2D-3D Real-time Rigid Registration to Compensate for Liver Motion During Interventional Therapy

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MOTIVATION

- In men, hepatocellular carcinoma (HCC) is the 2nd leading cause of cancer related deaths worldwide, mostly in developing countries.\(^3\)
- Minimally invasive percutaneous techniques, such as radio-frequency and microwave ablation, are a rapidly expanding research field to treat 70\% of patients who are not candidates for surgical resection or liver transplant.\(^2\)
- These techniques have higher local recurrence rates than surgical resection, often caused by insufficient or inaccurate local ablation of cancerous cells.
- Deformation and motion of the liver from breathing and cardiac cycles are the most significant sources of error.\(^3\)
- 3D transrectal ultrasound (TRUS)-guided systems have recently been used to compensate for prostate motion near real-time (~1 s) to an accuracy < 2 mm with an automated intensity based method.\(^4\)

OBJECTIVES

- Similar to the developed prostate motion compensation algorithm,\(^6\) the normalized cross correlation (NCC) using Powell’s method will be evaluated for liver 2D-3D registration.
- Future HCC tumors will be segmented preoperatively and registered real-time to increase accuracy of therapeutic applicators currently not available.

METHODS

3D US Abdominal Scanning System

- A commercial Ultrasonix Sonixtouch system with a C5-2 curvilinear transducer was used.
- A stabilizing arm was manufactured to support the custom built transducer holder. The holder was moved by 3 motors, allowing full range of motion needed for ultrasound acquisition.
- Acquisition software was developed to control and reconstruct linear, tilt, and hybrid US volumes with fully automated real-time motion compensation capabilities.
- Written consent from 7 healthy volunteer subjects was obtained to test the system.

METHODS

2D-3D Registration Workflow and Analysis

- 3D hybrid and tilt US volumes and 2D live stream images were acquired during subject breath hold, similar to a percutaneous treatment.
- The volume was transformed and resampled to compute the target registration error (TRE) from the Euclidean distance between corresponding fiducials \(f\) in the volume and \(N\) 2D images:

\[
TRE = \sqrt{\frac{\sum_{i=1}^{N}(f_{vol} - f_{2D})^2}{N}}
\]

- To account for user variability, the fiducial localization error (FLE) was measured in 5 acceptable 3D and 2D images over 5 days with 15 identified fiducials \(n\):

\[
(FLE)^2 = \sigma_x^2 + \sigma_y^2 + \sigma_z^2
\]

- For each fiducial \(i\) the variance \(\sigma^2\) of the X, Y, and Z coordinates over the 5 days was calculated to find the mean FLE:

\[
FLE = \frac{\sum_{i=1}^{N}(FLE)^2}{N}
\]

RESULTS

Hybrid Scan TRE

- 10 2D images were used per corresponding volume to calculate TRE values. Errors < 5 mm were considered clinically acceptable.

Subcostal Scans

Intercostal Scans

Tilt Scan TRE

FLE and TRE Component Error Analysis

- 3D volume FLE = 0.5 ± 0.2 mm
- 2D image FLE = 0.28 ± 0.05 mm
- Euclidean distance components between 3D and 2D fiducials after transformation were used to create a 95\% confidence error ellipsoid

REFERENCES


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