Performance of ultrasound based 3D intra-fraction organ motion tracking

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Introduction and background

- We propose that 3D commercially available ultrasound probes can be used to monitor intra-fraction abdominal organ motion during radiotherapy[1] (see Fig.1).This will:

  Eliminate set-up error related to probe pressure

  Enable us to monitor organ motion without the use of surrogates

- 3D abdominal probes have a spherical geometry and therefore spatial sampling varies with depth (see Fig.2) .

  Spatial sampling can be adjusted via spatial sampling settings (high, medium, low). However higher spatial sampling degrades temporal resolution.

- This paper:

  1. Evaluates the tracking performance as a function of depth, direction of motion and sampling setting in the absence of motion
  2. Investigates the trade off between trackable organ speed and depth
  3. Presents initial *in-vivo* measurements of liver motion due to respiration

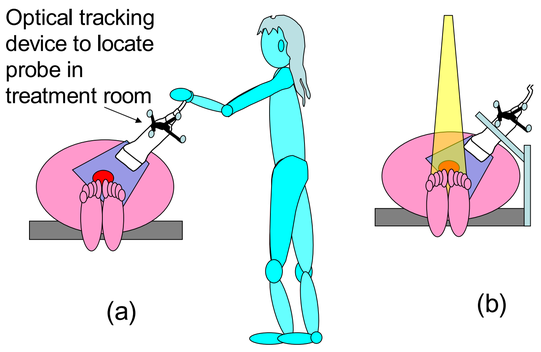


Fig.1 (a) Position of organ is found using 3D ultrasound

(b) 3D probe is clamped in place and 3D volume images are acquired during treatment.

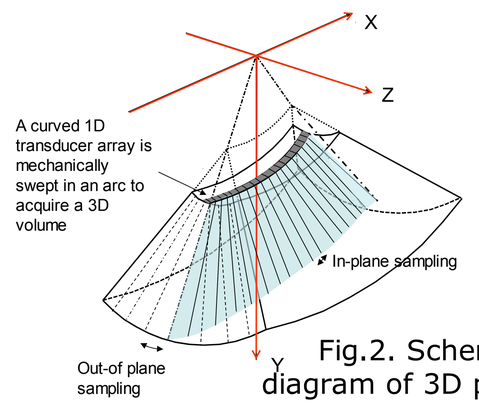


Fig.2. Schematic diagram of 3D probe geometry.

Method

- ***Phantom measurements (see Fig.3):*** 50 volume images were acquired before and after the probe had been moved by a known displacement. 3D tracking was performed using 3D cross-correlation and displacements were estimated for the parameters in Table 1.
- ***In-vivo measurement:*** Liver tissue motion was tracked in 3D as a function of time using 3D cross-correlation.

Depth	*4 – 18cm*
Spatial sample size (at 15cm)	*3mm (high), 4mm (med), 5mm (low)*
Distance	*1, 2 and 8mm*
Direction	*X, Y, Z and XYZ*

Table 1. Parameters investigated

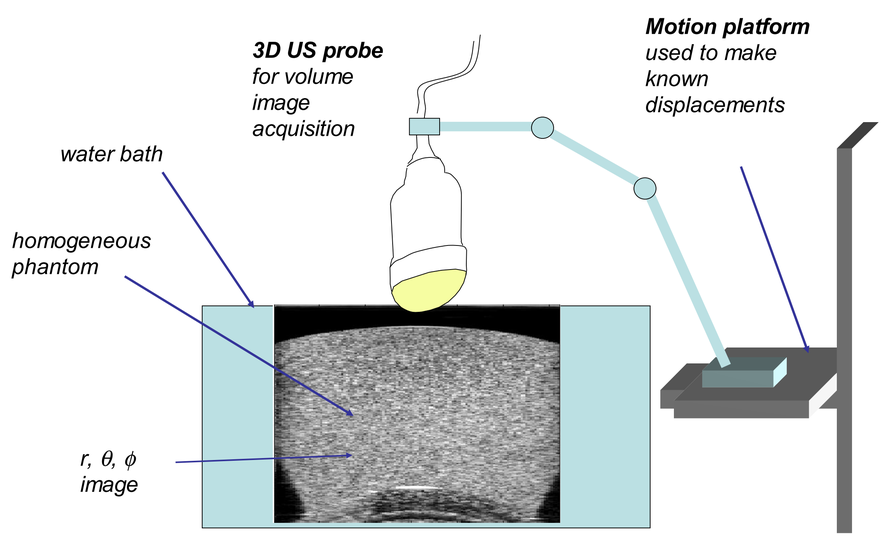
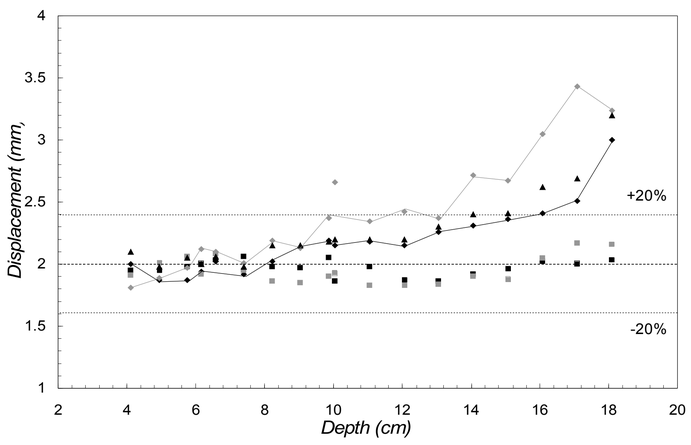


