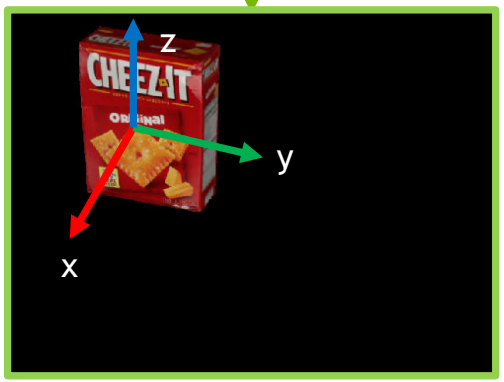
PoseRBPF: A Rao-Blackwellized Particle Filter for 6D Object Pose Tracking

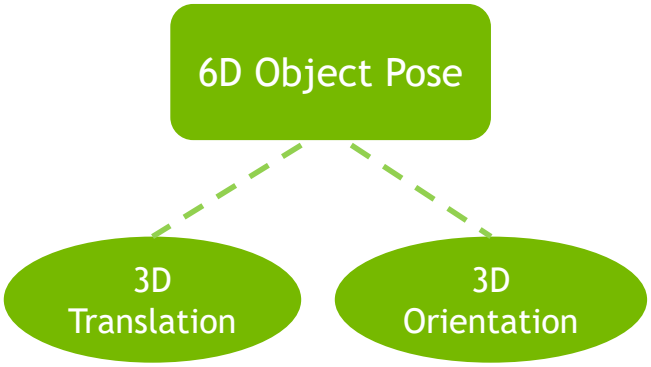
Yu Xiang, 9/27/2019

6D OBJECT POSE ESTIMATION

3D Model

Input image



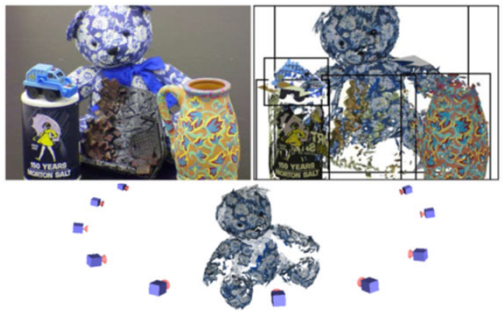


Pose information useful for

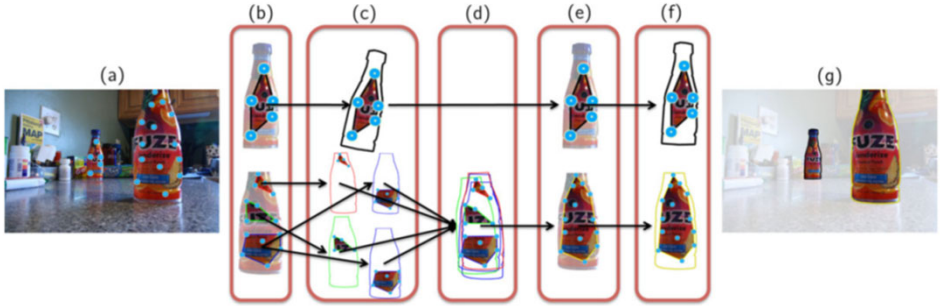
- Object manipulation
- Semantic navigation
- Human robot interaction

TRADITIONALLY

- Feature matching

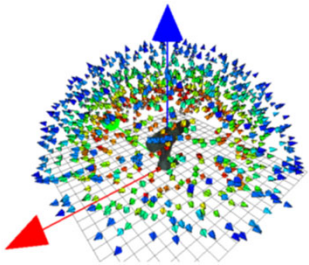


Rothganger et al. IJCV, 2006

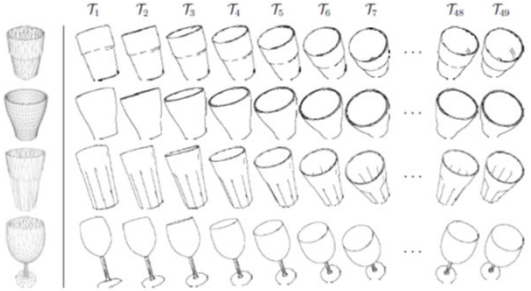


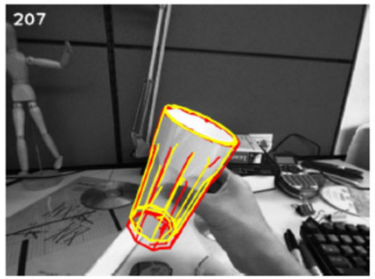
MOPED, Collet, Martinez, Srinivasa, IJRR, 2011

