Occlusion-Aware Non-Rigid Point Cloud Registration via Unsupervised Neural Deformation Correntropy

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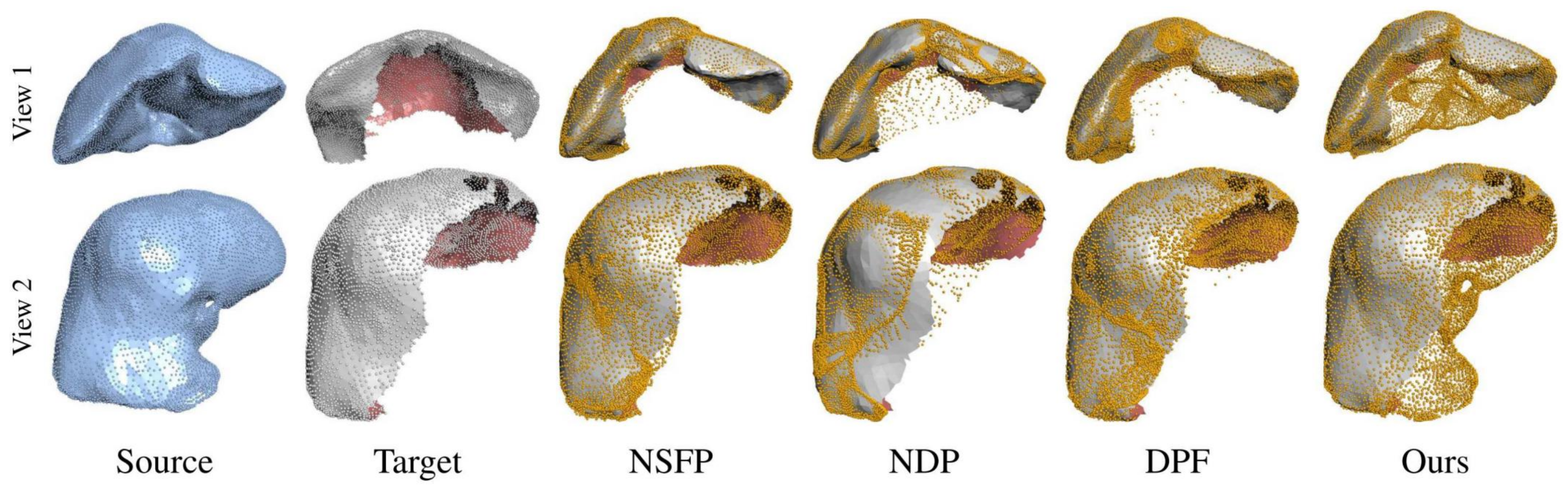
ICLR
Project Page: (paper & code)

Motivation

- Non-rigid registration under occlusion is a universal yet understudied problem
- Unsupervised methods without annotations are more generalizable
- Ensure correct deformation in overlapping regions while maintaining plausible deformation in occluded areas—avoiding collapse or tearing



Method

- Maximum correntropy-based unsupervised implicit neural representations for occlusion-robust registration
- Locally linear reconstruction enforces natural deformations in regions lacking correspondences

Problem Formulation

- Correntropy

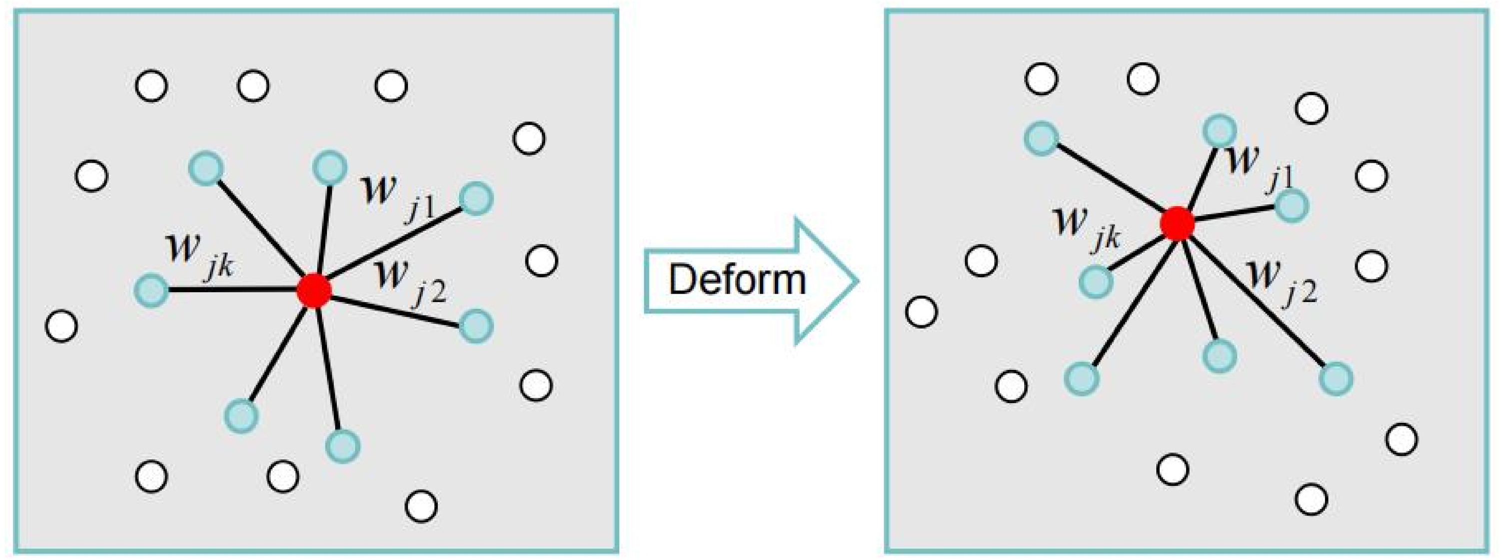
$$V(X,Y) = \mathbb{E}_{XY}[k(X,Y)] = \iint_{x,y} k(x,y)p_{XY}(x,y)dxdy$$

