Hot Spot Tracking for Focused Ultrasound Surgery of Liver using Filtered Venography

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Introduction The purpose of this study is to develop a magnetic resonance technique for tracking a hot spot created in focused ultrasound surgery (FUS) in abdominal organs such as the liver, which moves and deforms with respiration. In order to provide a sufficient thermal dose to the target and to protect the surrounding normal tissues, the focal spot has to be "locked on" the target and the temperature distribution around the target has to be imaged even when the position and shape of the organ change. Although breath-holding would be effective for a single sonication, it is not practical for multiple sonications required for a large target volume. To date, a few navigator-echo-based techniques have been reported to determine the present position of the organ and to synthesize a retrospective baseline k-space data in which the organ position was closest to the present[1, 2]. In these methods, however, no organ deformation is considered. More recently, the combined method of target tracking and multiple-baseline temperature imaging has also been reported[3] based on the assumption of periodic organ motion. In this approach, errors in tracking and thermometry may increase when the periodicity of organ motion is lost. The "referenceless" or "self-reference" thermometry does not require baselines[4, 5]. This type of techniques is robust for organ displacement and deformation as far as the hot spot is tracked. In the FUS treatment, no needle or fiber is used and hence tracking of the target position and placement of the temperature-imaging slab have to be performed without any external markers. Thus, in this work, we have examined a hot spot tracking technique based on relative displacement of blood vessels in the liver.

Methods Sagittal images of healthy volunteer's liver (N=3; 26, 24, 25 y/o) were acquired by a 1.5 T MRI (Signa Excite 11, GE Healthcare Inc, Milwaukee, WI) with Fast Imaging Employing STeady state Acquisition (FIESTA) under the following conditions; TR / TE, 5.2 / 1.7 ms; slice thickness, 4.3 mm; field of view, 400 × 400 mm^2; spatial matrix, 128 × 128; flip angle, 45 or 50; and read out band width, 31.25 kHz.

The vessel edges, which appeared as hyper-intense in the T2/T1 contrast because of in-flow effect, were enhanced by "Sobel" filter of 1-10-1 × 0-0-0 × (-1)-(-10)-(-1) kernel after the entire image fields were smoothed by a 3 × 3 moving average filter. An edge enhanced image is shown in Figure 1, where the brightness of the vessels edges has a higher intensity than other areas in the liver. Several vessels of interest were the extracted and numbered. The positions of the gravity points of the vessels of interest were obtained by calculating the average of x- and y-coordinates of the voxels included in the vessel contours, and were recorded. Figure 2 shows a schema for determining the hot spot from the positions of three vessels of interest before and after respiration. The relative relationship between the vessels and hot spot was kept as an elastic four-node mesh. To prevent estimation mistakes and to assess the estimation accuracy, various combinations of the vessels (more than three) were examined. The hot spot position was obtained as the average of the estimated coordinates which were derived from those combinations.

Moreover, the prediction technique of the hot spot using the prior images was proposed to correct the time delay declination which was caused by the MR imaging, calculation of hot spot estimation and transducer setup. The criterion image in the prior images was set by comparing the positions of the vessels of interest between the prior and present images, and the positions of the hot spot after present images were predicted by using the images obtained from the criterion image. The images of five respiratory motions as the prior images, and the five present images per volunteer were used.

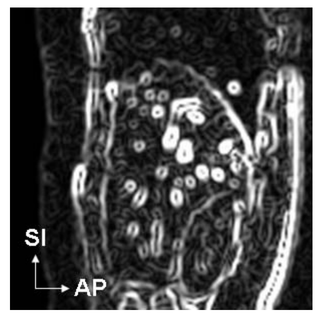

Figure 1 Edge-enhanced image. The boundaries of vessels were reinforced by executing the image processing.

Results Figure 3 shows the average errors of distance acquired by comparing the estimated and measured positions of 127 images in the experiments in which vessels were used to resemble the hot spot. From this result, five vessels of interest in each trial were used to make the combinations. The average error in eighteen trials was approximately 1.2 mm. Figure 4 shows the average errors of distance acquired by comparing the predicted and measured positions of ten present images; five images spanning 1200 ms. The average error in the later 1200 ms was less than 4 mm per volunteer. The magnitude and the trend of errors which were caused by the time delay were different for each volunteer.

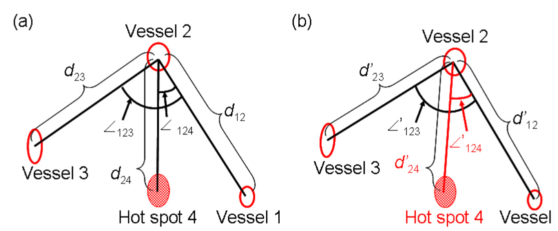

Figure 2 Schematic diagrams of positional relationship between the vessels of interest and hot spot (a) before and (b) after respiration. The relative positional relationships among the vessels and the hot spot were maintained like those in an elastic four-node mesh.

Discussions The proposed method was applied to the vessel structures in liver. Although a similar approach can be found in the analysis of pulmonary kinematics[6], our target was a internal target determination in the liver. As shown in Figure 3, the targets were successfully estimated in all the trials. The maximum error was not larger than 3 mm. Thus, this method may be acceptable for determining the target position and the imaging slab orientation, because the typical effective size of the hot spot in FUS is larger than the maximum errors. As shown in Figure 4, there was variation in the errors for each volunteer. The reasons for this were thought to be a result of the difference in the respiratory conditions of each volunteer, and that the images which were acquired after the present image were not the same as the prior images after the criterion image. However, the predicted accuracy of hot spot tracking was sustained. Therefore, the proposed technique is sufficient for guiding the focus and imaging slab position and orientation.

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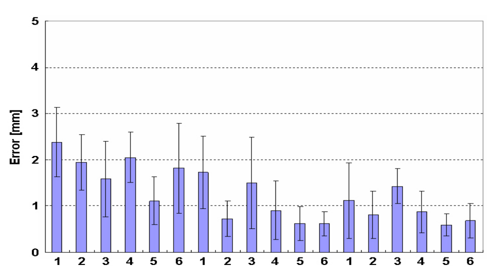

Figure 3 Average errors in distance between the measured and estimated positions of the target. Error bar shows the range of standard deviation.

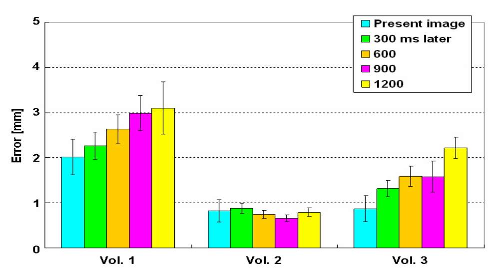

Figure 4 Average errors in distance between the measured and predicted positions of the target. Error bar shows the range of standard deviation.