- Template matching



Hinterstoisser et al., ACCV, 2012





Choi et al., IROS, 2012

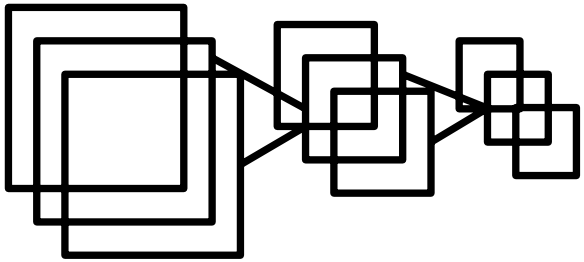
NVIDIA

CHALLENGES

- Model capability
  - Texture, texture-less objects
  - Symmetry objects
  - Clutter scenes
- Accuracy and Robustness
  - Lighting change
  - Different background
  - Uncertainty
  - Speed

DEEP LEARNING

- Better image features and stronger model capacity



Feature

3D Rotation

3D Translation
3D Rotation

- Rad & Lepetit, ICCV 2017
- Kehl et al. ICCV 2017
- Tremblay et al. CoRL 2018
- Tekin et al. CVPR 2018
- Xiang et al. RSS 2018
- Sundermeyer et al. ECCV 2018
- Li et al. ECCV 2018
- Wang et al. CVPR 2019

Our goal:

