR supervision unit. To make sure all components involved in calculating local SAR, a 10ms automated consistency check is performed before each scan. The local SAR supervision system was built based on a MAGNETOM 7T scanner equipped with a TIM TX Array extension (Siemens Healthcare, Erlangen, Germany).

Results: To validate the proposed local SAR supervision system, the local SAR calculated by the online supervision for a GRE sequence with transmit array excitation pulses was compared to three different offline calculations: The 10s average local SAR calculated from 1) the full electric field model using theoretically expected RF pulses (6.72W/kg), 2) the compressed model using expected RF pulses (6.74W/kg), 3) the compressed model using measured RF (6.53W/kg). All offline calculations use different algorithms than the online supervision and are implemented in Matlab. For the given GRE sequence, the online calculated local SAR is 6.53W/kg for a 10s average. The electric field compression tool was configured to yield a worst-case overestimation of local SAR of one percent. The online local SAR values are identical to case 3) except for numerical rounding errors. Case 1) compared to the online calculation defines the total error of the supervision system plus possible imperfections in the transmitted RF. Figure 2 shows the online calculated local SAR versus the offline calculated local SAR using method 1) for a large number of arbitrary TX Array RF pulse shapes. For patient scanning, a error term to account for measurement errors is added to the compressed coil model to make sure local SAR is not under-estimated. In addition to the quantitative validations shown above, the local SAR calculation speed was evaluated for high RF duty-cycle sequences. Therefore, a GRE sequence with 5ms excitation pulses per TR and minimum TR was run for several minutes. Online calculation was fast enough to work well with this sequence and needed approximately 100us calculation time per 500VOPs and one millisecond RF sampled at one microsecond dwell time.

Discussion & Conclusion: We presented a real-time high performance local SAR calculation and supervision system without user interaction after a coil/patient model is selected. It was shown that the system is capable of supervising high RF duty-cycle sequences. This is only possible using compressed electric field models. The error between expected and online calculated local SAR was always less than 6% for a high number of test cases. This error includes imperfections in the transmitted RF, which are correctly modeled by the supervision system.

Because the standard image reconstruction system is used for local SAR calculation, additional supervision tasks based on measured forward and reflected complex RF pulse shapes can be implemented easily. The proposed system works independently of a local SAR look-ahead which can be implemented as a separate and independent second safety shell.

References: [1] Graesslin et al., MRM 68:1664-1674 (2012), [2] Graesslin et.al. ISMRM 2008, p.74 [3] Gagoski et al. ISMRM 2010, 781,[4] Eichfelder et al., MRM 66:1468-1476 (2011)

The concepts and information presented in this paper are based on research and are not commercially available.