Fig.3. Schematic diagram of the experimental set-up.

Results & Analysis

1. Tracking performance

- Adequate tracking performance is defined as 80% accuracy
- Best tracking performance was obtained for 2mm displacements (Fig.4): in x up to 18cm and in z up to 13cm for both high and medium sampling settings
- Tracking is limited for small displacements at depth due to bias error in sub-pixel displacement estimate
- Poorer tracking for 8mm displacements due to angular de-correlation



Standard deviation of 50 measurements was < 0.1mm

Fig. 4. Displacement estimate as a function of depth for 2mm x,z and z(xyz) motions using high & medium spatial sampling settings

- All y-motions for all settings were tracked to within 95% accuracy
- Low sampling setting was not adequate for accurate measurement of x, z and z(xyz) motions

2. Organ speed as a function of depth (Fig.5)

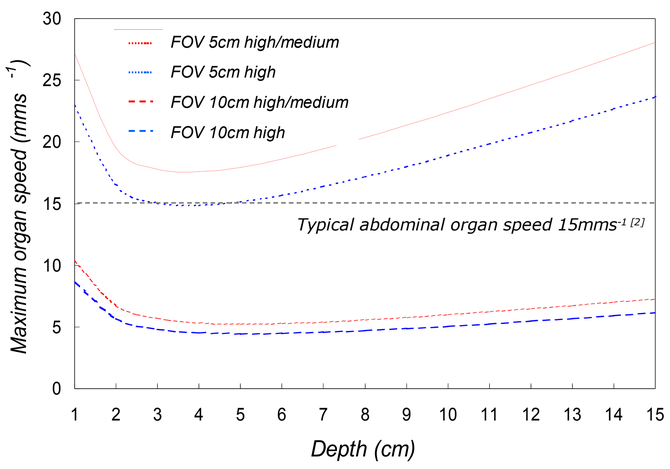


Fig.5. Maximum trackable organ speed as a function of depth using high and high/medium sampling settings

- Inter-volume motion can be limited to 2mm with adequate temporal resolution
- By reducing sampling setting in x-direction and/or FOV we can achieve temporal resolution that can measure organ speeds up to 25mms^{-1}
- Improved temporal resolution with depth due to reduction in acquisition time due for fixed FOV

3. In-vivo 4D tracking of liver motion (Fig.6)

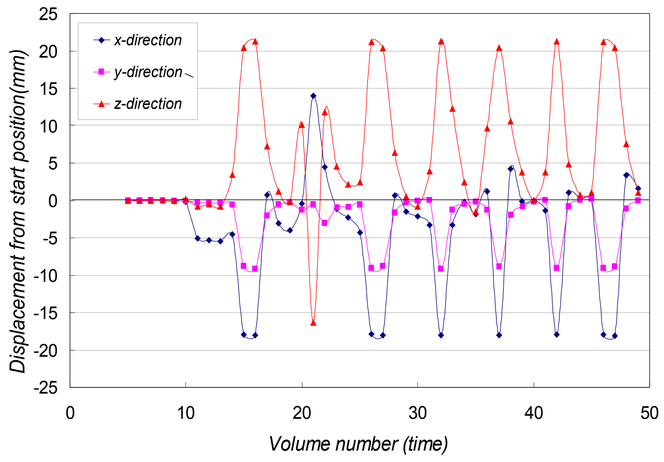


Fig.6. Liver motion tracking in the x y and z directions

- High sampling setting, FOV 10cm
- X, Y and Z motion tracked
- Larger (~2cm) liver motions can be tracked using consecutive displacement measurements

Conclusions & Future Work

- 3D displacements of 2mm can be accurately measured using a curved probe to depths of 13cm – this is suitable for radiotherapy intra-fraction motion tracking in which we want to detect ~mm movement
- Adequate temporal resolution can be obtained to track typical organ speeds[2]
- Initial in-vivo results demonstrate feasibility
- The next step is to look at effect of motion during acquisition on correlation tracking performance.

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References
[1] Hsu A *et al* 2005 *Med. Phys.* **32** 1500-15
[2] Pernot M, Tanter M and Fink M 2004 *Ultra. Med. Biol.* **30** 1239-1249