✓ Symmetry objects

✓ Pose Tracking

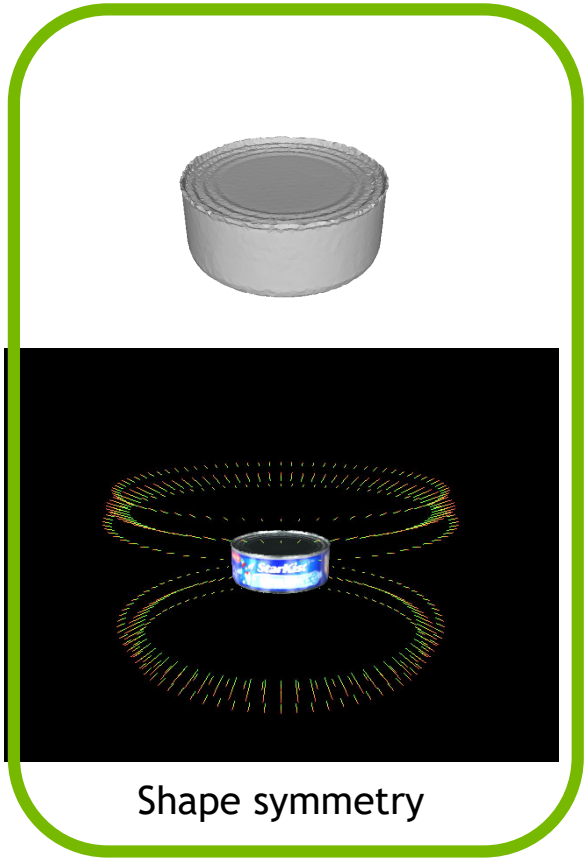
✓ Pose uncertainty

ORIENTATION UNCERTAINTY

Depends on context, shape, sensor

Observation

Orientation uncertainty

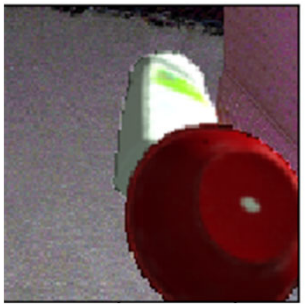


Shape symmetry

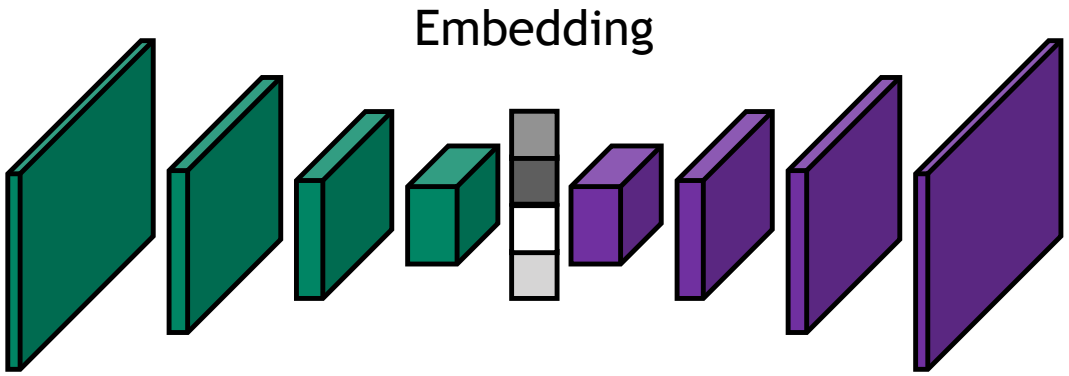
Texture breaks symmetry

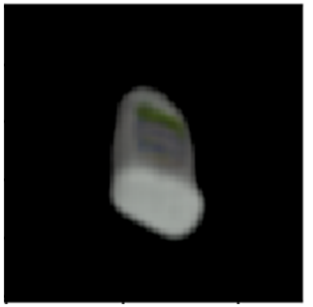
View-based uncertainty

IMPLICIT ROTATION LEARNING



Input





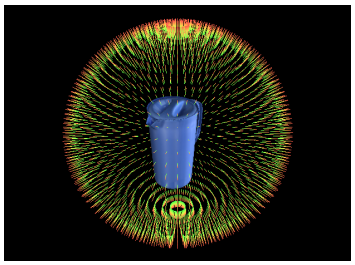
Reconstruction

Sundermeyer et al. Implicit 3D orientation learning for 6D object detection from RGB images. In ECCV, 2018.

ROTATION ESTIMATION WITH CODEBOOK MATCHING

[Sundermeyer et al. ECCV 2018]

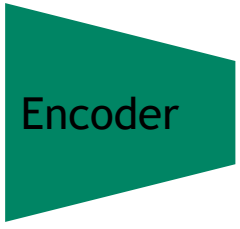
- Inherently handles symmetric views
- Only orientation, no translation
- Single image, single estimate

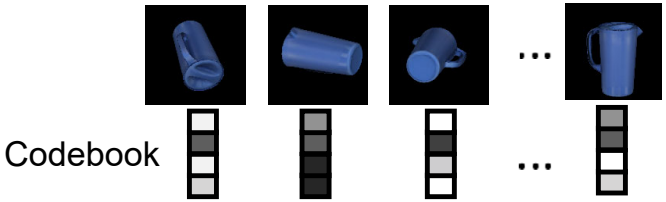


191,808 discrete rotations

Input

Detection



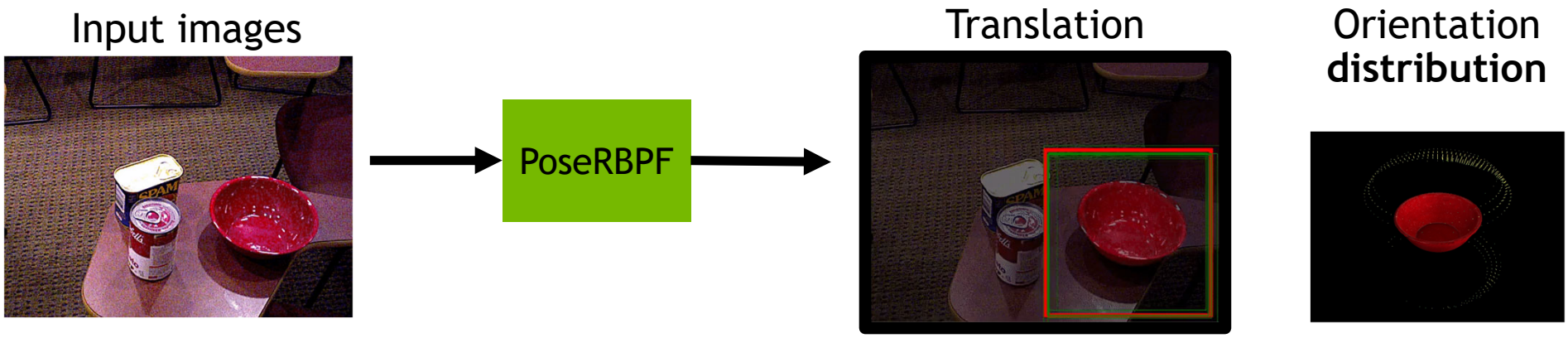


Similarity scores

PoseRBPF

Generic and Efficient Framework for 6D Object Pose Tracking

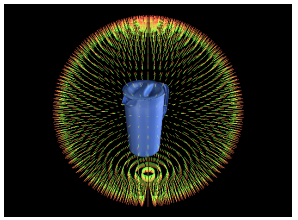
- Main idea: Instead of sampling all state dimensions, sample some of the dimensions and solve remaining ones analytically
- Successfully applied to SLAM, tracking, activity recognition, …
- Here: Sample translation and estimate discrete orientation distribution over orientation



Xinke Deng*, Arsalan Mousavian, Yu Xiang, Fei Xia*, Timothy Bretl and Dieter Fox. PoseRBPF: A Rao-Blackwellized Particle Filter for 6D Object Pose Tracking. In RSS, 2019 (*intern at NVIDIA).

