Image processing for on-line reduction of thermometry artifacts

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Purpose/Introduction

Local hyperthermia has been developed in clinical practice as a tool for ablation of non operable tumours. An on-line monitoring of temperature evolution and an immediate estimation of the effectiveness of the treatment are both highly desirable during the intervention. The Proton Resonance Frequency (PRF) technique gives an estimate of the temperature changes by comparing phase contrast between dynamically acquired images and reference data sets [1]. The temperature evolution allows on-line thermal dose evaluation during the intervention, which in turn permits an accurate estimate of tissue necrosis. However, organ displacements due to physiological activity (heart and respiration) may induce important artefacts on apparent temperature maps. When motion effects have been reduced in the MR pulse sequences (e.g. saturation slabs, respiratory and/or cardiac synchronisation, navigators), additional image post-processing may be applied to reduce inter-scan motion related errors in PRF. Processing of an image must be done between two successive acquisitions to ensure on-line monitoring of temperature.

Subjects and Methods

Both PRF-shift with temperature and movement of the patient result in phase variations and it is not possible to separate these two contributions within a single phase image. Therefore, for mobile organs, the phase is modified by the two addititive effects:
First, organ displacements induce a modification of the spatial localization of the MR-signal. Therefore, temporal phase variation for temperature measurement is performed on pixels corresponding to different spatial localization in the magnet. Thermal dose computation is thus also prone to errors as, for each pixel, the history of the temperature corresponding to the same spatial localization in the organ is no longer assured. Organ displacement can thus be evaluated using robust motion estimation algorithms based on MR anatomical images for rigid as well as elastic motion. Indeed, "optical flow" processing approaches can relate the coordinate of each part of the tissue in the current acquired image with the reference corresponding one [2]. The reference image is chosen to be the first one in the temporal serie. The obtained motion field is then used to improve the precision of on-line temperature measurement by performing phase difference on pixels corresponding to identical spatial localisation.
Second, although the spatial transformation of the reference phase image can be corrected, an unwanted phase shift cannot be suppressed as the local magnetic field is modified when a motion occurs. Modelling of an inhomogeneous susceptibility field in-vivo is difficult. Therefore, phase perturbation with motion is analyzed in a pre-treatment step performed prior to the intervention. A complete set of reference magnitude and phase images is constructed. During the intervention, the phase image of the reference set acquired with the corresponding organ position is selected with an inter-correlation coefficient computed for magnitude image, and then used as a reference for temperature computation. This strategy allows correcting on-line periodical inter-scan motion related errors in PRF, avoiding explicit modelling of the susceptibility field.

Results

Stability of the thermometry has been evaluated both on ex-vivo meat samples heated with a focus ultrasound device (n=5) and the abdomen of healthy volunteers without heating (k=3).

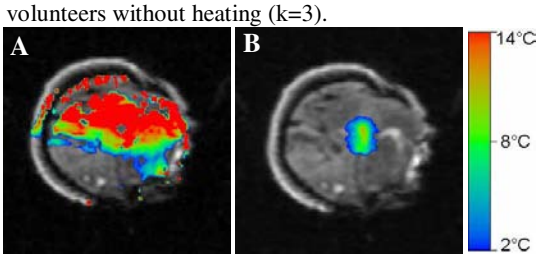

Figure 1. Thermometry stability on an ex-vivo muscle heated with a focused ultrasound device.

Figure 1 displays temperature maps obtained on-line on ex-vivo meat undergoing a mechanical periodic motion of amplitude 14mm and period 5s. One slice (resolution 128x128, pixel size of 1.5x1.5mm) was acquired each second with a single shot sequence (TE 40,9ms). Temperature maps after one minutes of heating at 100W are reported without (A) and with (B) the proposed correction. The heating area is spread along 14mm length illustrating the motion of the target whereas the focal point position is fixed. Temperature standard deviation outside the heating region is respectively 30°C and 0.7°C without and with the correction.

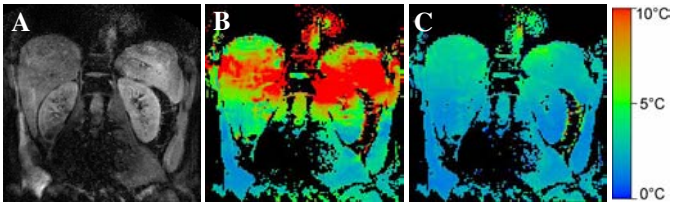

Figure 2. Thermometry stability on the abdomen

Figure 2 displays a coronal magnitude image (A) of the abdomen for one of the volunteers without synchronisation techniques. One slice (resolution 128x128n, pixel size of 2.5x2.5mm) was acquired each 400ms with a segmented EPI sequence (TE 18ms, 21 lines/TR). Temperature temporal standard deviation maps are reported without (B) and with (C) the proposed approach. Temperature standard deviation in the kidney and the liver are respectively measured to 2.7°C and 3.7°C.

The implemented algorithm for image registration required 250ms of computation time on an Athlon 3.2GHz with 1.5Gb of RAM, demonstrating that temperature correction can be performed on line even without synchronisation techniques.

Discussion

This study demonstrates that efficient improvement of temperature stability can be obtained with the use of additional image processing. The proposed approach can be used without synchronisation techniques, with the condition that the imaging plane contains the main direction of motion, to increase the temporal resolution of the acquisition and allow regular time delay between successive acquisitions. Alternatively, it can also be combined with synchronisation techniques to improve the stability of thermometry on organs with high susceptibility perturbations when synchronisation techniques are insufficient.

References

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2-Barron J.L., et al [1994], International Journal of Computer Vision, 12:43-77.