CardioSpectrum: Comprehensive Myocardium Motion Analysis with 3D Deep Learning and Geometric Insights

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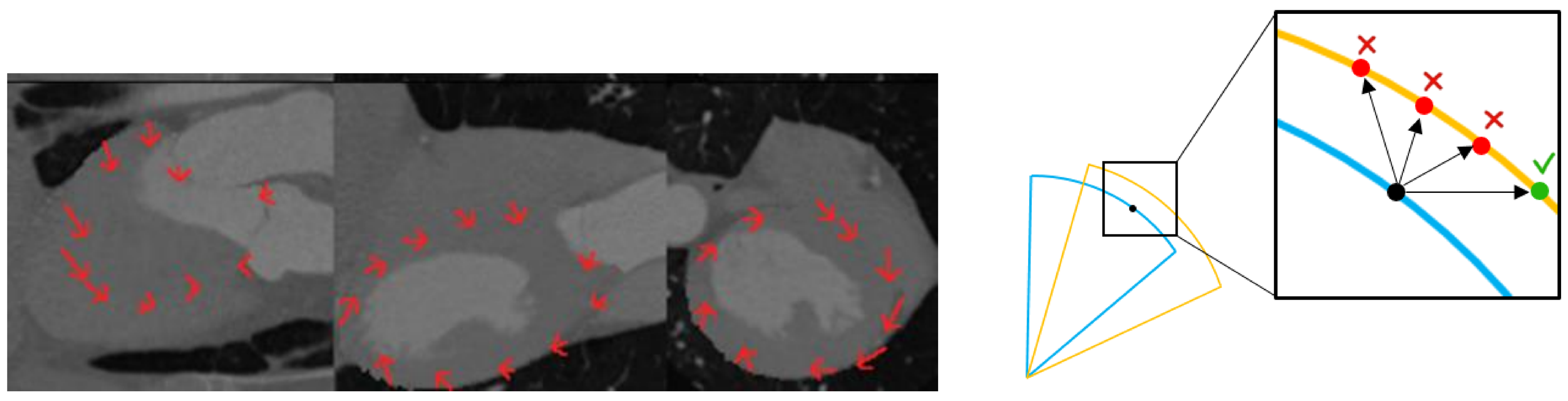
Introduction

- **Cardiac Motion Analysis:** Accurately capturing both **radial** and **tangential** myocardium motion is essential for improving diagnosis and treatment planning.
- **Challenge:** Neural networks typically perform poorly on the tangential component of motion, resulting in reduced accuracy due to the aperture problem.
- **Approach:** Implementing global constraints using spectral methods (Functional Maps) to enhance the prediction of tangential motion.
- **Objective:** Improve the accuracy of tangential motion prediction in cardiac motion analysis by introducing geometric constraints via spectral methods.



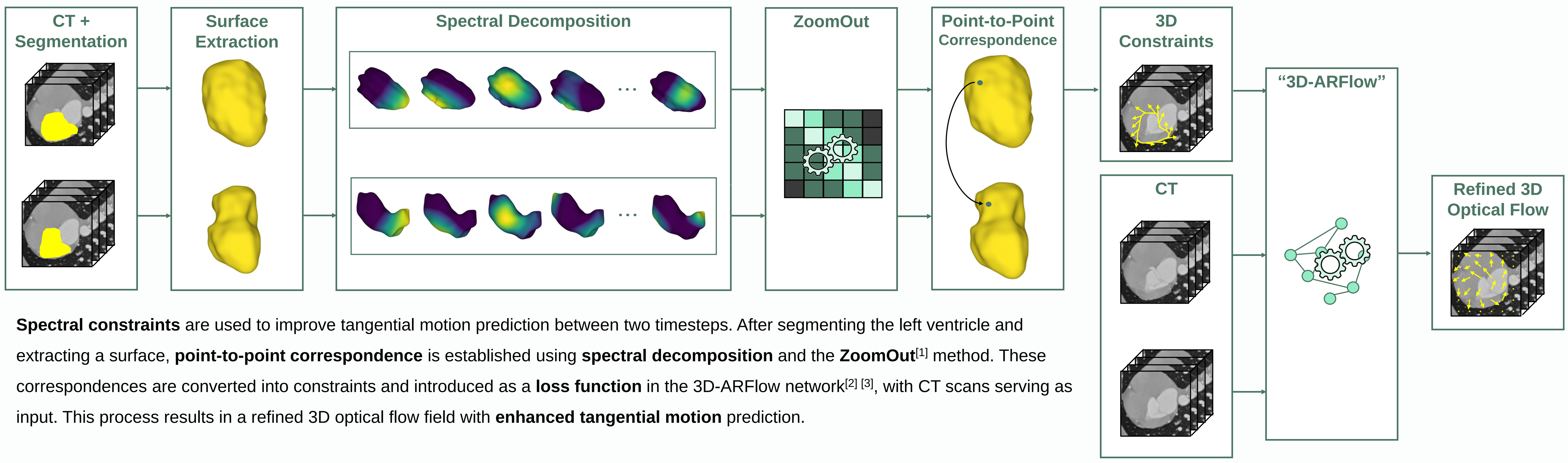
Contribution

We present a novel pipeline that:

- **Enhances Tangential Motion Prediction:** By applying geometric constraints through spectral methods, we improve accuracy in cardiac motion analysis.
- **Addresses the Aperture Problem:** Introducing global constraints overcomes neural network limitations for tangential component estimation.
- **Refines Optical Flow:** The incorporation of spectral constraints refines the 3D optical flow field, leading to more precise cardiac motion analysis.

Incorporating geometric global features improves the network ability to predict tangential deformation

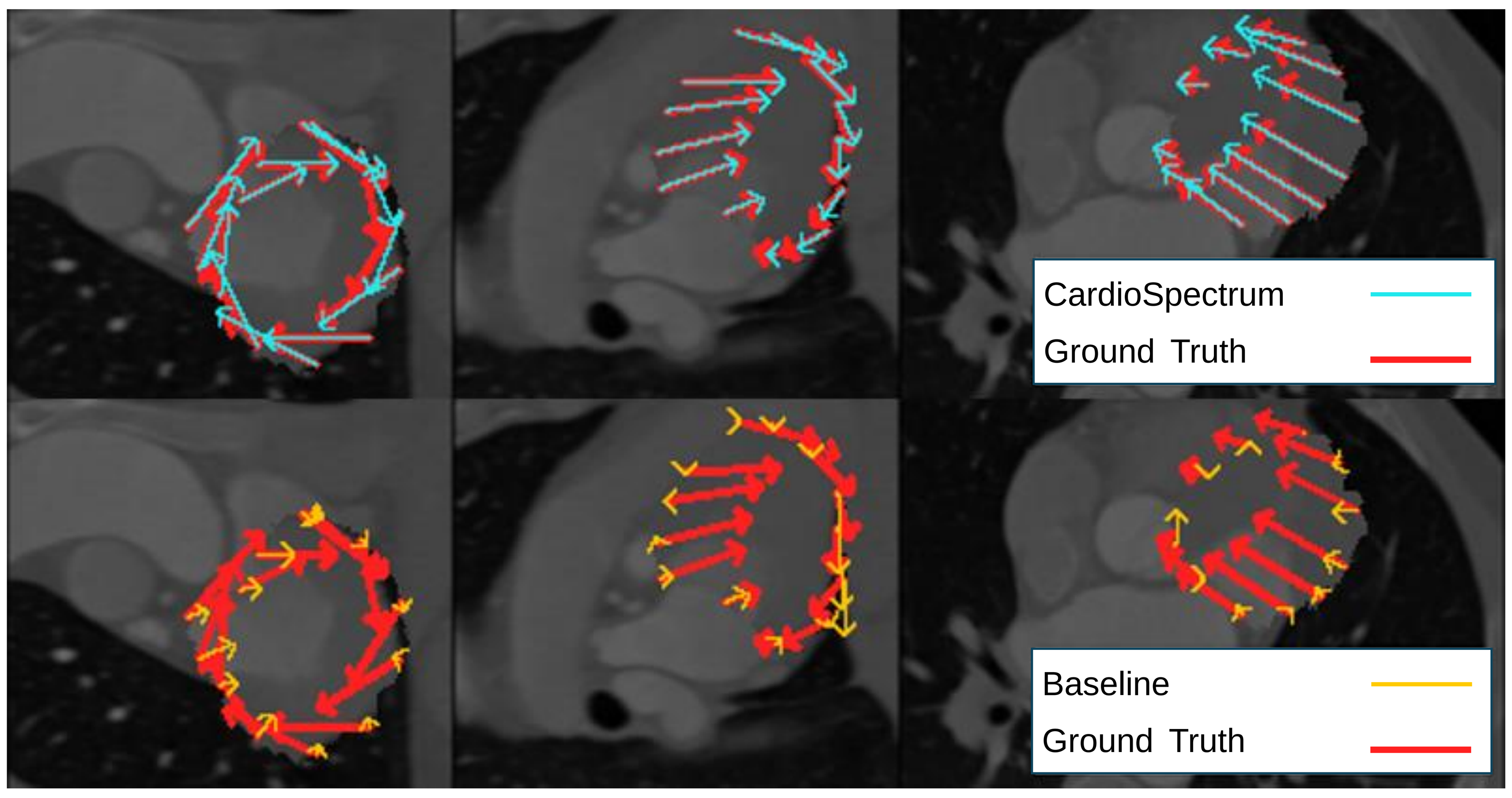
Methods



Spectral constraints are used to improve tangential motion prediction between two timesteps. After segmenting the left ventricle and extracting a surface, **point-to-point correspondence** is established using **spectral decomposition** and the **ZoomOut**[1] method. These correspondences are converted into constraints and introduced as a **loss function** in the 3D-ARFlow network[2] [3], with CT scans serving as input. This process results in a refined 3D optical flow field with **enhanced tangential motion** prediction.

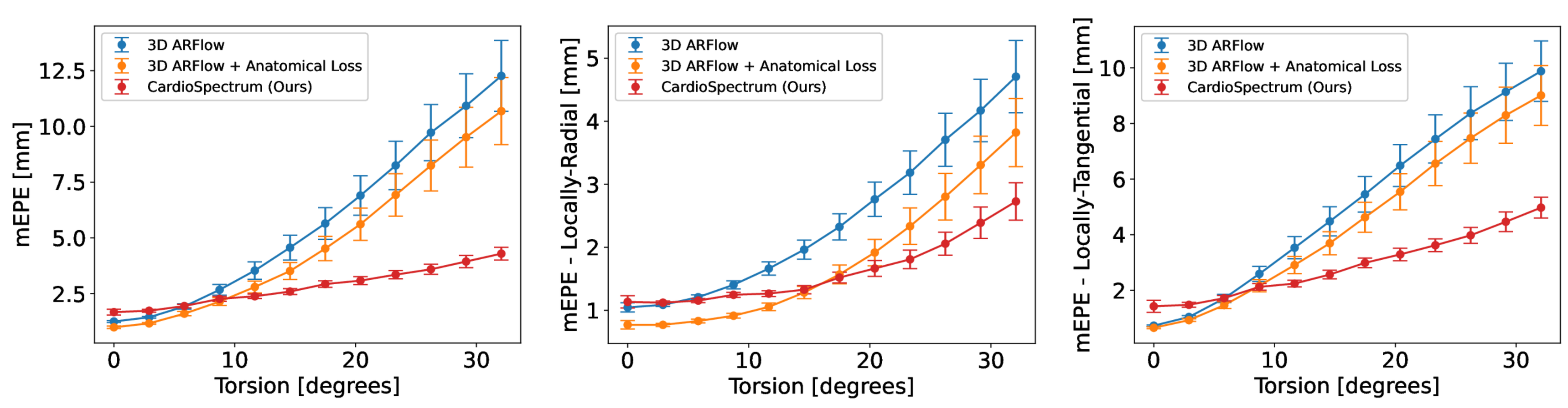
Qualitative Results

CardioSpectrum effectively captures cardiac tangential movement (top), outperforming traditional methods that predominantly focus on local features, which often lead to inadequate results due to the aperture problem (bottom).