PoseRBPF: Particle Representation

$$\mathcal{X}_i = \{\mathbf{T}_i, P(\mathbf{R}_i|\mathbf{T}_i, \mathbf{Z}_{1:k})\}$$



191,808 bins

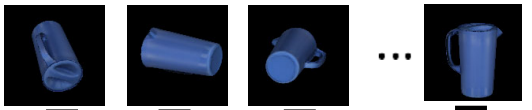
3D Translation
T_i

Orientation Distribution
$P(R_i|T_i, Z_{1:k})$

RoI

Encoder

Discretized Rotations

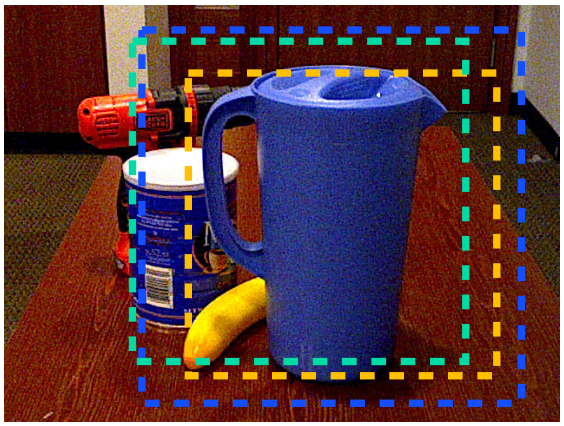


Codebook

Particle Code

Rotation Likelihood

PoseRBPF: Observation Update



Particle RoIs

Encoder

Encoder

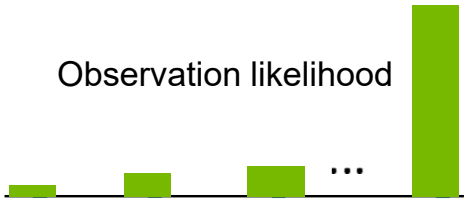
Encoder

Particle Code

Compute posterior

$$P(\mathbf{R}_k|\mathbf{T}_k^i, \mathbf{Z}_{1:k}) \propto P(\mathbf{R}_k|\mathbf{T}_k^i, \mathbf{Z}_k)P(\mathbf{R}_k|\mathbf{R}_{k-1})$$

