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Patient Specific Respiratory Motion Modeling on a Voxel-by-Voxel Basis Using Deformable Image Registration and 4D CT Imaging

Deformable Image Registration Enables Voxel-Level Respiratory Motion Tracking for Adaptive Radiation Therapy

AFFILIATIONS

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01. *Introduction*

Respiratory motion is one of the most significant challenges in radiation therapy for thoracic and abdominal cancers. Per AAPM TG-324, 83% of physicists consider motion management very important or required, and 95% use it clinically [1].

Current approaches—breath hold/abdominal compression (25%), ITV expansion (60%), gating (13%)—each have limitations. Respiratory motion causes tumors to shift from planned positions, resulting in geometric misses and dosimetric errors [1].

02. *Background*

4D-CT acquires volumetric images across multiple respiratory phases by scanning in ciné mode and sorting by phase (10 bins, 0–90%), capturing the full range of anatomical motion [2].

Deformable image registration (DIR) estimates a displacement vector field (DVF) mapping each voxel between images [3]. For 4D-CT, each phase is registered to a reference (0%), producing DVFs encoding full 3D voxel displacements. Approaches include Demons, Horn-Schunck optical flow, iterative variational, and level set methods [4].

03. *Purpose*

To develop and test a 4D motion model capable of accurately extracting respiratory motion on a voxel-by-voxel basis using 4D-CT imaging and deformable image registration.

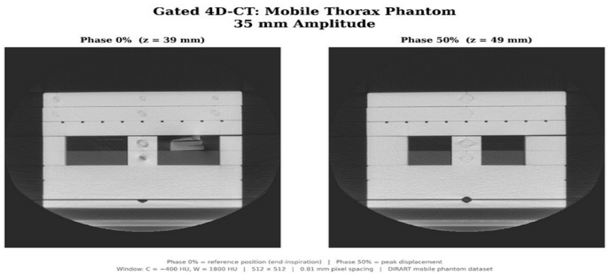

Figure 1: Gated 4D-CT of mobile thorax phantom at 35 mm amplitude. Phase 0% (z = 39 mm) vs Phase 50% (z = 49 mm). From raw DICOM. W/L: 1800/−400 HU.

04. *Methods*

Phantom and Data Acquisition

A mobile lung phantom was driven with cyclic motion at 5–35 mm amplitudes. Images acquired in gated ciné mode, sorted into 10 phase bins.

Registration Protocol

Four DIR algorithms from DIRART were used:

- Demons (Thirion, 1998) [4]
- Horn-Schunck Optical Flow
- Iterative Optical Flow
- Level Set

Each registered phases 10–90% to the 0%-phase reference. DVF values were calibrated against known amplitudes and used to reconstruct voxel-level motion trajectories.

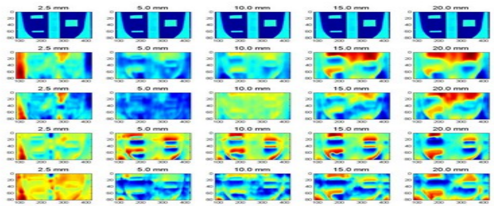

Figure 2: DVF in z-dimension via Horn-Schunck. Columns: amplitudes (2.5–20 mm); rows: phases. Color = displacement magnitude.

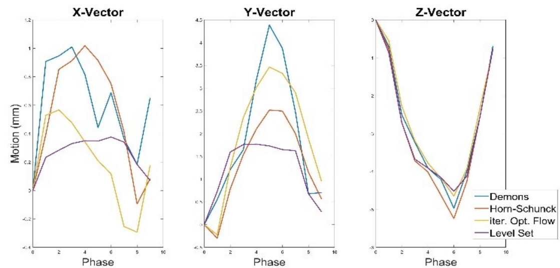

Figure 3: X, Y, Z deformation vectors for a single diaphragm voxel across phases. Four DIR algorithms compared.

05. *Results*

DVFs correlated with phantom motion amplitudes. All four algorithms produced consistent patterns: voxels displaced from the reference as the phantom moved through its cycle.

Slight inter-algorithm DVF magnitude differences were observed—Demons showed larger X/Y displacements—but the Z-axis showed strong agreement across all algorithms, consistent with the predominantly SI phantom motion.

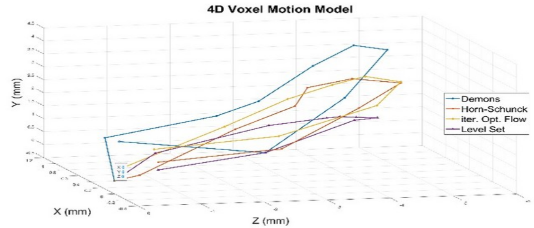

Figure 4: 3D voxel motion trajectory through all phases in X-Y-Z space. Four DIR algorithms compared.

06. *Discussion*

Agreement among four algorithms strengthens confidence that trajectories reflect genuine motion. Z-axis consistency aligns with dominant diaphragmatic motion.

A limitation is the rigid phantom. Patient-specific validation is essential before clinical translation.

07. *Conclusion*

Voxel-level motion trajectories were successfully reconstructed using DIR on 4D-CT. This technique has clinical potential for adaptive radiation therapy. Future work: patient data and dose accumulation integration.

08. *References*

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09. *Acknowledgements*

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