Towards real-time tracking of anatomic features for HIFU beam steering

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Introduction

A challenge for High Intensity Focused Ultrasound (HIFU) therapy in the upper abdomen is maintaining the ultrasound focal spot on the target during free breathing. Normal breathing can cause liver tissue to move by as much as 5.5 cm[1]. Consequently, current approaches require the patient to hold their breath during the deposition of focused ultrasound[2]. This practice assumes that the target lesion will return to the same location in each breath hold throughout the treatment. While consistent breath holding may be possible with patient training and feedback mechanisms, a more significant limitation to this approach is that gating ultrasound delivery to the respiratory cycle reduces the treatment duty cycle to the point where perfusion results in a significant dissipation of the ablation energy.

To obviate the need for breath holding and to increase the treatment duty cycle, we developed a real-time method to automatically locate the target lesion location during a free-breathing treatment. Target coordinates generated in this fashion can then be fed to the Focused Ultrasound system to dynamically steer the beam in response to physiological motion.

Materials and Methods

The algorithm we developed employs user-selected Reference Points (RPs) to locate the therapeutic target during free-breathing examinations. The algorithm is able to handle a variety of expected and unexpected motions due to free-breathing and mild patient motion while providing real-time feed back to the clinician, and simultaneous target position updates to the HIFU system.

Two different feature tracking methods were developed. The first method exploits the strong pixel intensity of blood vessels compared to liver parenchyma in many high-speed imaging protocols. This algorithm searches for approximately circular features having high pixel intensity as they move during breathing. User controlled parameters define search zones and provide an expectation for maximum feature movement between imaging frames.

The second feature tracking method targets the sharp contrast change between the diaphragm and lung. With this algorithm, the user simply identifies several points along the diaphragm. These points are then interpolated to define a curve and in subsequent image frames, the location of the diaphragm at each point along the curve (as many as 100) is determined. Several algorithms to locate the diaphragm were investigated. The most robust algorithm developed to date looks for the sharpest discontinuity in signal intensity in the Superior/Inferior direction in which the stronger pixel intensity occurs in the inferior direction, and there are no low-signal pixels (i.e. lung) inferior to the point. This algorithm proved particularly adept at avoiding the misidentification of pulmonary blood vessels as diaphragm.

The software was written in C++ and developed in Qt to facilitate integration with RTHawk. Image data from a healthy volunteer was acquired on a Philips 3T Achieva system.

Table 1

Algorithm Requirements
- Handle at least 5 images/second
- Can relocate RPs independent of each other
- Adapts to varying motions
- Uses between one and eight RPs

Software Requirements
- Programmed in the Qt development framework
- Provide easy to use user interface
- Provide compatibility for DICOM and Analyze image formats.
- Provide Window-Level Settings
- Adjustable Playback Speed for testing

Results and Discussion

Real-time feature tracking was tested retrospectively on MRI images of the liver during free-breathing. The diaphragm and blood vessel tracking methods successfully followed arbitrarily defined targets during free-breathing, and could be used independently or together (see Figure 1). The accuracy of target tracking was estimated to be better than two image pixels (or 1/128 of the Field-of-View) over several minutes of free-breathing.

The image data sets that were used to test the new software algorithms were acquired at rates of 5 frames/s. This is considerably slower than the CPU-limited feature tracking rate of 30 frame per second that was observed when the tracking software was used to retrospectively follow arbitrarily targets in the liver.

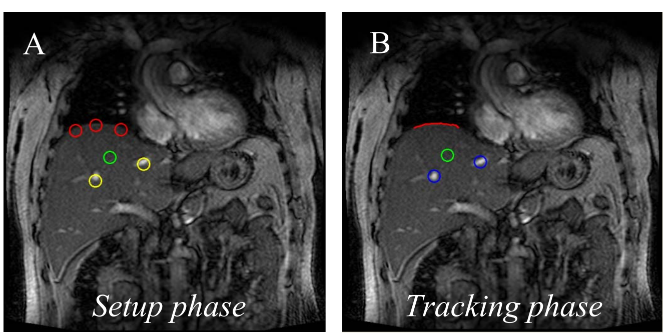

Figure 1: Screen snapshots from the new feature-tracking software. (A) Image A shows two blood vessel RPs (yellow circles) and the initial diaphragm RP selection (red circles) during the setup phase of the procedure. (B) During the tracking phase of the procedure, blood vessel RPs become blue circles and the diaphragm RPs become a red curve that follows the diaphragm during free breathing. In this example, the target (green circle) was selected arbitrarily. Although a continuous stream of target coordinates were generated at the rate exceeding image acquisition, these results were obtained off-line and the coordinates have not yet been sent to the focused ultrasound transducer.

Conclusion

The simple algorithmic approaches that we developed appear to be both sufficiently fast and robust to steer a HIFU beam in real-time to permit HIFU lesion ablation during free-breathing. The next step will be to use these algorithms to steer an actual HIFU beam during real-time MR imaging of free breathing.

References

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