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› Mass-Preserving Motion Correction of PET: Displacement Field vs. Spline Transformation

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Introduction

Motivation:

- Cardiac and respiratory motion cause artifacts and spatial blurring
- Non-linear cardiac motion → PVE induced intensity modulations

Contribution:

- *Given*: Mass-Preserving (MP) transformation model VAMPIRE [1]
- Evaluation of different motion models
  ... displacement field (DF), compute an individual displacement for each voxel
  ... spline transformation (ST), i.e., free-form deformation
- Focus on parametrization of ST
  1. Number of spline coefficients
  2. Regularization type and parameter

Materials and Methods

XCAT Software Phantom Data

- Generation of two gates (Processing: simulation of PVE (Gaussian blurring), forward projection, Poisson noise, EM reconstruction [2])
  $\mathcal{T}$: Template image - systolic heart phase at maximum inspiration (see Fig. 1 (a))
  $\mathcal{R}$: Reference image - diastolic heart phase at mid-expiration (see Fig. 1 (b))

VAMPIRE - Variational Algorithm for Mass-Preserving Image REgistration [1]

- Implementation based on FAIR toolbox [3] in MATLAB
  - Multi-level strategy along with a Gauss-Newton optimization
- Find optimal transformation y by minimizing the following functional:

$$\min_y \; \mathcal{D}^{\text{SSD}}\left[(\mathcal{T}\circ y)\det(\nabla y),\; \mathcal{R}\right] + \alpha\, \mathcal{S}\left[y\right]$$

$\mathcal{D}^{\text{SSD}}$: SSD distance functional; $\mathcal{S}$: Regularization functional; α: scalar value

Displacement Field (DF) Regularization

- Hyperelastic [4] (parameter search by minimizing the error measure e below)

Spline Transformation (ST) Regularization

- Hyperelastic (same values as estimated for the hyperelastic DF registration)
- Internal FAIR regularization of the spline coefficients' norm
  - Evaluation of different scalar values $\alpha \in \{5\cdot 10^5, 10^6, 5\cdot 10^6\}$

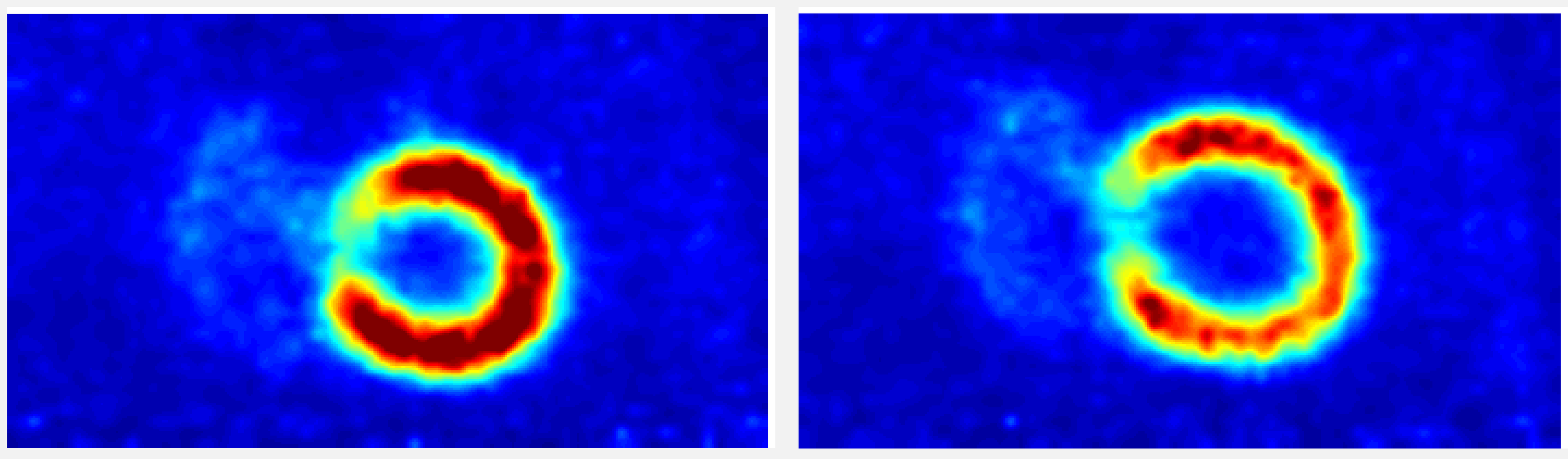
Spline coefficients

- Optimization of spline coefficient factor $s \in \{2,4,6,8,10,12,14,16,18\}$
  → image size is divided by s to define the number of spline coefficients; given an image size of $80\times 80\times 44$, the number of spline coefficients ranges between $40\times 40\times 22$ ($s=2$) and $4\times 4\times 2$ ($s=18$)

