Consistent Multi-Modal Ventilation Imaging for Online Adaptive Radiotherapy Using Biomechanically Constrained Deformable Image Registration

P. Tzitzimpasis[1] , C, Zachiu[1], K. Keijnemans[1], M. Ries[1], B.W. Raaymakers[1]
[1]Department of Radiotherapy, UMC Utrecht

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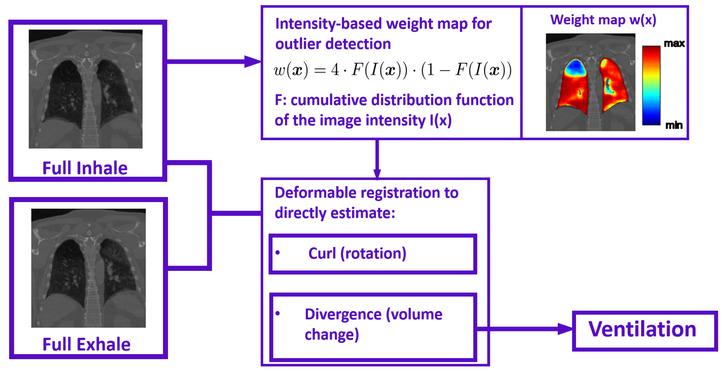
INTRODUCTION

Despite the significant volume of research in ventilation imaging, there is no existing method that can achieve high ventilation imaging accuracy while maintaining the ability to do so using different input data. To this end, we introduce a framework which relies on geometric information while incorporating information about the image intensity distribution without relying on the specific intensity values themselves.

METHODS

Hybrid image registration using:

- Non-linear diffusion regularization
- Intensity-based outlier detection for gradient filtering



Equation for estimated divergence:

$$\partial_t f(\boldsymbol{x}) = \hat{g}(\boldsymbol{x}) + \lambda \nabla (D(f) \cdot \nabla f(\boldsymbol{x}))$$

Gradient filtering

- Similarity-Gradient weighting by weight map w(x)
- Gradient normalization

Diffusion based regularization

$$D(f(\boldsymbol{x})) = \alpha \cdot \exp\left\{ -\beta \cdot \sqrt{|f(\boldsymbol{x})|} \right\} + \gamma$$

- Strong regularization when f(x) =0
- More confidence in regions with large local expansion
- Our implementation: $\alpha = 50, \beta = 4, \gamma = 2$

EXPERIMENTS/RESULTS

Patient datasets

- 45 4DCT/nuclear medicine patients (VAMPIRE dataset)
- 10 4DCT/4DMRI images of lung cancer patients
- 15 4DCT/4DCBCT images of lung cancer patients

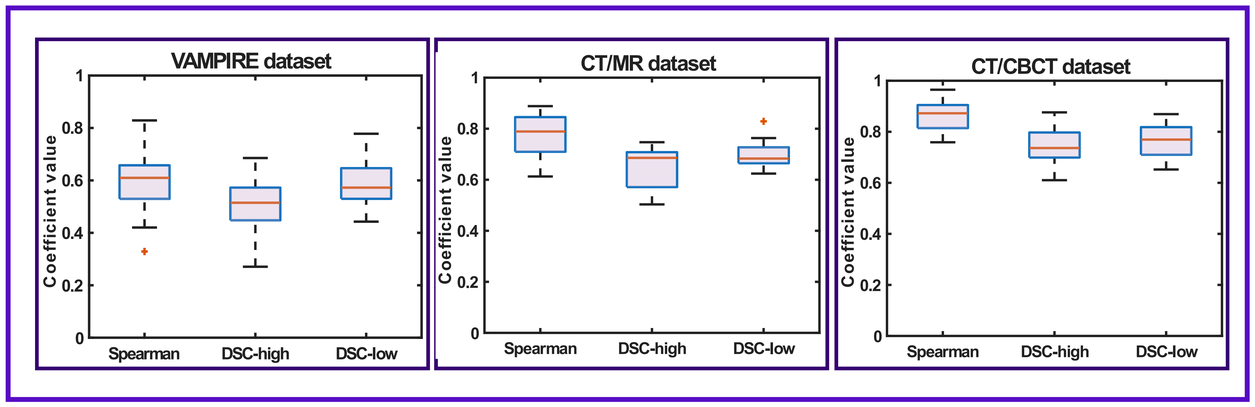


Figure 1: Results from the three experiments on the accuracy (4DCT/nuclear medicine) and reproducibility (CT/MRI and CT/CBCT) of the proposed method.

