A Variational Method for Scar Segmentation with Myocardial Contour Correction in DE-CMR Images

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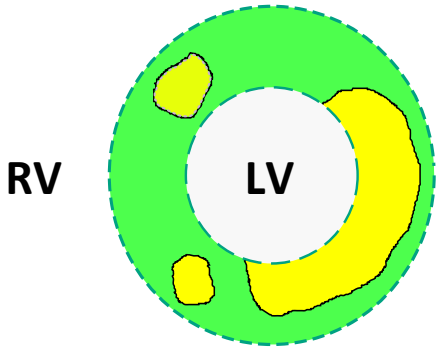
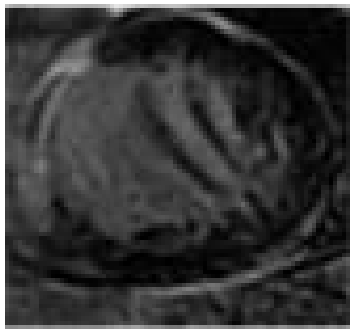
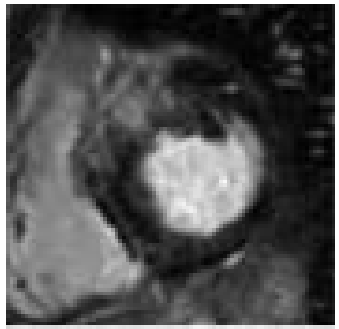
Motivation

- Cardiac MR images:
  - Good contrast between soft tissues
  - The full heart can be imaged
  - There are many modalities: CINE, Tagging, DE-CMR…
- DE-CMR allows the identification of scarred tissue in the myocardium.







Review of DE-CMR Segmentation

- Most current methods restrict the segmentation of the myocardium.
  - It simplifies the problem.
  - What if there are misalignments in the myocardial mask?

Method	Myocard. Contours	Scar identification method	Post Processing included in the method
TFA1 [5]	Fixed	2 step thresholding	FP, FN removal by feature analysis, region growing and hole filling
TFA2 [10]	Fixed	2 step thresholding	FP, FN removal by feature analysis
PWD [3]	Fixed	Mixture Model + Watershed	Noise removal + hole filling

[5] Q. Tao, J. Milles, K. Zeppenfeld, H. J. Lamb, J. J. Bax, J. H. C. Reiber, and R. J. van der Geest, "Automated segmentation of myocardial scar in late enhancement MRI using combined intensity and spatial information", Magnetic Resonance in Medicine, vol. 64, no. 2, pp. 586-594, 2010.

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[10] LY Hsu, Natanzon, A, P Kellman, GA Hirsch, AH Aletras, and AE Arai, ``Quantitative myocardial infarction on delayed enhancement MRI. Part I: Animal validation of an automated feature analysis and combined thresholding infarct sizing algorithm,'' Journal of Magnetic Resonance Imaging, vol. 23, pp. 298-308, 2006.

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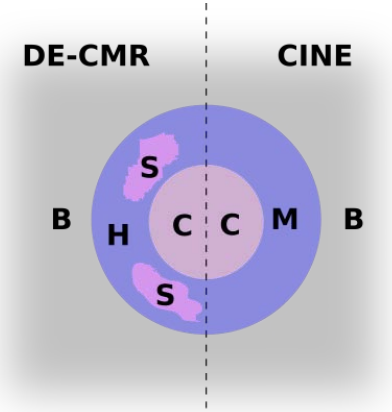
[3] A. Hennemuth, A. Seeger, O. Friman, S. Miller, B. Klumpp, S. Oeltze, and H.-O. Peitgen, ``A Comprehensive Approach to the Analysis of Contrast Enhanced Cardiac MR Images,'' IEEE Transactions on Medical Imaging, vol. 27, no. 11, pp. 1592-1610, 2008.

Objectives

- To propose a segmentation method for DE-CMR that:
  - Is able to modify the myocardial contours if necessary
  - Provides smoothness to the myocardial contours.
  - At the same time, uses the information provided by a CINE segmentation to increase robustness.

- To explore how the state of the art segmentation methods behave:
  - when the myocardial contours have misalignments.
  - with non ischemic myocardiopathies .

