PolarNet: 3D Point Clouds for Language-Guided Robotic Manipulation

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Motivation

Goal: Train a robot to follow language instructions to perform various manipulation tasks

Dominant approaches based on **2D representations**:

+ Benefit from pretrained 2D vision models.
- Hard to address visual occlusion with multi-view cameras.

We propose using **3D point cloud representations**:

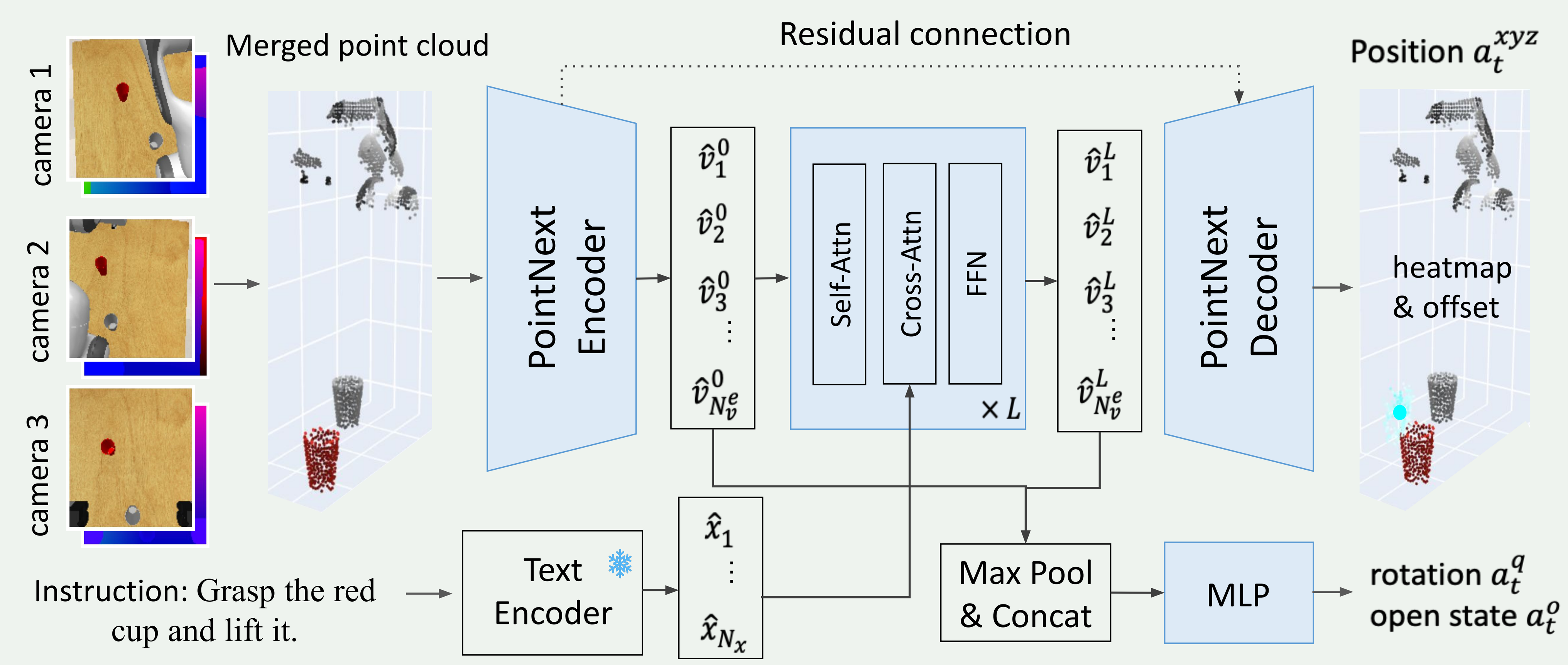
+ Natural way to merge multi-view observations.
+ Geometric structure: easy to select relevant point via preprocessing.
+ Accurate 3D localization.
- Need special models to efficiently process them.
- Multiple design choices.

Contribution

- Systematically explore the designs of 3D inputs: 3D features, coordinate systems, point removal.
- Efficiently predict 7 DoF actions given the point cloud and instruction using a light-weighted PointNext encoder-decoder and multimodal transformer
- Outperform state-of-the-art methods and achieve promising real world results

di.ens.fr/willow/research/polarnet/

PolarNet architecture



Point cloud design

Training: 100 demonstrations per task.

Evaluation: 500 unseen episodes per task.

Metric: Success Rate (SR).