Quantitative Results

- CardioSpectrum outperformed the baselines in particular with **increasing torsion angles**.
- Presented are mean End-Point Error (mEPE) values across the myocardium volume, including locally-radial and locally-tangential directions within the segmentation hull.
- CardioSpectrum exhibited significant advantages in **overall mEPE** and especially in the **locally-tangential components**, addressing the aperture problem more effectively than traditional methods.



As torsion angle increases, CardioSpectrum consistently reduces mEPE across the myocardium region compared to baseline models.

References

[1] Melzi S, Ren J, Rodola E, Sharma A, Wonka P, Ovsjanikov M. ZoomOut: Spectral upsampling for efficient shape correspondence. arXiv preprint arXiv:1904.07865; 2019.

[2] Lifshitz G, Raviv D. Unsupervised volumetric displacement fields using cost function unrolling. In: International Conference on Medical Image Computing and Computer-Assisted Intervention; 2021. Cham: Springer International Publishing; p. 153-60.

[3] Liu L, Zhang J, He R, Liu Y, Wang Y, Tai Y, Luo D, Wang C, Li J, Huang F. Learning by analogy: reliable supervision from transformations for unsupervised optical flow estimation. In: Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition; 2020. p. 6489-98.

Project Page

https://shaharzuler.github.io/CardioSpectrumPage