Device Monitoring and Dynamic Scanner Feedback Control for Active Device Safety in Interventional MRI

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Introduction

Active devices for real-time MRI-guided interventions provide rapid and clear identification of device location and orientation. Components in device and circuitry design are used to reduce the potential for radiofrequency (RF)-induced device heating (1-2) but atypical device use, loss of device connection to the scanner, or device failure may exceed such protection mechanisms in rare instances. Identifying these events rapidly and altering scan parameters to reduce transmit power when pausing scanning may be detrimental during an intervention could quickly mitigate the heating risk and provide an additional mechanism to ensure safe device use. Signal and noise levels from the device channel can indicate device connection and performance status which could result in an increased risk of device heating. Reasonable increases in RF pulse width and reductions in flip angle can substantially reduce deposited power and subsequent device heating while maintaining acceptable image quality. RF energy deposition decreases linearly with increasing RF pulse length and, additionally, the associated increase in sequence TR provides a further small reduction in heating. In practice, we find that the TR of a balanced SSFP sequence can be increased to ~5.5ms for a 5-fold lengthening of pulse width without incurring too many off-resonance artifacts for typical cardiovascular interventions. In this work, we demonstrate a system to monitor proper active device performance and provide additional safeguards with dynamic scanner feedback control during MRI-guided interventions.

Methods

A real-time balanced SSFP sequence was modified to briefly sample device noise (RF transmit off) and then signal after a 2 degree non- selective pulse prior to each real-time slice acquisition to confirm device connection and signal. These data were sent via a TCP/IP connection to a custom LabVIEW (National Instruments, Austin, Texas) interface which monitored and analyzed the changes in device signal input and device temperature through a fiber optic sensor attached to an active device. Additionally the sequence was modified to include a) features for real-time adjustment of RF pulse length and flip angle, and b) a "fail-safe", which was automatically activated if the sequence was not perpetually informed that the active device was functioning appropriately. The LabVIEW monitoring tool was programmed to send a reply to the scanner confirming proper performance and with any changes in pulse width or flip angle to the protocol control according to device status and heating. If the device or monitoring system became disconnected (and thus stopped sending data), the fail-safe would force the sequence into a "safe mode" with a long RF pulse (2500 microseconds) and a low flip angle (20 degrees) which decreases applied power almost 50-fold from normal acquisition parameters. Signal and noise levels were measured in different device conditions to set limits for system response. Phantom heating tests of active devices were used to determine acceptable initial temperature increase rates to maintain device temperature increases below desired limits and the impact of altering scan parameters on the temperature increases.

Results

The monitoring system quickly identified and triggered the scanner to a low power state before the next slice when device signal was suddenly lost, unacceptable temperature increases (absolute or rate) occurred, or any of the monitoring components were lost. An example of device signal drop is shown in Figure 1 when the connector was unplugged and triggered a change in operating status. Device heating was limited by controlling the acceptable temperature increase rate and scaling the scan parameters accordingly. This is displayed in the temperature plots in Figure 2 where the same device was tested with and without the monitoring system active and the heating controlled by varying the pulse width up to 3 times the base value (changes reflected in temperature fluctuations). Minimal reductions in flip angle were used if additional power drop was necessary to maintain the desired increase rate.

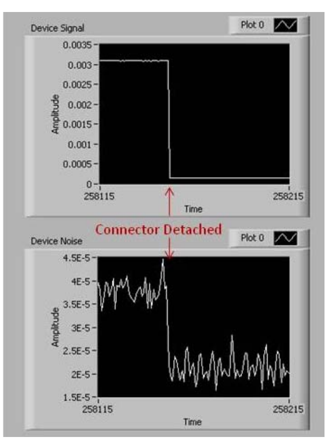

Figure 1: Signal and noise plots for the device channel. This demonstrates sudden drop when the device is disconnected and triggers a low-power scan mode.

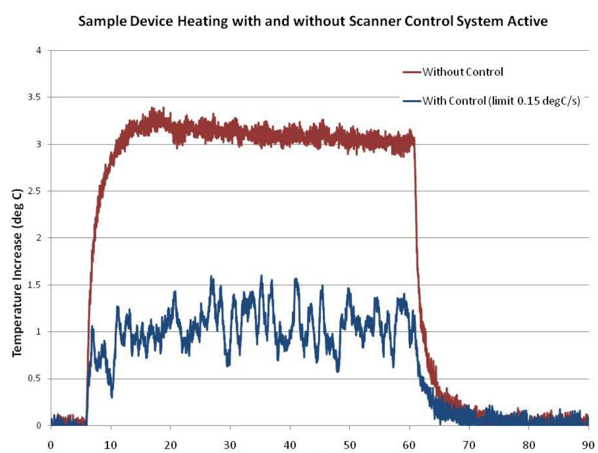

Figure 2: Device heating profiles with and without the system active. Enabling the system limited heating by altering the scan parameters according to temperature increase rates.

Discussion

We were able to monitor several aspects of proper device operation (signal, temperature changes) and dynamically alter scan parameters of flip angle and pulse width accordingly to adjust deposited power. Different parameter optimization strategies could be used to determine the appropriate operating conditions and ensure safe device use without having to immediately stop scanning which may be detrimental in the middle of a procedure. While we have demonstrated the performance of this system with heating measurements from an attached temperature sensor, this system could also readily incorporate other potential inputs to monitor and control operating parameters as new measures of device safety are developed (3-5).

References

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