Continuous Liver Tracking During Free Breathing MRI Guided Focused Ultrasound

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Introduction

MRI guided focused Ultrasound (FUS) tissue ablation of the liver during free breathing requires continuous tracking of all the points to be treated (target points) throughout the treatment so that the FUS transducer can deliver the energy to the right position. In this work we present a tracking method based the liver blood vessels. The tracking is applied using a restricted FOV (rFOV) single shot gradient echo EPI sequence with imaging speed of up to 25 images/sec, suitable for temperature measurement using the Proton Resonance Shift (PRS) method.

Method

During FUS heating the EPI sequence is applied continuously. Due to the short TR the blood vessels of the liver appear bright and therefore they are used as landmarks that track the liver motion. The landmarks locations are calculated continuously, and the movement of any arbitrary point in the liver is determined by 2D interpolation of these locations. Tracking is done as follows: 1) One of the first EPI images is used as a reference image. The landmarks are set automatically on some of the blood vessels that are suitable for tracking. 2) The point to be treated (target point) is set on the reference image. The location of the target point is derived from a high-resolution planning image acquired shortly before the reference image. 3) During FUS heating the landmarks are tracked and the location of the target point is found by interpolation. This procedure is repeated for all the target points and the reference image is refreshed before each heating.

Landmark selection: The landmarks are selected as follows: 1) Set a threshold on the signal amplitude such that the brightest N (we use N = 12) isolated groups of pixels are above it and all the rest of the pixels (below threshold) are ignored. 2) Calculate autocorrelation maps (ACM) (1) for each of the N groups around its surrounding. 3) Find how directional are the N ACM's. Use only groups with circular or square shape to avoid long in-plane blood vessels and other features that are not related to the liver motion.

Tracking: During tracking, a cross-correlation map (CCM) (1) is calculated over a search patch around each landmark between the reference image and the first image. The shift of the CCM maximum value is the shift of the landmark in the first image relative to the reference. This shift is calculated during heating for all image-pairs k – 1 and k. A major problem is the pulsatile motion and change of shape of blood vessels. This causes low cross-correlation and sometimes a shift that exceeds a predefined maximum. If this happens the relevant landmark is ignored in the target point interpolation. Later on, if the cross-correlation increases again, the feature becomes usable again.

Target point interpolation: The current landmarks positions are used to calculate the current target point location using regularized radial basis functions 2D interpolation (2) or the Shepard method (2).

Results

This tracking algorithm (MATLAB) was applied to 10 datasets of 3 different volunteers with 200 images in each dataset. The data was acquired with an 8 channel phased array coil at 1.5T, TR = 68 msec, slice width 6 mm FOV 30 x 12 cm and pixel size of 1.8 x 1.8 mm. In all cases the landmark tracking and the target point interpolation (at any arbitrary location) detected the motion correctly with ~1mm accuracy. This is demonstrated in the Figures below. Figure 1 is the reference image and the red circles represent the landmarks over the blood vessels. Figure 2 shows image 20 from a series of 200 images during tracking. The squares are the tracked landmarks. Green squares represent "good" landmarks and the red square ("bad" landmark) is ignored. The yellow circle is the target point.

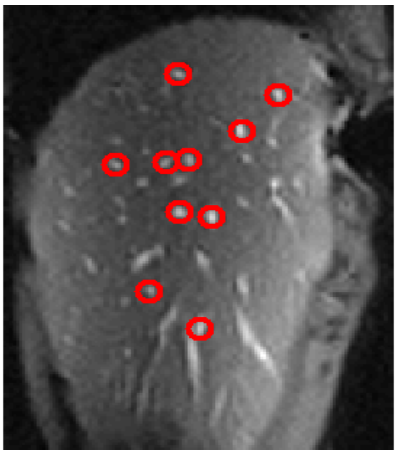

Figure 1: Reference image.

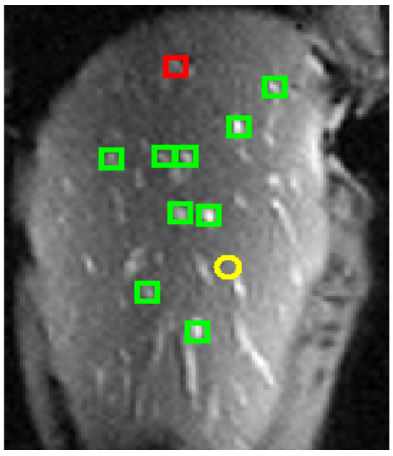

Figure 2: Image 20 from a series of 200 images during tracking.

References
(1) Numerical Recipes in C, chapter 14.5 (1992).
(2) Numerical Recipes, chapter 3.7 (2007).