Variational Framework



$$\mathcal{L} = \{\mathrm{C}, \mathrm{H}, \mathrm{S}, \mathrm{B}\}$$ DE-CMR labels

$$\mathcal{A} = \{\mathrm{C}, \mathrm{M}, \mathrm{B}\}$$ CINE labels

- C: Blood cavity
- M: Myocardium
- B: Background
- H: Healthy tissue
- S: Scar

Convex Potts Model (From [7])

$$\min_{\mathbf{u}(\mathbf{x}) \in \Delta_+} \Psi(\mathbf{u}) = \sum_{l \in \mathcal{L}} \int_\Omega \left(f_l(\mathbf{x}) u_l(\mathbf{x}) + g_l(\mathbf{x}) \left| \nabla u_l(\mathbf{x}) \right| \right) d\mathbf{x}$$

Data Fidelity

Contour Regularization

$$f_{L_i}(\mathbf{x}) = -\ln\left(P\left(L_i(\mathbf{x}) | I(\mathbf{x})\right)\right)$$

[7] E. Bae, J. Yuan, and X.-C. Tai, "Global minimization for continuous multiphase partitioning problems using a dual approach," Int J Comput Vis, vol. 92, no. 1, pp. 112--129, 2011.

Label Posterior Probability Formulation

$$P(L_i|I) = \frac{\sum_{k=1}^{K} P(I|A_k, L_i)P(L_i|A_k)P(A_k)}{\sum_{j=1}^{L}\sum_{k=1}^{K} P(I|A_k, L_j)P(L_j|A_k)P(A_k)}$$

$P(I|A_k, L_i)$

- Models the probabilistic distribution of I(x).
- Assumption of independence with respect to Â(x).
- The Rician distribution is chosen for the blood and the myocardial tissues.

$P(A_k)$

- Probability of the CINE label A_k.
- Decays with the distance to the CINE ROI k.
- The binary indicator function for all A_k are smothed with a Gaussian kernel and normalized.

Label Posterior Probability Formulation

$$P(L_i|I) = \frac{\sum_{k=1}^{K} P(I|A_k, L_i)P(L_i|A_k)P(A_k)}{\sum_{j=1}^{L}\sum_{k=1}^{K} P(I|A_k, L_j)P(L_j|A_k)P(A_k)}$$

$P(L_i|A_k)$

- Controls the influence of the CINE segmentation and the image likelihood locally.
- The value at each location is a linear combination of 3 extreme situations:
  - Fully trust the CINE probability
  - Fully trust the a priori tissue probability…
    - …at the epicardial border
    - …at the endocardial border
- Weights are computed using the edge information of the DE-CMR image.

Contour Regularization

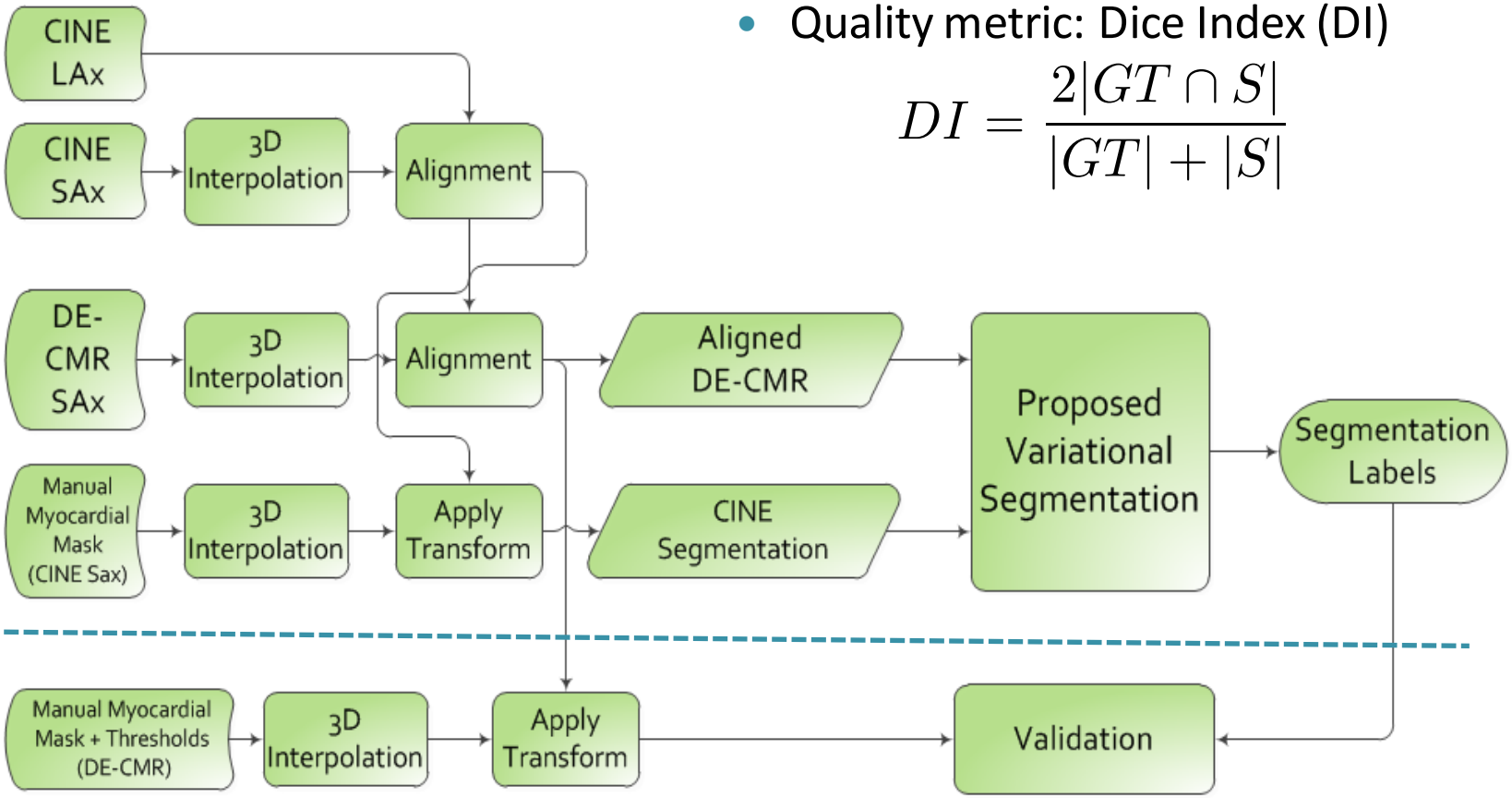
The regularization local weights $g_l(x)$ depend on the image gradient *AND* the CINE segmentation:

$$g_C(\mathbf{x}) = \gamma_0 H(1 - a_1(\mathbf{x}), \varepsilon) + \gamma_c r(\mathbf{x}) H(a_1(\mathbf{x}), \varepsilon)$$
$$g_H(\mathbf{x}) = \gamma_0 H(1 - a_2(\mathbf{x}), \varepsilon) + \gamma_t r(\mathbf{x}) H(a_2(\mathbf{x}), \varepsilon)$$
$$g_S(\mathbf{x}) = g_H(\mathbf{x})$$
$$g_B(\mathbf{x}) = \gamma_0 H(1 - a_3(\mathbf{x}), \varepsilon) + \gamma_c r(\mathbf{x}) H(a_3(\mathbf{x}), \varepsilon)$$
$$r(\mathbf{x}) = H\left((3/2)\sigma_{b(\mathbf{x})} - b(\mathbf{x}), \varepsilon\right)$$

Experimental Setup

- 11 studies from Hypertrophic Cardiomyopathy patients.
- Quality metric: Dice Index (DI)

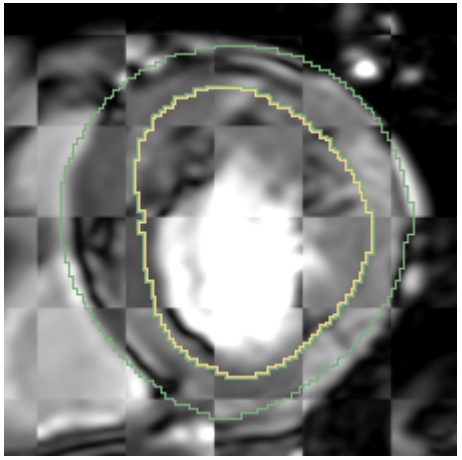
$$DI = \frac{2|GT \cap S|}{|GT| + |S|}$$

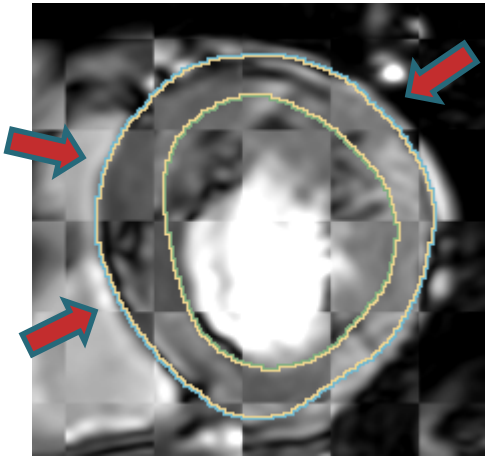


Experimental Results

Study	TFA1	TFA2	PWD	PROP
1	0.407	0.638	0.533	0.688
2	0.554	0.595	0.359	0.677
3	0.674	0.569	0.620	0.700
9	0.183	0.213	---	0.207

DI between the scar and healthy tissue ROIs yielded by the considered segmentation methods.





Conclusions

- A variational segmentation method for DE-CMR where:
  - The scar is identified
  - The myocardial contours may be modified.
  - The data fidelity uses a Bayesian approach that takes into account both the image intensity probability distributions and a registered myocardial segmentation coming from CINE.
  - The CINE myocardial segmentation is also used to compute the regularization weights.
- The correction of the myocardial contours improves the scar identification.
- The correction is stronger in the volumes with lower CINE myocardial alignment.

Thank you!