Observation likelihood



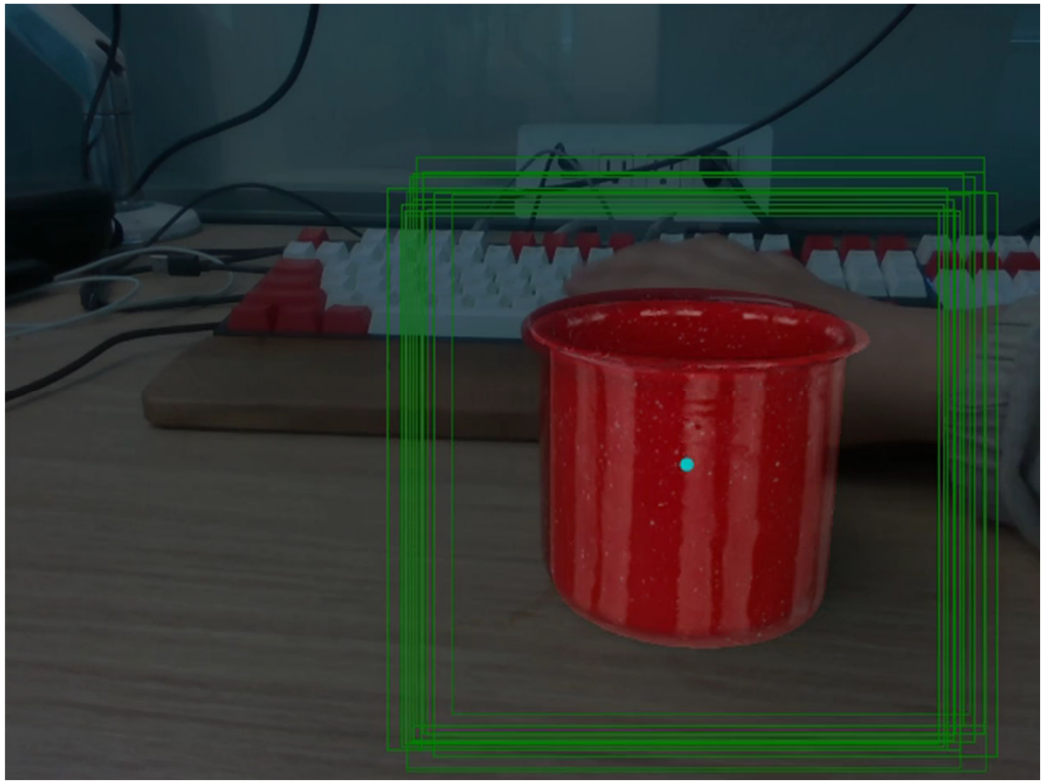
Normalizer

Orientation Distribution

Weights

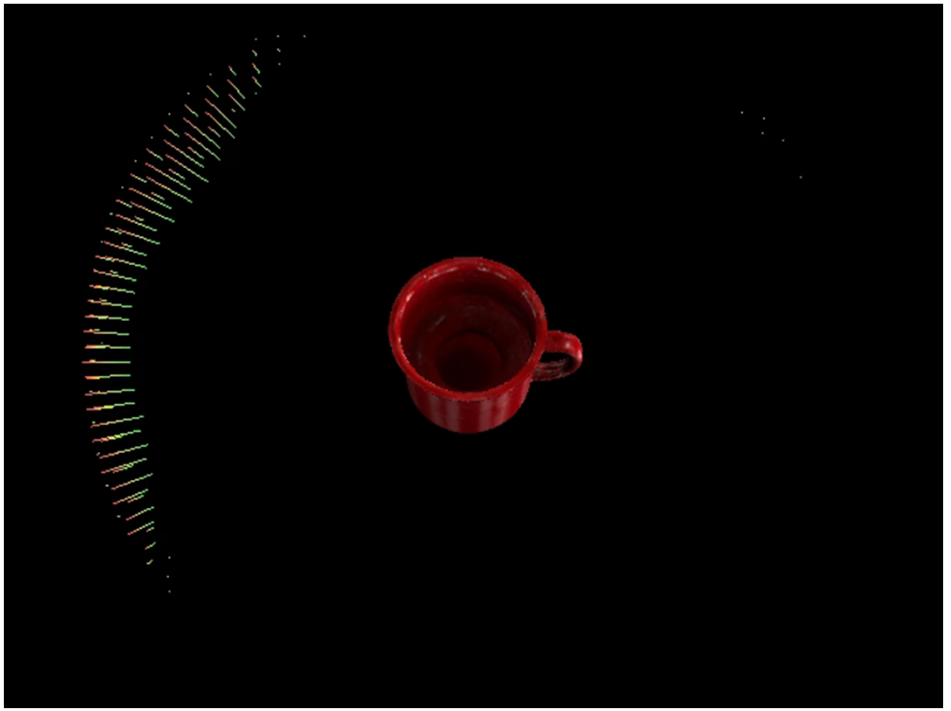
Results: YCB Objects

Example: YCB mug (50 particles, ~20fps)



