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From 2D+t Cine MRI to 3D Ventricular Models: A pipeline for Segmentation, Registration, and Shape Modeling

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Effective segmentation and registration of 2D+t cardiac cine magnetic resonance images (cMRI) is crucial for accurate and fast 3D cardiac model construction, forming the basis for individual hearts in cardiac digital twins. While 2D cMRI scans often have higher temporal resolution and quality than 3D MRI, they frequently suffer from spatial misalignment due to patient movement and irregular breath holds during acquisition. These misalignments pose significant challenges for 3D model construction, as they introduce artifacts and inaccuracies that compromise model fidelity.

Building on Banerjee et al. (2021), we present the developments of a semi-automated, modular pipeline for segmenting and registering 2D+t cMRIs to construct personalized 3D anatomical models of the ventricles, designed for future integration into a multi-modal imaging environment. Data from the ILearnHeart project (ILearnHeart 2016; Gillette et al.,2021) consist of 2D+t cMRI scans in 2-chamber (2CH), 4-chamber (4CH), and stacked short axis (SAX) views from seven healthy subjects. Each slice includes 30 time frames covering a full cardiac cycle with an in-plane resolution of approximately 1.4 mm x 1.4 mm and slice thickness of 8 mm (SAX) and 1 mm (2CH/4CH). After preprocessing and metadata extraction, we segment the left and right ventricle blood pools and left ventricular myocardium (MYO) across all 2D+t slices using nnU-Net (Isensee et al., 2018; Isensee et al., 2021) and a few-shot segmentation approach based on Gaussian processes (Johnander et al., 2022; Viti et al., 2025). For registration, we employ a two-step approach. First, intensity-based registration aligns 2CH and 4CH slices at each time step by optimizing the normalized cross-correlation (NCC) at their intersection line via rigid transformations. Second, contours-based registration aligns the SAX stack contours to the previously registered 2CH and 4CH contours by minimizing intersection distances through translations in x, y, and z.

Initial results show an average NCC improvement of $(17.5 \pm 16.7)\%$ from intensity-based registration compared to the unregistered slices. Contours-based registration shows promising results but requires further refinement, including in-plane rotation corrections. Future work will focus on 3D ventricle modeling across time frames testing Gaussian splatting and NeRFs.

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