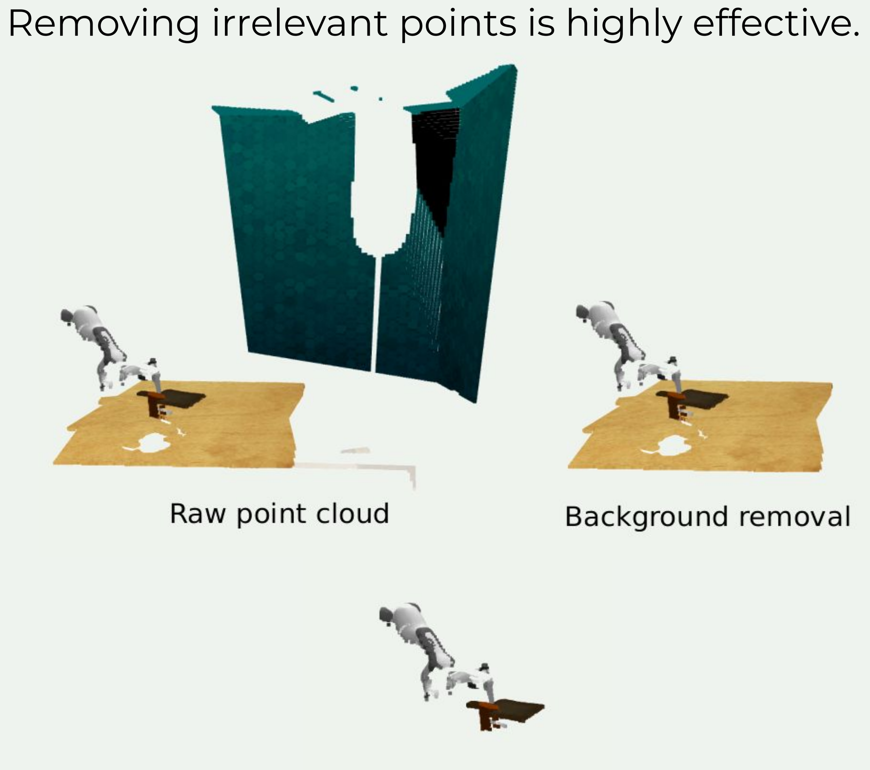
Three setups:

- Single-task (10 / 74 tasks)
- Multi-task (10 / 74 tasks)
- Multi-task multi-variation (18 tasks - 249 variations)

Point cloud preprocessing

Coord origin	Remove Table	Remove Background	Avg.
Center	✓	✓	92.1 ±2.0
Gripper	×	×	81.6 ±3.2
	×	✓	89.9 ±2.8
	✓	✓	**92.1** ±0.4

- Gripper and center coordinate frames perform similarly.
- Removing irrelevant points is highly effective.



Raw point cloud

Background removal

Background and table removal

Camera views

Left	Right	Wrist	Avg.
✓	×	×	37.6 ±4.8
×	✓	×	48.0 ±4.5
×	×	✓	35.0 ±5.5
✓	✓	×	67.0 ±4.7
✓	×	✓	80.2 ±3.0
×	✓	✓	76.6 ±5.6
✓	✓	✓	**92.1** ±0.4

- Single camera insufficient due to occlusions.
- Wrist camera alone performs worst but more complementary to the other two cameras.

