DeepSPF: Spherical SO(3)-Equivariant Patches for Scan-to-CAD Estimation

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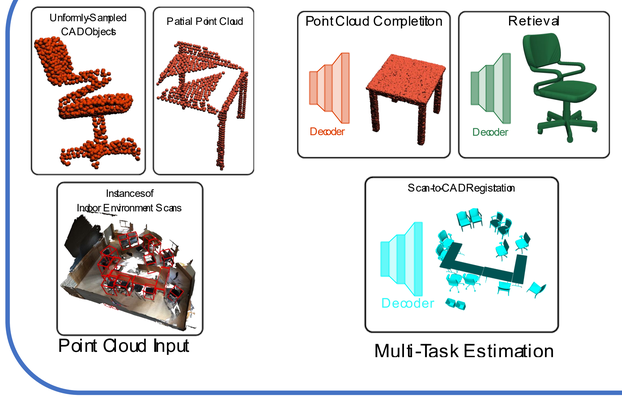
Information

We introduce Spherical Patch Fields, a representation technique designed for patch-wise, SO(3)-equivariant 3D point clouds, anchored theoretically on the principles of Spherical Gaussians. Second, we present the Patch Gaussian Layer, designed for the adaptive extraction of local and global contextual information from resizable point cloud patches. Culminating our contributions, we present Learnable Spherical Patch Fields (DeepSPF) – a versatile and easily integrable backbone suitable for instance-based point networks.

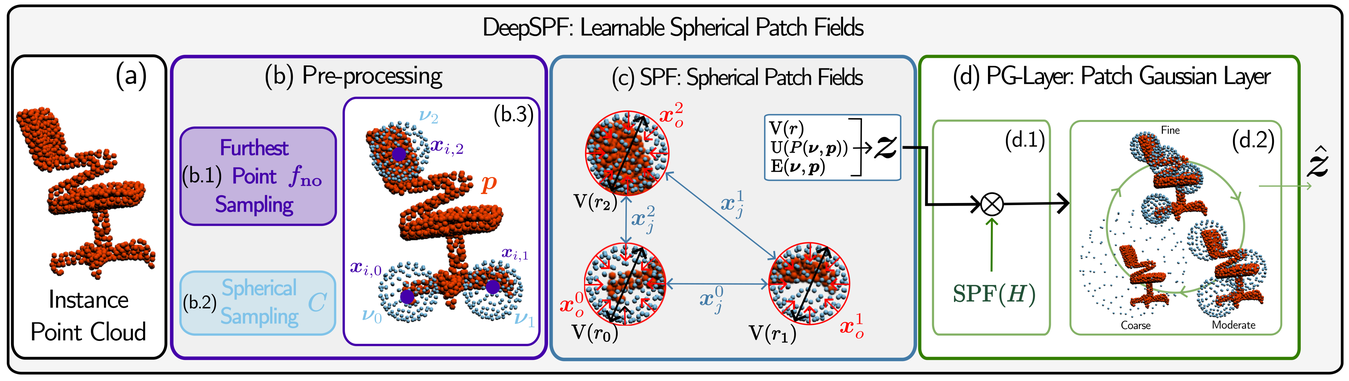
Motivation



Problems:

- Registration: Uniformly sampled CAD object and scanned object have no point-to-point correspondences
- Retrieval:
  - CAD object and scanned object have no point-to-point correspondences
  - Pose and cale are vastly different between sensor and designed object
  - Overall similar structures but patch-wise differences
- Completion: Vast amount of augmentation needed Learning different over different datasets

Approach



$$\text{SPF}(\boldsymbol{p};\lambda,\boldsymbol{\nu},r) = \text{E}(\boldsymbol{\nu},\boldsymbol{p})\,\text{V}(r)\,\text{U}(P(\boldsymbol{\nu},\boldsymbol{p}))\,e^{\lambda(\boldsymbol{\nu}^T\boldsymbol{p}-1)}$$

Spatial Graph | Volume Information | Low frequency information

We present a network that represents a point cloud through a patch-wise rotation-equivariant radial representation termed SPF. PG-Layer improves the learnable SPF representation using low-frequency information and adaptive resizable patches.