Evaluation

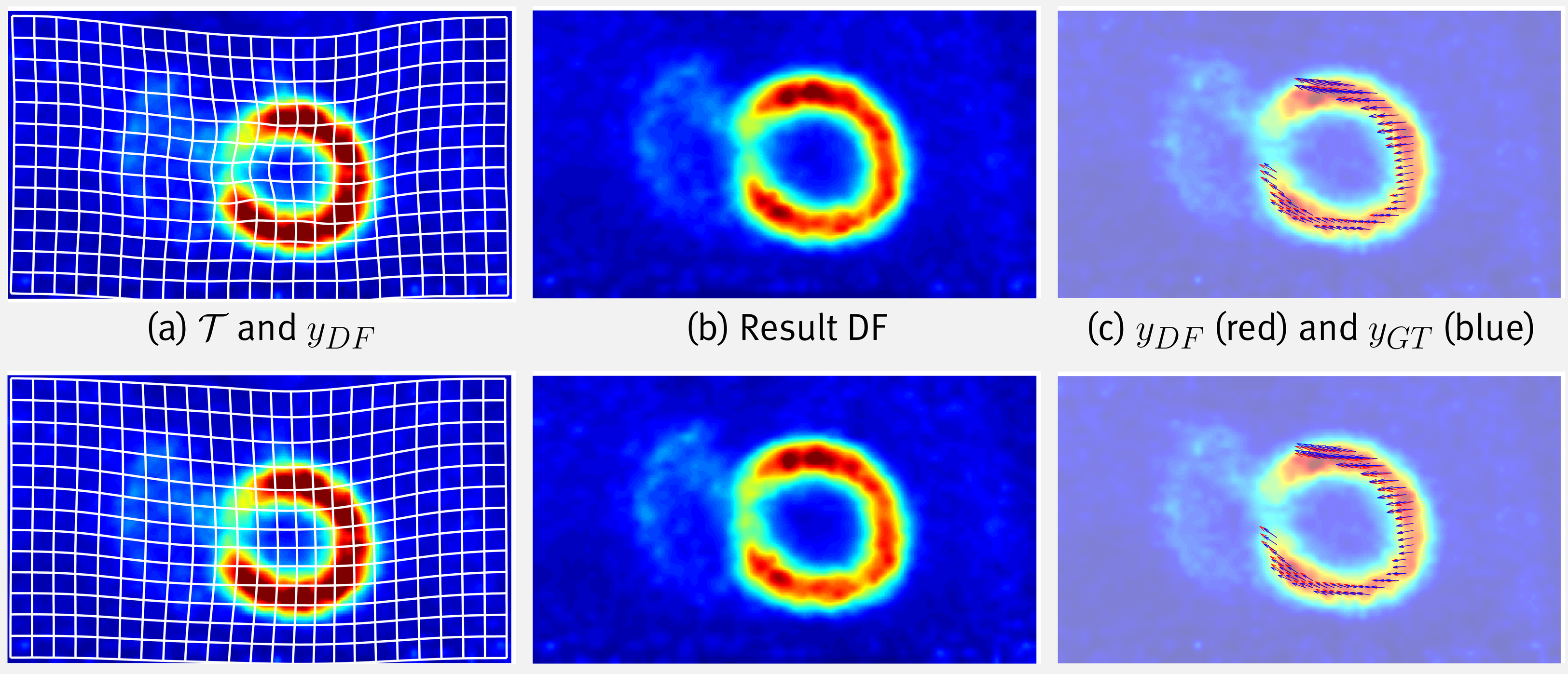
1. Error measure $e(y, y_{GT}) := \frac{1}{|\Omega|}\int_\Omega \|y(x) - y_{GT}(x)\| dx$
   - y_{GT} is the ground-truth deformation provided by the XCAT phantom
   - Ω is the left ventricle
2. Total processing time t