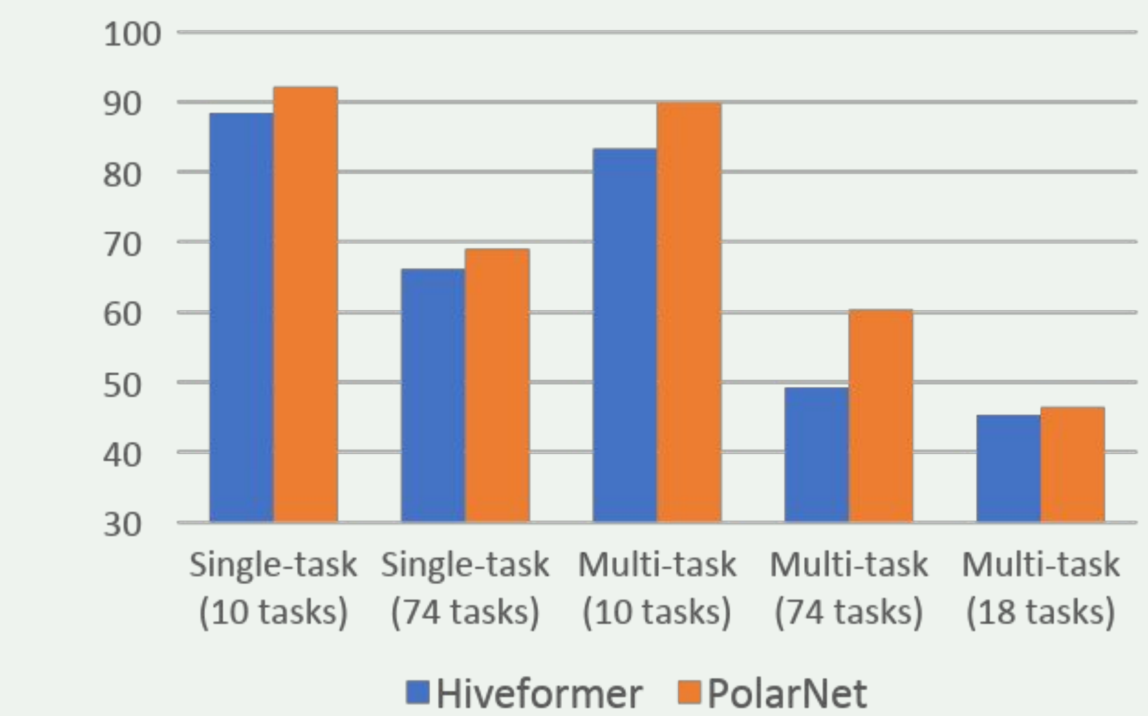
Point cloud representations

RGB	Normal	Height	Avg.
×	×	×	72.1 ±4.4
✓	×	×	91.3 ±1.6
✓	✓	×	90.3 ±3.1
✓	×	✓	91.5 ±1.4
✓	✓	✓	**92.1** ±0.4

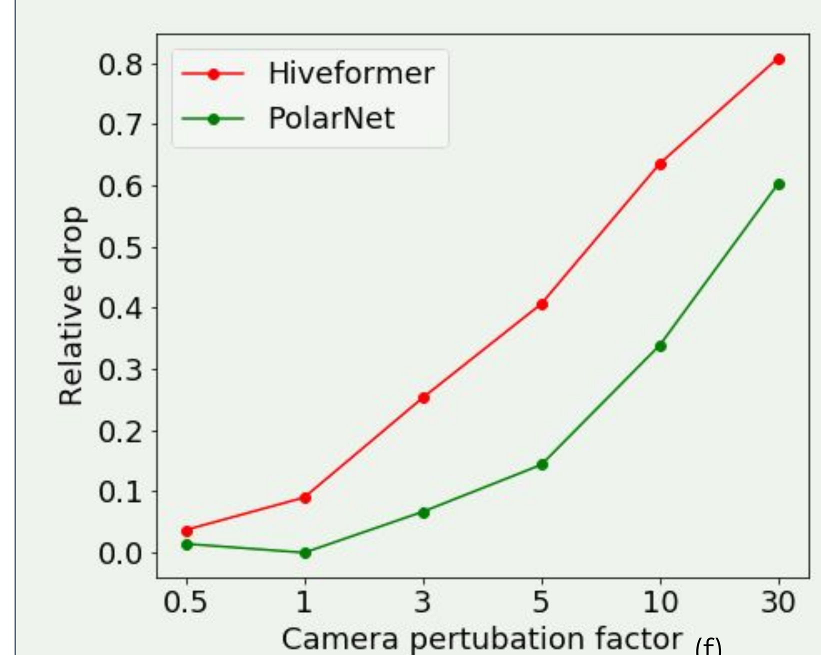
- Vanilla point cloud with only XYZ perform the worst.
- RGB color important to distinguish colors.
- Height relative to the table slightly improve results.
- Improvement from normal is less stable.

State-of-the-art comparison

Comparison to Hiveformer [1] (state-of-the-art method based on 2D representations) :



Robustness of viewpoint variances:



Training

Fixed viewpoints.

Evaluation

Randomly shifted viewpoints:

- Position: ± f cm
- Rotation: ± 5f degrees

[1] Instruction-driven history-aware policies for robotic manipulations, P.-L. Guhur etc., CoRL 2022

Real robot experiments

Policy pretrained on simulation and finetuned on real robot data. Policy shows promising results on 7 different tasks:

Task	PolarNet
Stack cup	8/10
Put fruit in box	8/10
Put plate on table	3/10
Open drawer	9/10
Put item in drawer	4/10
Put item in cabinet	4/10
Hang mug	6/10
Average	6/10