- Correntropy-induced similarity metric

$$\mathcal{M}(\boldsymbol{x},\boldsymbol{y}) = \left(k_\sigma(0) - \frac{1}{n}\sum_{j=1}^{n} k_\sigma(x_j - y_j)\right)^{\frac{1}{2}}$$

- Locally linear reconstruction

$$\min_{\boldsymbol{w}_j} \mathcal{L}(\boldsymbol{w}_j) = \frac{1}{2}\|\boldsymbol{y}_j - \mathbf{Z}_j\boldsymbol{w}_j\|_2^2 = \frac{1}{2}\boldsymbol{w}_j^\top \mathbf{G}_j \boldsymbol{w}_j$$
$$\text{s.t. } \boldsymbol{w}_j^\top \mathbf{1}_k = 1$$



- Locally linear reconstruction regularization

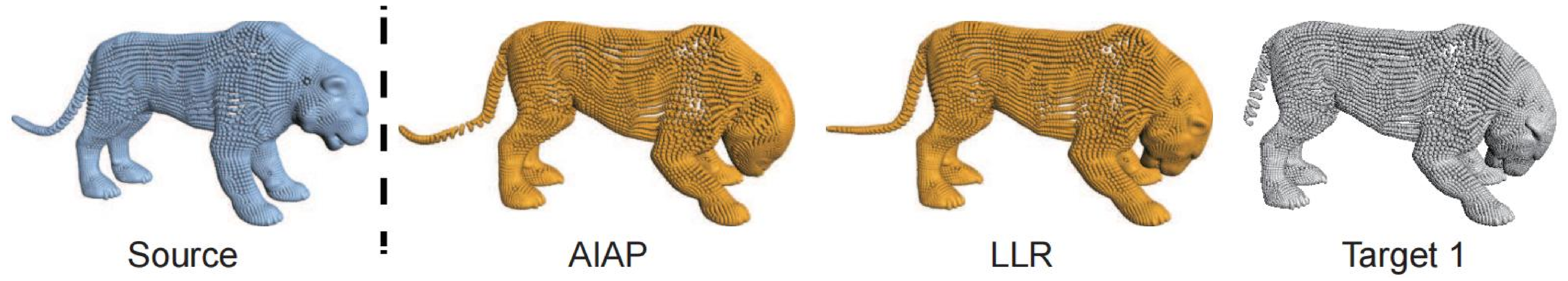
$$\mathcal{R}(\boldsymbol{\Theta}) = \sum_{j=1}^{N} \|\mathcal{T}_{\boldsymbol{\Theta}}(\boldsymbol{y}_j) - \mathcal{T}_{\boldsymbol{\Theta}}(\mathbf{Z}_j)^\top \boldsymbol{w}_j\|_2$$

- Unsupervised optimization

$$\boldsymbol{\Theta}^* = \arg\min_{\boldsymbol{\Theta}} \mathcal{F}(\boldsymbol{\Theta}) = \alpha_1\mathcal{L}(\boldsymbol{\Theta}) + \alpha_2\mathcal{R}(\boldsymbol{\Theta})$$

