Non-contact Tracking of Involuntary Head Motions by Ultra-Wideband Radar for improved High- and Ultra-High Field Magnetic Resonance Brain Imaging

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Introduction and Motivation

Subject motion appears to be a limiting factor in numerous MR imaging applications (e.g. high resolution fMRI, DTI, etc.), especially at high and ultrahigh fields. For head imaging the subject's ability to maintain the same head position for a considerable period of time places restrictions on the total acquisition time. This period typically does not exceed several minutes and may be considerably reduced in case of pathologies. In particular, head tremor, which often accompanies stroke, may render certain high-resolution techniques inapplicable. Several navigator techniques have been proposed to circumvent the subject motion problem. Optical techniques suffer from resolution issues and are incapable to detect inner organ motions. MR navigators, however, not only lengthen the scan because of the time required for acquisition of the position information, but also require additional excitation pulses affecting the steady state magnetization. Furthermore, if the very high spatial resolution offered by ultrahigh-field MR scanners shall be exploited, the displacements caused by respiration and cardiac activity have to be considered. Thus, we propose applying a novel method, based on an ultra-wideband radar technique (UWB radar) [1] to monitor involuntary head displacements. Electromagnetic waves are reflected at interfaces between materials with different dielectric properties. This characteristic of UWB radar (0.1-10GHz, P_{rms}~4mW) has proved its ability to monitor non-invasively the motion of organs within the human body [2] or selected parts of the body as well as obtaining images of internal structures. With our combined MRI/UWB prototype system we could demonstrate the absence of any mutual interference between both systems, proving the feasibility of the UWB radar method in a 3T scanner [3, 4]

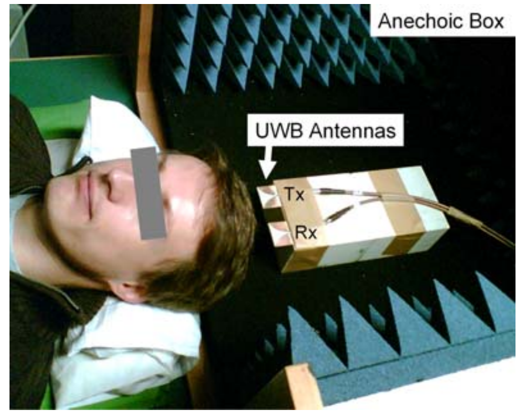

Fig. 1: Volunteer in supine position breathing normally exposed to UWB signals in the GHz range using transmitting and receiving tapered slot antennas.

Materials and Methods

To monitor the involuntary displacements of the head induced by respiration and cardiac contraction, we positioned a volunteer in supine position at the opening of an anechoic box. The MR-compatible tapered slot UWB-antennas (Tx/Rx, Vivaldi type) are positioned perpendicular to the vertex where larger vessels rarely occur (Fig.1). In this way the pulsation signals from subcutaneous vessels, especially from those of the side of the head, the throat and the brain stem can be excluded. In contrast to optical techniques the volunteer's hair does not affect the measurements. The resulting reflected UWB signal is a superposition of multiple reflections. Cross-correlation data $\mathbf{R}_{xy}(\tau)$ from the transmitted and received signals provide information of the propagation time τ necessary for the electromagnetic pulse to reach the air/skin-interface of the vortex. In our case $\mathbf{R}_{xy}(\tau)$ is provided directly by the UWB controller. We utilized an M-sequence UWB radar system [1] (up to 5 GHz) which transmits a periodic pseudorandom waveform (maximum length binary sequence, MLBS).

Results

First in vivo results are shown in Fig.2. Since the UWB signals are very sensitive to interface displacements (< 0.1 mm) we used four small nodding events of about 1 mm in amplitude to localize the position of the head's surface in $\mathbf{R}_{xy}(\tau)$. The displacement of this reference point was then analyzed by observation of the (relative) variation of $\mathbf{R}_{xy}(\tau)$ over time. Thus we could detect all kinds of involuntary motions (respiratory, cardiac), even doze-off-events are visible, demonstrating the feasibility of interfacing a MR scanner with an external UWB radar based motion tracking system. Our system is capable of determining the object's position with sub-millimeter accuracy and an update rate of 44 Hz. Using the UWB tracking data of the volunteer's head the motion artifacts can be compensated in real time or by post-processing, enhancing the actual resolution of the MR scan.

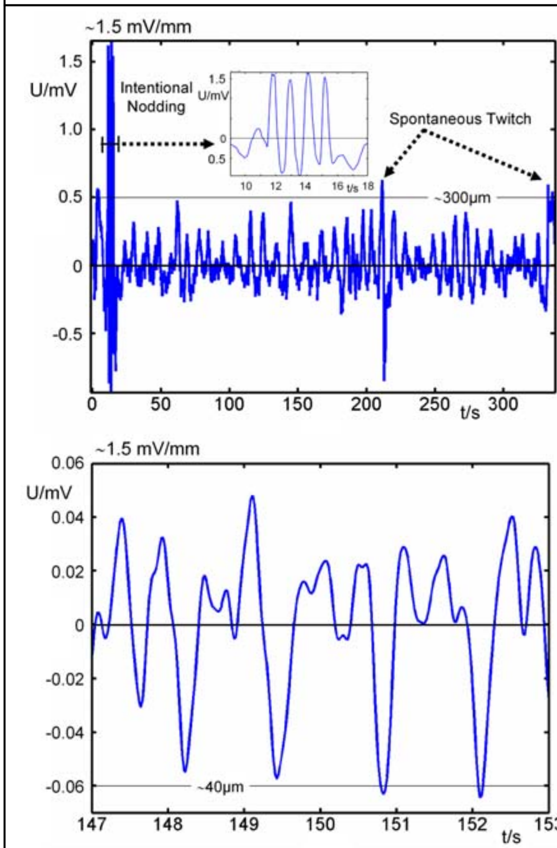

Fig. 2: *Top:* reconstructed motion from a 350 second measurement. The insert displays the 4 nodding events (~1 mm amplitude) to localize the head's surface. Respiratory displacement is clearly visible. Spontaneous twitches are highlighted. *Bottom:* selected filtered time interval from the upper time course, showing the cardiac induced displacements.

Acknowledgements

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References

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