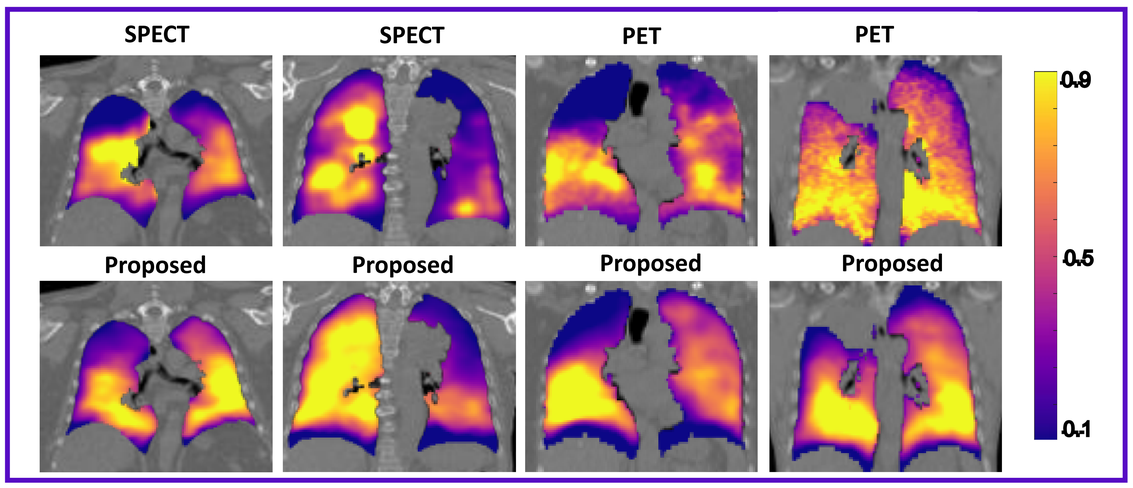


Figure 2: CT-derived ventilation images generated using the proposed method are shown together with the corresponding nuclear medicine ground truth (SPECT/PET). The Spearman coefficients for the four cases are (from left to right) 0.81,0.54,0.67 and 0.63.