Results

- LLR vs. AIAP



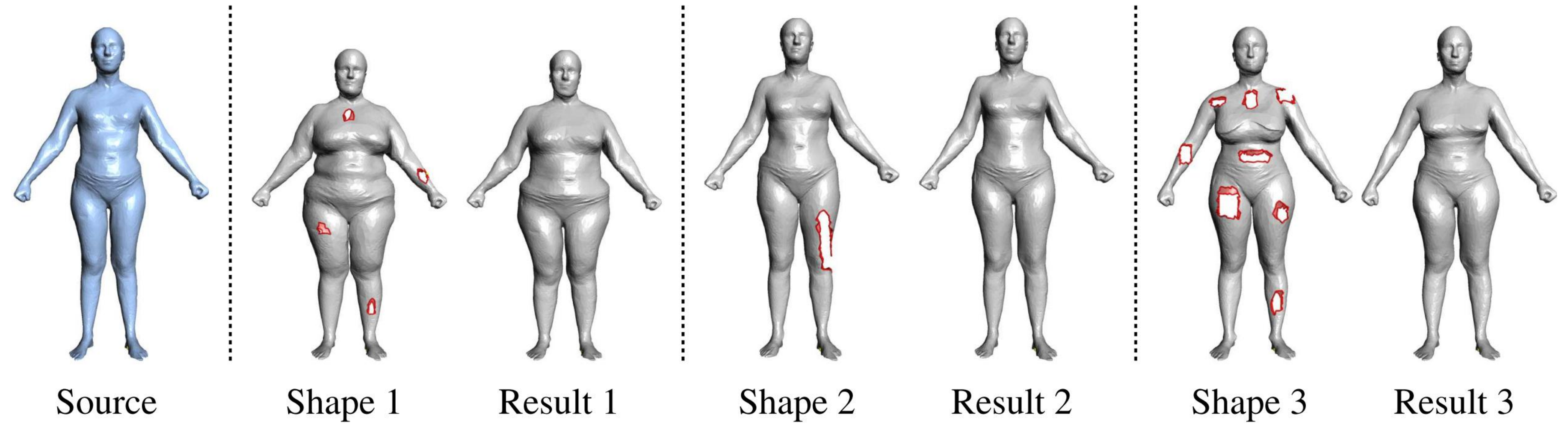
- Liver occlusion dataset

Method \ Metric	Liver 1				Liver 2				Liver 3			
	EPE ↓	AccS ↑	AccR ↑	Outlier ↓	EPE ↓	AccS ↑	AccR ↑	Outlier ↓	EPE ↓	AccS ↑	AccR ↑	Outlier ↓
GBCPD (Hirose, 2022)	11.849	18.770	65.263	0.000	9.169	48.871	75.534	0.000	16.240	31.770	53.162	0.000
AMM_NRR (Yao et al., 2023)	28.505	21.549	36.683	1.353	19.188	36.997	47.030	0.000	18.744	35.593	49.289	0.000
NSFP (Li et al., 2021a)	49.655	18.057	39.494	27.218	32.520	45.011	53.659	9.514	28.789	37.742	50.696	14.167
NDP (Li & Harada, 2022b)	58.470	2.795	8.504	25.961	37.456	10.357	21.674	11.131	29.508	26.675	43.407	12.780
DPF (Prokudin et al., 2023)	35.090	9.065	21.797	1.225	25.180	20.158	46.976	0.000	23.045	26.507	43.491	5.041
OAR (Ours)	**8.662**	**29.228**	**96.813**	**0.000**	**5.687**	**75.193**	**97.184**	**0.000**	**12.112**	**42.372**	**56.564**	**0.000**

- Combination with point correspondence

Method \ Metric	4DMatch				4DLoMatch			
	EPE ↓	AccS ↑	AccR ↑	Outlier ↓	EPE ↓	AccS ↑	AccR ↑	Outlier ↓
Lepard (Li & Harada, 2022a)+SVD	0.137	6.91	24.50	43.43	0.160	5.27	19.77	44.16
PointPWC (Wu et al., 2019)	0.182	6.25	21.49	52.07	0.279	1.69	8.15	55.70
FLOT (Puy et al., 2020)	0.133	7.66	27.15	40.49	0.210	2.73	13.08	42.51
GeomFmaps (Donati et al., 2020)	0.152	12.34	32.56	37.90	0.148	1.85	6.51	64.63
SyNoRiM-pw (Huang et al., 2022)	0.099	22.91	49.86	26.01	0.170	10.55	30.17	31.12
Lepard+NICP (Li & Harada, 2022a)	0.097	51.93	65.32	23.02	0.283	16.80	26.39	52.99
Lepard+NDP (Li & Harada, 2022b)	0.077	**61.30**	74.12	17.37	0.177	26.59	41.05	33.81
Lepard+OAR (Ours)	0.059	59.32	**74.33**	16.41	0.251	**27.25**	**42.01**	45.04

- Application to mesh hole filling



- Robustness against outliers