A Reliable Real Time Liver Motion Tracking for Application in Magnetic Resonance guided High Intensity Focused Ultrasound Therapy

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Introduction

High-intensity focused ultrasound has shown potential for ablating liver tumors without the need for surgical procedures [1]. However, the long duration of HIFU scans (~2hrs) and the varying respiratory motion requires that features identified for sonication be tracked in real time during the procedure [2]. The real time tracking would enable a free-breathing MRgFUS treatment and thus avoid the need for general anesthesia. Recently, a thin plate spline (TPS) based interpolation algorithm has been shown to independently track several salient features (typically blood vessels) in the vicinity of the treatment target for MR guided focused ultrasound [3]. In this work, we performed statistical evaluation of the interchangeability of this automatic tracking algorithm as compared to the manual tracking of the features on the liver. This analysis is necessary to: a. ensure that the liver features can be tracked accurately in clinical setting; b. determine the size of the errors introduced due to automated tracking c. provide the clinicians a measure of quality control when using the automated tracking algorithm in case of moving targets such as liver.

Methods and Materials

Real-time, free breathing single slice coronal MR datasets, covering the abdomen were acquired from five healthy subjects on a 1.5 T, GE Signa Excite MRI scanner. The acquisition was done using 2D MR Echo Fiesta protocol (TE/TR = 0.98/2.39 ms, in plane resolution = 2.8 mm x 2.8 mm, Slice thickness = 8mm, spatial matrix = 128 x 128, flip angle = 45º, FOV = 360 x 360 mm^2) using a 8-channel cardiac coil. A trained radiologist selected a total of 12 features (Fig 1) over the five subjects and manually tracked them. The scans being in coronal plane, abscissa represented motion along the left –right (LR) anatomical direction, while the ordinate represents the motion along superior-inferior (SI) direction. We then placed small squares (15 x 15 pixels), centered at manual points in the first frame of the time-series and ran the automated tracking algorithm as described in [3]. Both the manual and automated tracking algorithms/programs automatically store the results in a MS excel worksheet, which was used for subsequent analysis. The repeatability evaluation was done by analysis of Bland – Altman plots for manually and auto-tracked coordinates along the L-R and S-I directions. The quantification was performed by calculating: a. the root mean square error (RMSE),

$$RMSE = \sqrt{\sum_{i=1}^{N} (auto - manual)^2 / N}$$ b.

Variability $var = |auto - manual| / 0.5 \times (auto + manual)$ and c. the 95% confidence interval bounds

$$Lim_{95\%} = \left(\frac{1}{n} \sum_n (auto - manual) \right) \pm 1.96 * \sigma(auto - manual)$$ along the L-R and S-I direction.

Figure 1. The sample slice data shown along with the features identified for automatic tracking. The red tracking boxes have been exaggerated for better visibility.

Results and Discussion

As seen in figure 2, the degree of motion is much higher and varied (broader distribution) along the S-I direction ($\overline{\sigma} = 3.7$ mm) compared to the L-R direction ($\overline{\sigma} = 0.84$ mm). The TPS based tracking algorithm performs excellent tracking along the S-I direction (Figure 3B) as compared to L-R direction (Figure 3A). This indicates that the performance of the TPS interpolation is affected by the noisy dataset (or degree of motion such as the motion along the L-R direction) and subsequently has a lower tracking accuracy. As demonstrated by figures 4a and 4B, the RMSE value (S-I = 1.8 +/- 1.5mm; L-R= 2.9 +/- 1.2 mm) and variability (S-I = 0.8 $\pm$ 0.6%; L-R = 15 $\pm$ 24 %) between manually and automatically tracked features were significantly lower for motion along SI compared to L-R direction (p < 0.05). The average error of less than 3 mm is favorable for use of feature detection for MRgFUS therapy as the focal spot radius for the HIFU beam is larger (typically 3 mm or greater). The results also compare favorable with another study whose tracking errors were similar; albeit with a different approach for motion detection [4]. On eliminating one outlier the variability along L-R dropped to 8 +/- 8% while no significant deviations were observed for RMSE and variability along S-I. This suggests that in cases were the degree of feature motion is significant, TPS based motion-based algorithm is capable of sub-pixel accuracy for determining the displacement of features around the HIFU target. This is significant as most of the motion of the liver is typically along the SI direction and accurate determination of motion along this axis is crucial to successful application of HIFU sonication to the tumor. The results also suggest that a minimum threshold has to be determined, below which other ways of tracking the motion have to be explored. This could possibly include changing of optimizer settings for the current algorithm or use of Kalman filter based variants. Figure 4 summarizes the Bland-Altman plots and indicates that the maximum bias of (95% confidence interval) of ~5mm along the L-R and ~3.5 mm along the S-I direction for the automated tracking algorithm.
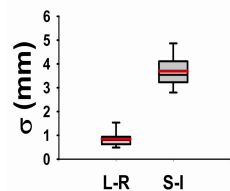

Figure 2. Standard deviation (σ) of the displacements along the L-R and S-I direction
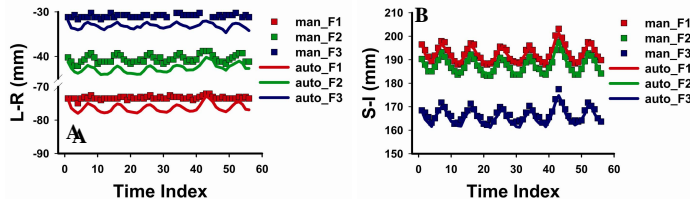

Figure 3A and B. The displacements (□) of a reference feature as traced manually are shown along the L-R and S-I direction. The motion tracked by the automated TPS algorithm is shown with lines super-imposed on the manual track -points
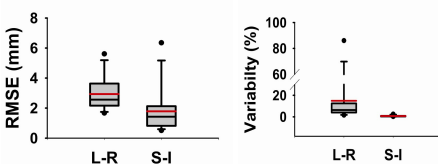

Figure 4A and B. The RMSE and variability between the manually and automatically tracked features along the L-R and S-I directions.
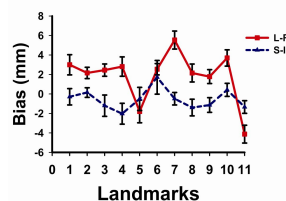

Figure 5. The mean bias and 95% CI (bars) for the landmarks (after eliminating one outlier) along the L-R and S-I direction obtained from Bland-Altman analysis

Conclusion

Real time motion tracking using a quasi-automatic algorithm is consistently comparable to manual tracking, and could reliably replace the tedious manual tracking of features during the MRgFUS therapy procedure. Clinically, this can reduce damage to the healthy tissue by sonicating only the pathological tissue and thereby improve the outcome of the HIFU procedure.

References

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