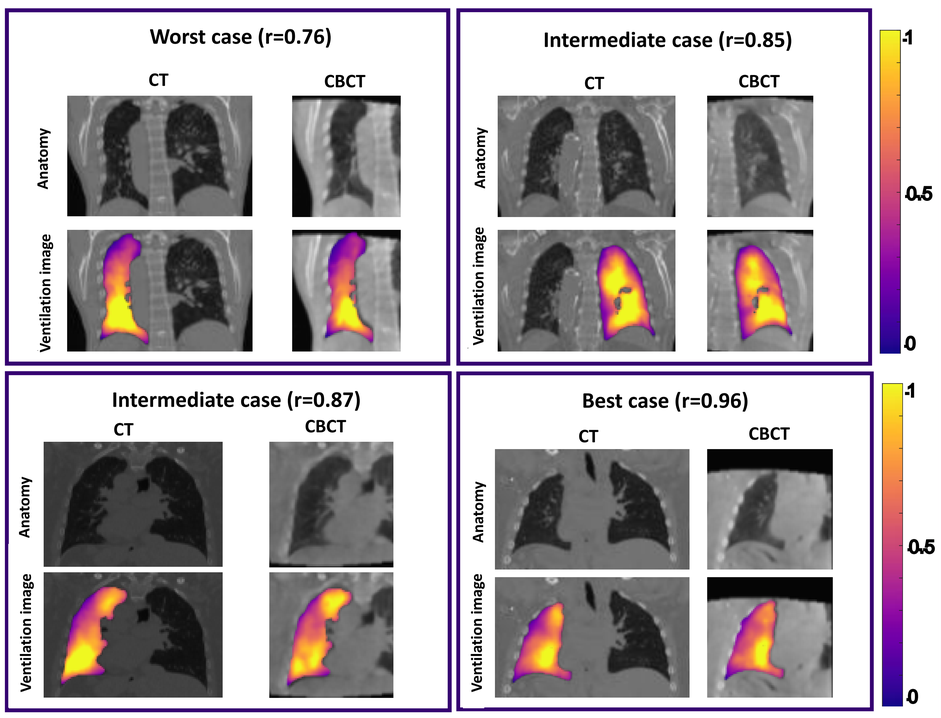


Figure 4: Four example cases from the CT/CBCT experiment. Anatomical (expiratory) CT/CBCT images are shown together with corresponding ventilation images generated using the proposed method. Ventilation images are normalized using the 90th percentile.

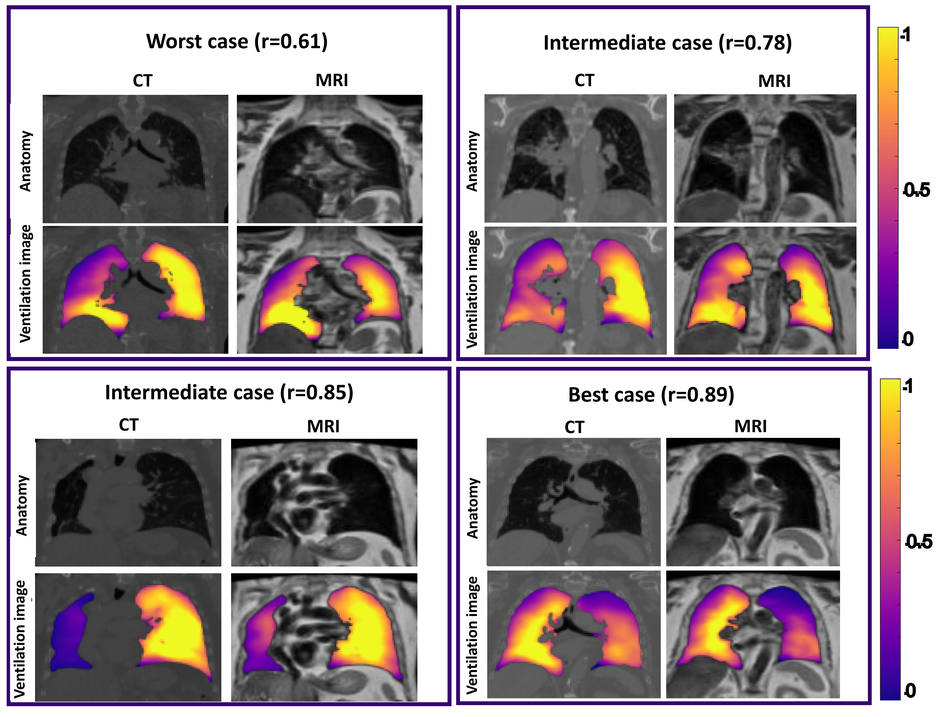


Figure 4: Four example cases from the CT/MRI experiment. Anatomical (expiratory) CT/MRI images are shown together with corresponding ventilation images generated using the proposed method. Ventilation images are normalized using the 90th percentile.

CONCLUSION

We have successfully implemented a modality agnostic ventilation imaging method that relies on image registration of inspiration/expiration images and combines intensity with anatomical information. Enabling the acquisition of functional information from multiple types of anatomical data can open new pathways towards the implementation of synthetic ventilation imaging in clinical practice.

MR-based and CBCT-based ventilation imaging can produce adequately consistent ventilation maps, but this is only true when appropriate DIR models are employed. Overall, enabling ventilation imaging from MR and CBCT image sets allows frequent evaluation of 3D spatially resolved pulmonary function, opening the way for function-based online adaptive treatments.