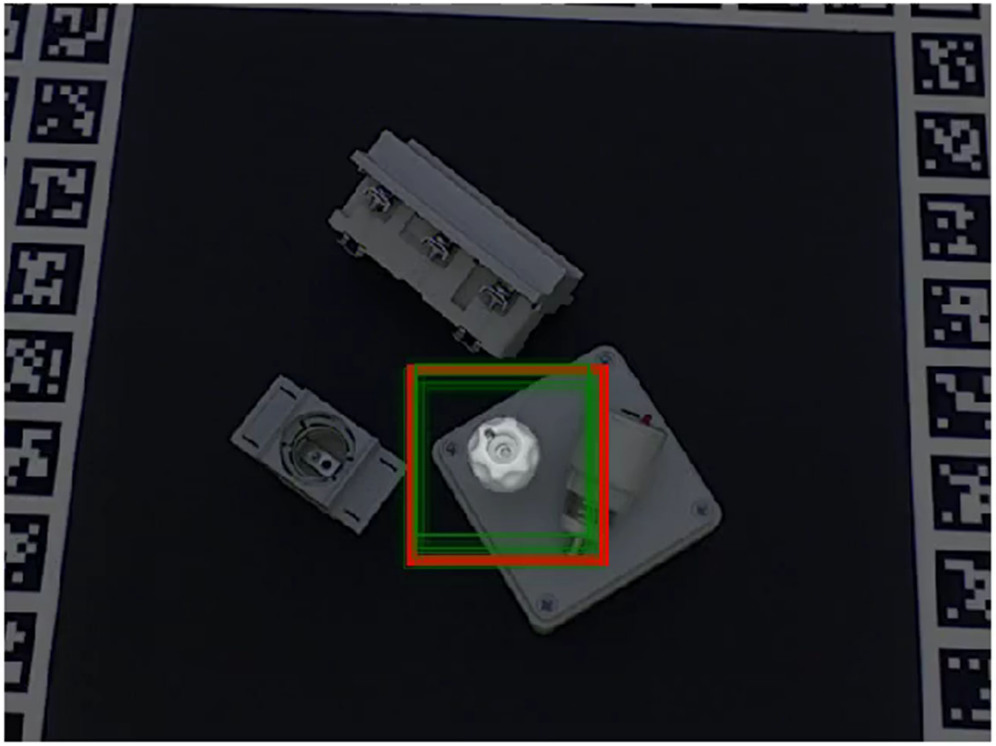
YCB-Video RGB

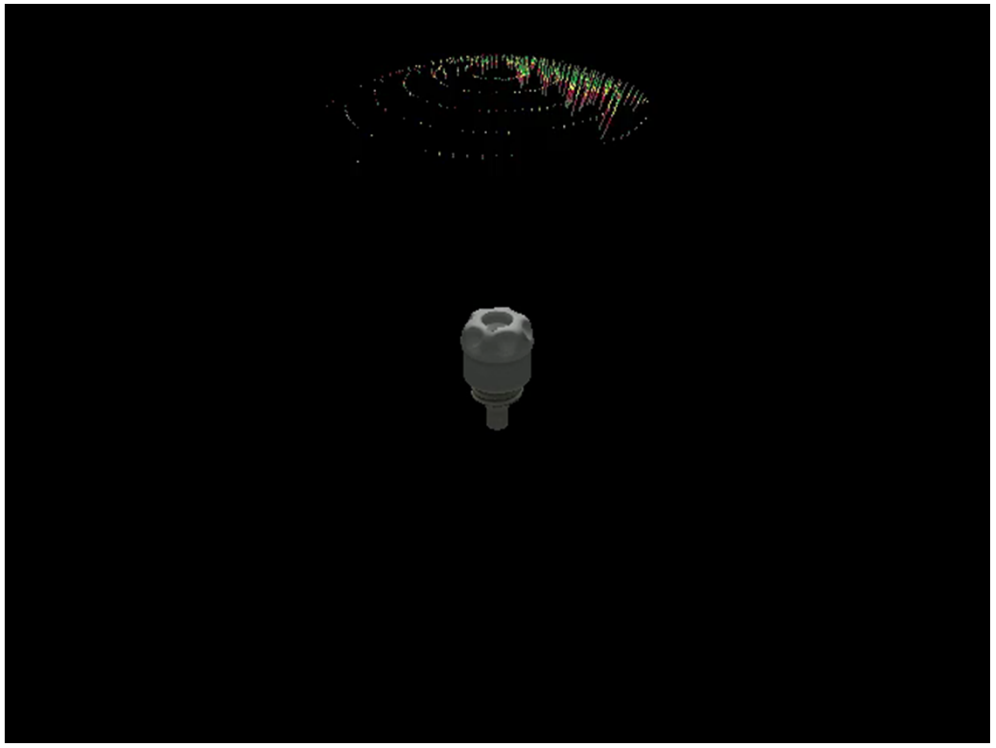
- PoseRBPF:
  ADD: 62.1, ADD-S: 78.4
- PoseCNN:
  ADD: 53.7, ADD-S: 75.9



Results: TLess Objects

Example: TLess 01 (100 particles, ~11fps)





TLess RGB

Object recall for Err_vsd < 0.3:

