Evaluation of a combined magnetic resonance (MR)/ultra-wideband (UWB)-Radar technique

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Introduction and Motivation

Due to the recent advances in ultra-wideband (UWB)-Radar technologies, there has been widespread interest in medical applications of UWB microwave Radar [1]. The reason for using UWB-Radar for probing the human body is obvious: Electromagnetic waves can propagate through the body and are reflected at interfaces between materials with different dielectric properties. This characteristic of UWB-Radar suggests an ability to monitor the motion of organs within the human body as well as obtaining images of internal structures. The specific advantages of UWB sensors are high temporal and spatial resolution (determined by the frequencies of operation and the total frequency bandwidth covered), penetration into objects (more pronounced at lower frequencies), low integral power, and compatibility with established narrowband systems [1]. The sensitivity to ultra-low power signals makes them suitable for human medical applications including mobile and continuous non-contact supervision of vital functions. Since no ionizing radiation is used, and due to the ultra-low specific absorption rate (SAR) applied, UWB techniques permit non-invasive sensing with no potential risks. This research aims at the synergetic use of UWB sounding combined with magnetic resonance imaging (MRI), to gain complementary information, e.g. to accelerate cardiac MR imaging or to measure the electromagnetic wave propagation through heterogeneous, malignant and benign, biological tissue more accurately. We propose the multi-modal combination of MR and UWB-Radar for improved functional diagnosis and imaging.

Materials and Methods

To evaluate a combined MRI-UWB technique, defined moveable MR-compatible tissue phantoms are needed mimicking both, dielectric and NMR properties of biological tissue in the frequency range covered by UWB technology (1-10 GHz) [2]. We developed a demonstrator made of MR compatible multilayer phantoms. When exposed to electromagnetic waves in the frequency range of 1-10 GHz, these phantoms provide reflection signals similar to those of the human thorax. These dielectric phantoms were built from planar disk-shaped slices (arbitrary thickness, ∅ 150 mm) utilizing an oil-in-water emulsion stabilized in an agarose gel (Fig.1). Materials with low permittivity ε', like fat tissue, are formed by a silicon gel. The dielectric phantoms were arranged in a sandwich structure, to mimic the sequence of biological tissue layers of the human thorax. Such a sandwich was placed in a moveable sledge-like fixture. This particular fixture allows the longitudinal movement inside a birdcage MR head coil. The movement is generated by a stepper motor over a long leverage (3 m). The stepper motor allows to move the sledge with a resolution of 5.2 µm. The leverage connecting the motor with the sledge is built from carbon-fiber reinforced plastic (CFK) to achieve smallest compressibility and deflection. Experimentally, we have shown that the error due to compressibility and deflection lies below 1 mm. The motion profile of the sandwich structure was shaped, to approximate a respiratory induced motion of the thorax superimposed by cardiac oscillations (Fig.2).

We utilized a M-sequence UWB-Radar system (up to 5 GHz) [3] and MR compatible UWB antennas to detect the motion of the phantom inside a 3 tesla MR scanner (Bruker MEDSPEC 30/100). The UWB antennas were placed perpendicular to the sandwich structure at a distance of 40 cm. A flow-compensated gradient echo CINE (time resolution 50 ms) sequence was used to reduce artifacts generated by the phantom (Fig.1) movements. For synchronization, this sequence was triggered by the stepper motor controller. Sporadic image artifacts caused by higher order movements (acceleration) did not hinder the analysis of the MR data which was simply done by manual determination of phantom edges in the 128 time frames.

Fig. 1: Coronal MR image of a muscle-equivalent layer phantom (∅ 150 mm) embedded in two fat-equivalent layers of 3 mm thickness (propane-1,2,3-triol doped silicon gel).

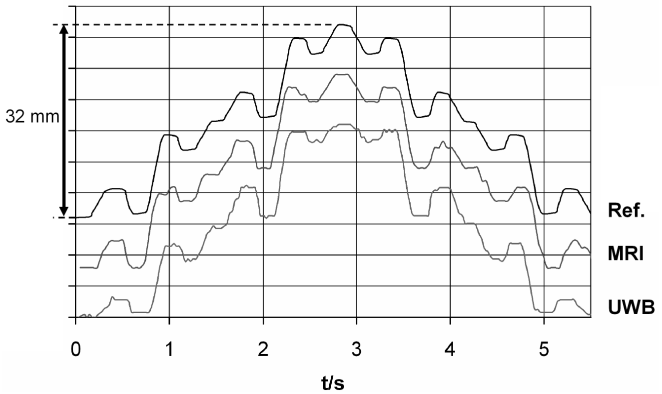

Fig. 2: Comparison of the reference profile with the data obtained simultaneously from MR and UWB-Radar measurements. The profiles are offset for clarity.

Results

Comparing the three datasets on the phantom position we find good agreement between the reference profile from the stepper-motor controller, MR derived edge positions and UWB measurements. Furthermore, the spatial resolution of the UWB-Radar is similar to the one provided by MRI (~1 mm). These first results are very encouraging for the development of multi-modal imaging techniques, which combine complementary information from different sources, e.g. to remove the ambiguities from inverse problems, to improve the image quality of cardiac MRI, and to extend its range of applicability to less-cooperative patients.

References

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