Results: DF vs. ST



(a) Template image $\mathcal{T}$ (b) Reference image $\mathcal{R}$

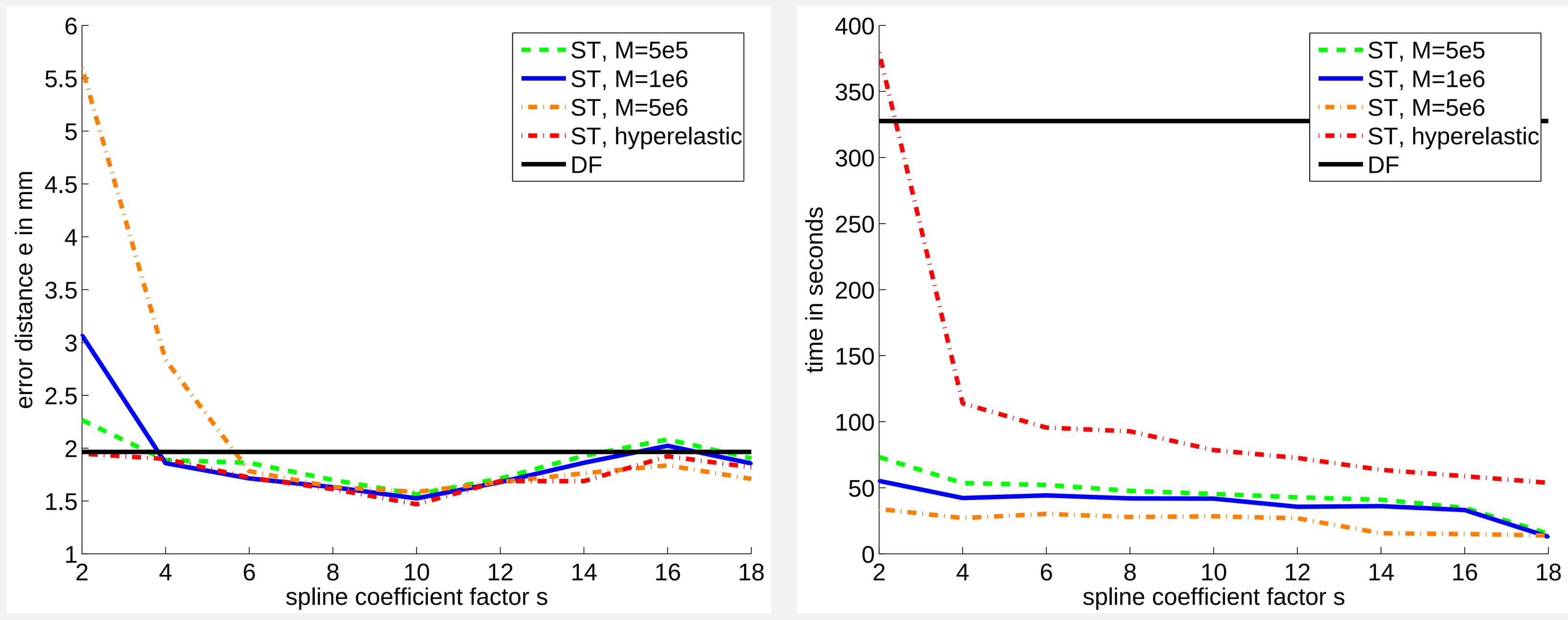
Fig. 1: The template image $\mathcal{T}$ (a) is registered to the reference image $\mathcal{R}$ (b).



(a) $\mathcal{T}$ and y_{DF} (b) Result DF (c) y_{DF} (red) and y_{GT} (blue)

(d) $\mathcal{T}$ and y_{ST} (e) Result ST (f) y_{ST} (red) and y_{GT} (blue)

Fig. 2: Results of VAMPIRE registration with deformation field (DF) (a)–(b) and spline transformation (ST) ($s=10$, $\alpha=5\cdot 10^6$) (d)–(e). A ground-truth comparison is shown in (c) for DF and in (f) for ST.



(a) Error measure e against coefficient factor s (b) Time t against coefficient factor s

Fig. 3: The error measure e (ground-truth distance) and the processing time t is plotted against the spline coefficient factor s. The solid black horizontal line represents the DF result. The voxel size is $3.375\,\text{mm}$.

Tab. I: Detailed comparison of the DF and ST results. For ST only the values for $s=10$ (optimal coefficient factor) are shown. Best results are labeled in green.

	DF (Fig. 2 (a)–(c))	ST	ST	ST	ST (Fig. 2 (d)–(f))
Coefficient factor	–	$s=10$	$s=10$	$s=10$	$s=10$
Regularization	hyperelastic	hyperelastic	$\alpha=5\cdot 10^5$	$\alpha=10^6$	$\alpha=5\cdot 10^6$
$e(y,y_{GT})$	1.96 mm	1.47 mm	1.56 mm	1.52 mm	1.59 mm
processing time t	326 s	79 s	45 s	42 s	28 s

Discussion and Conclusion

- ST model is superior to DF strategy in terms of processing time and accuracy
- Optimal number of spline coefficients:
  - $8\times 8\times 4$ ($s=10$) → comparable results for all regularizations with subvoxel accuracy for $s=10$ (voxel size: $3.375\,\text{mm}$)
- Optimal regularization for ST:
  - Hyperelastic regularization (highest accuracy; guaranteed diffeomorphism)
  - FAIR regularization with $\alpha=5\cdot 10^6$ (good accuracy; short processing time)

References

[1] F. Gigengack, L. Ruthotto, M. Burger, C.H. Wolters, X. Jiang, and K.P. Schaefers. *Mass-Preserving Motion Correction of Dual Gated Cardiac PET*. In NSS/MIC, IEEE, 2011. http://vampire.uni-muenster.de/

[2] T. Kösters, K.P. Schäfers, and F. Wübbeling. EMRECON: *An expectation maximization based image reconstruction framework for emission tomography data*. In NSS/MIC, IEEE, 2011.

[3] J. Modersitzki. *FAIR: Flexible Algorithms for Image Registration*. SIAM, Philadelphia, 2009.

[4] M. Droske and M. Rumpf. *A variational approach to nonrigid morphological image registration*. SIAM J. Appl. Math., 64(2):668–687, 2003.

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