- PoseRBPF: 41.47%
- Sundermeyer et al: 18.35%

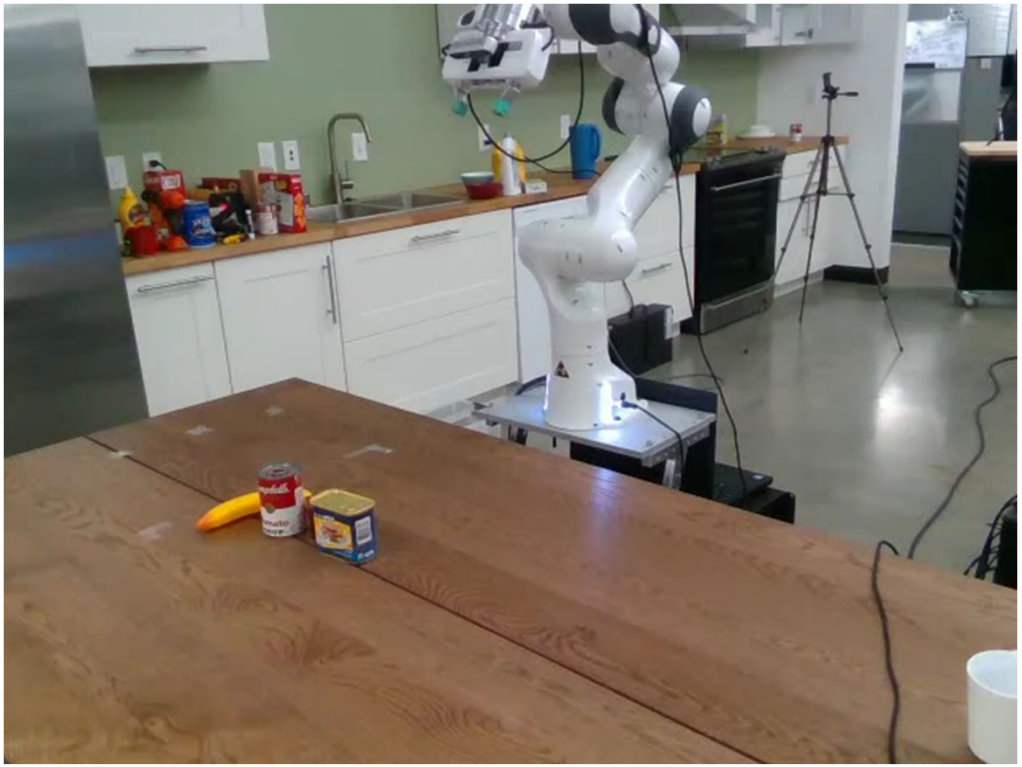
ROBUSTNESS?

Self-supervised Learning

Lift-long Learning

SELF-SUPERVISED 6D POSE ESTIMATION

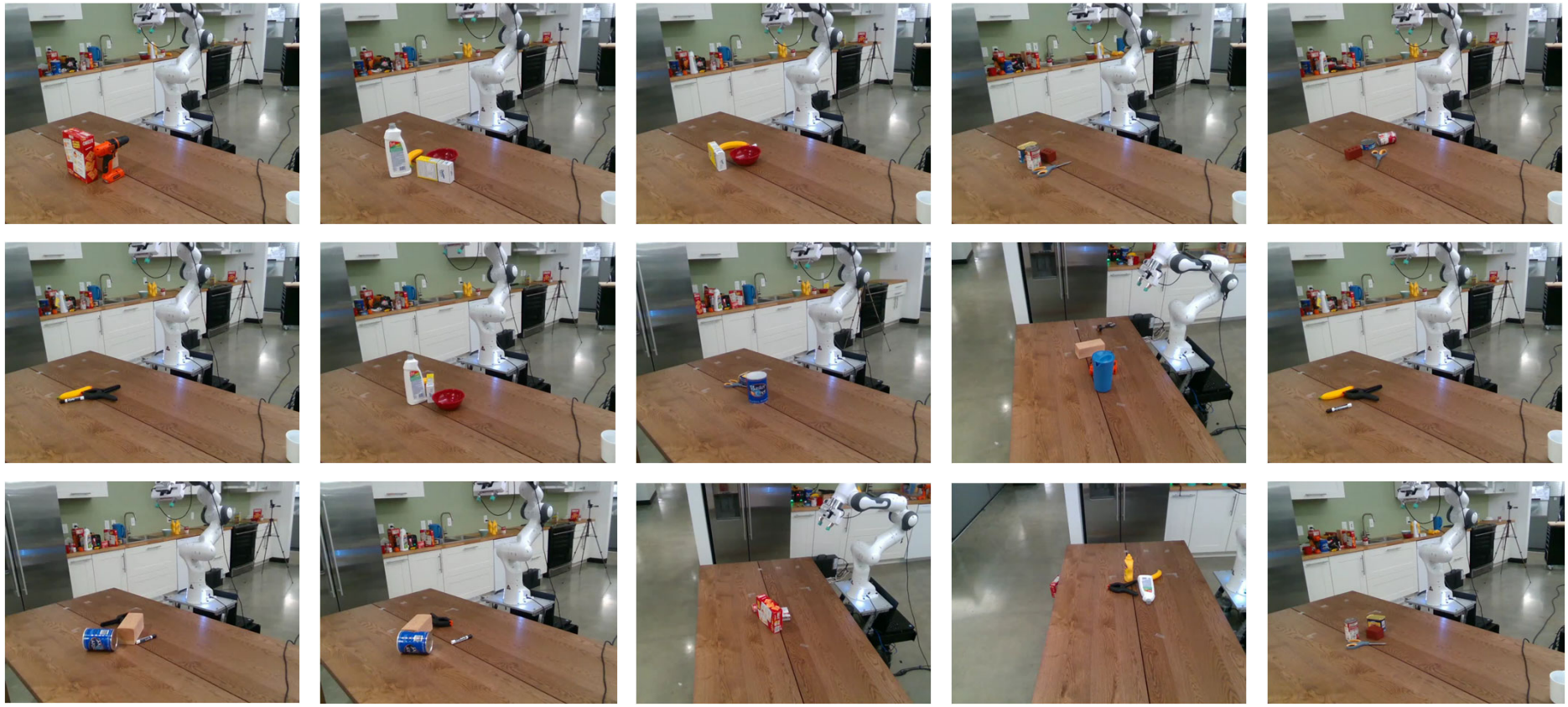
Interactive data collection (5x)