Quantitative Evaluation

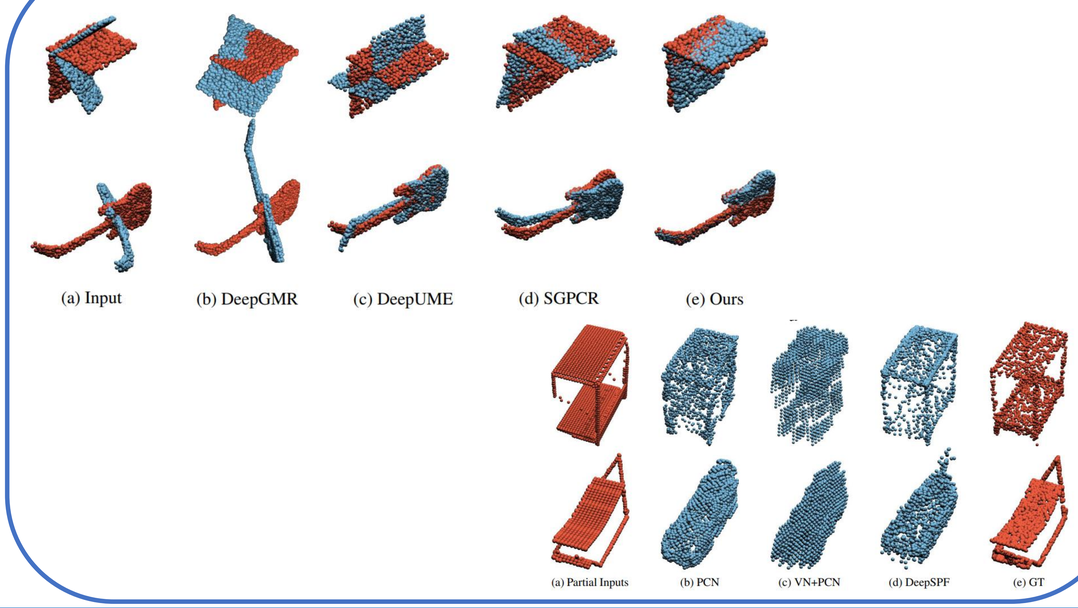
Model	$d_C \downarrow$	RRMSE ↓	RMSE(t) ↓
DCP (Wang & Solomon, 2019)	0.059	93.221	0.014
RGM (Fu et al., 2021)	0.254	100.97	0.388
RoITr (Yu et al., 2023)	-	81.14	0.1353
DeepGMR (Yuan et al., 2020)	0.026	67.282	0.010
DeepUME (Lang & Francos, 2021)	0.011	70.818	0.009
SGPCR (Salihu & Steinbach, 2023)	0.0010	8.57	0.0034
Ours (*E*)	0.0007	7.45	0.0031
Ours (*E+U*)	0.0006	6.49	0.0029
Ours (*E+U+V*)	**0.0004**	**5.17**	**0.0022**
Ours + DeepGMR (Yuan et al., 2020)	0.0016	5.32	0.0210

Model	$d_C \downarrow$	RRMSE ↓	RMSE(t) ↓
PointNetLK (Aoki et al., 2019)	0.026	81.843	1.037
DCP (Wang & Solomon, 2019)	0.055	90.715	0.014
RGM (Fu et al., 2021)	0.254	100.11	0.389
DeepGMR (Yuan et al., 2020)	0.011	42.515	0.004
DeepUME (Lang & Francos, 2021)	0.002	2.425	0.001
Ours + DeepGMR (Yuan et al., 2020)	**0.0001**	**0.40**	**0.0068**

Class	Avetisyan et al. (2019a)	Avetisyan et al. (2019b)	Avetisyan et al. (2020)	Ours
Bathtub	36.20	38.89	42.42	**56.66**
Cabinet	34.00	51.52	**58.33**	56.22
Chair	44.26	73.04	**81.23**	78.39
Sofa	30.66	76.92	**82.86**	73.56
Table	30.11	48.15	45.60	**61.64**
Bin	20.60	18.18	32.26	**36.99**
Avg. ↑	38.17	51.11	57.11	**60.57**

We demonstrate significant enhancements in Scan-to-CAD performance for point cloud registration, retrieval, and completion.

Qualitative Evaluation



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