Generated pose annotations

The robot can automatically interact with the objects to create new scenes by grasping and pushing.

DATA COLLECTION



The system can automatically collect large scale datasets.

GRASPING RESULTS

Success Rate (30 grasps)
- Synthetic: 46.7%
- Fine-tuned: 86.7%

trained with only synthetic data

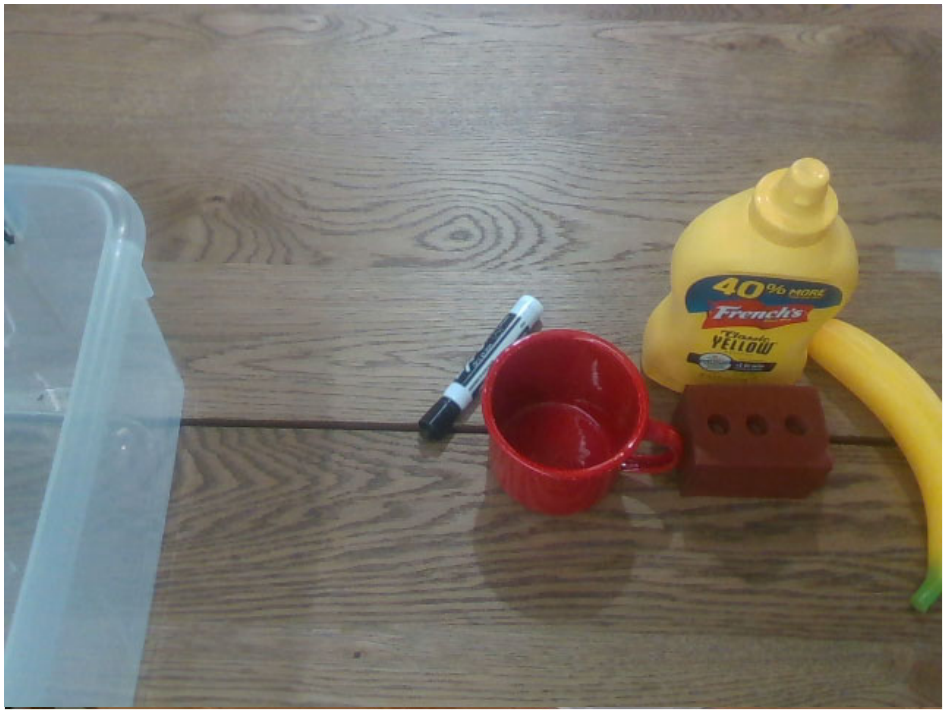
fine-tuned with self-annotated data

Better pose estimates lead to higher grasp success.

GRASPING RESULTS

Scene 1

Scene 2



Here, we show the performance of our system on pick-and-place tasks.

POSERBPF

- Estimates full 6D object pose distributions
- Combines Bayesian filtering with deep learning for embeddings
- Handles symmetric objects and pose uncertainty
- Fully trained in simulation, state-of-the-art results on RGB only datasets
- Enables us to build a self-supervised 6D pose estimation system for manipulation

Questions?