A System for General In-Hand Object Re-Orientation

CoRL 2021 best paper

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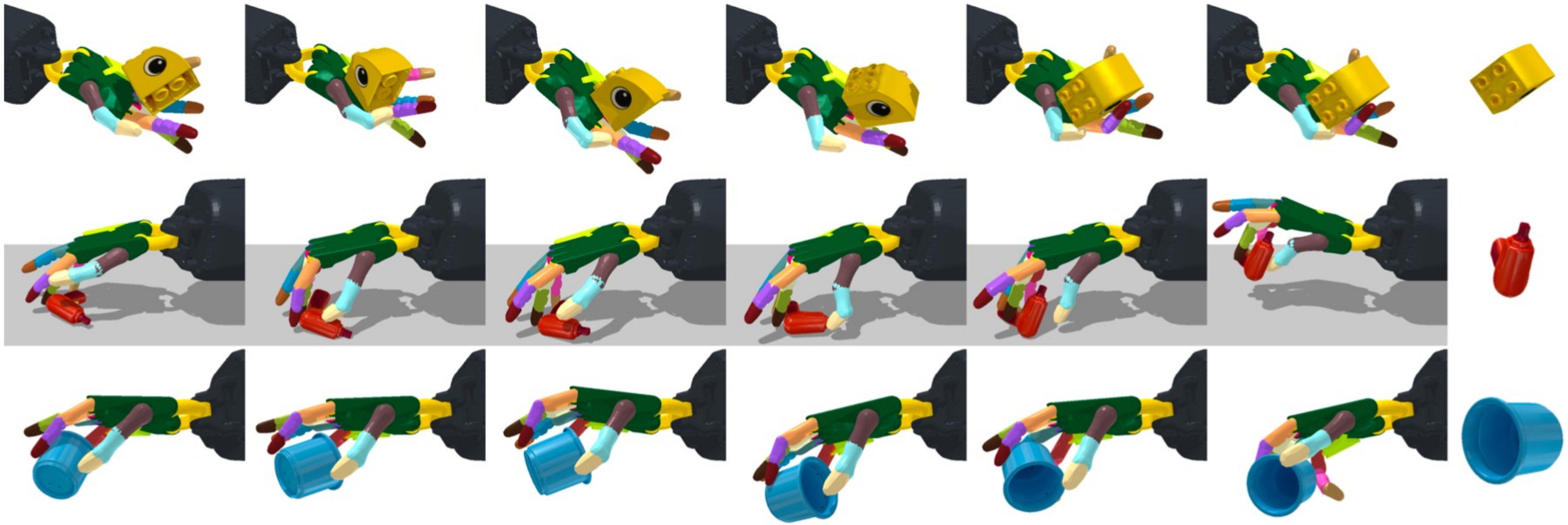
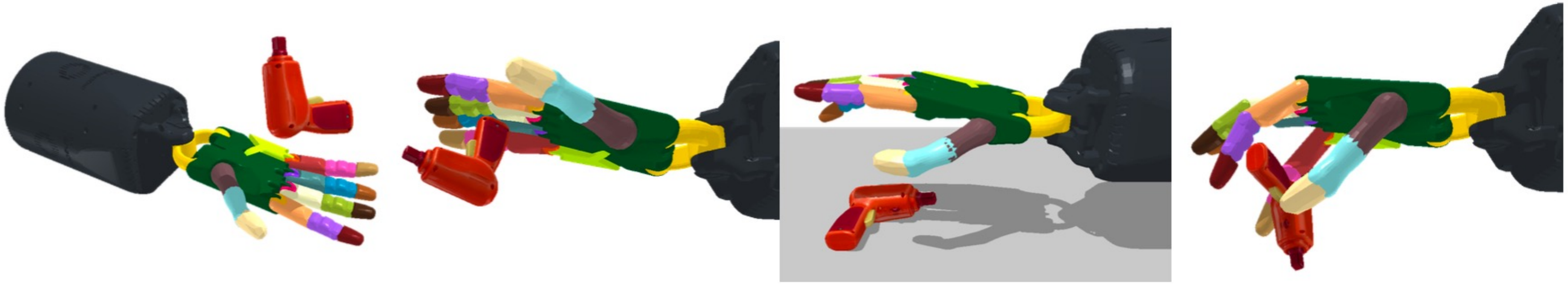
Overview

- A model-free framework that learns to reorient objects of all kinds



Contributions

- Hand facing upward and downward
- Zero-shot transfer on new objects
- Try vision-based observation

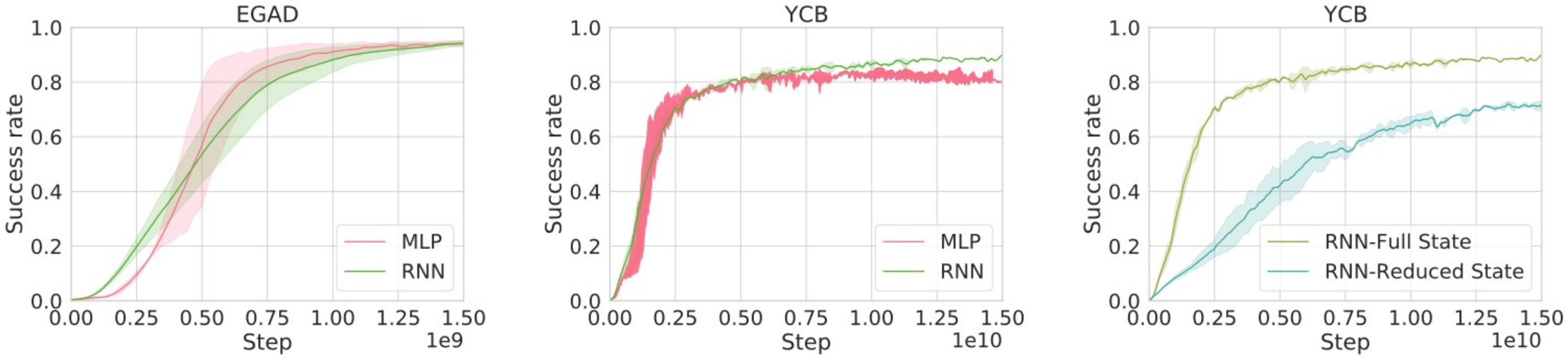


Method

- Teacher-student Learning
- Gravity Curriculum
- Stable initialization

Teacher Policy

- Full Observation
- MLP or RNN
- Dynamic randomization



Teacher Policy

- Reward Function

$$r(s_t, a_t) = c_{\theta_1} \frac{1}{|\Delta\theta_t| + \epsilon_\theta} + c_{\theta_2} \mathbb{1}(|\Delta\theta_t| < \bar{\theta}) + c_3 \left\| a_t \right\|_2^2$$

Student Policy

- Reduced Observation

  Which can be obtained when in real world

- Vision or Non-vision

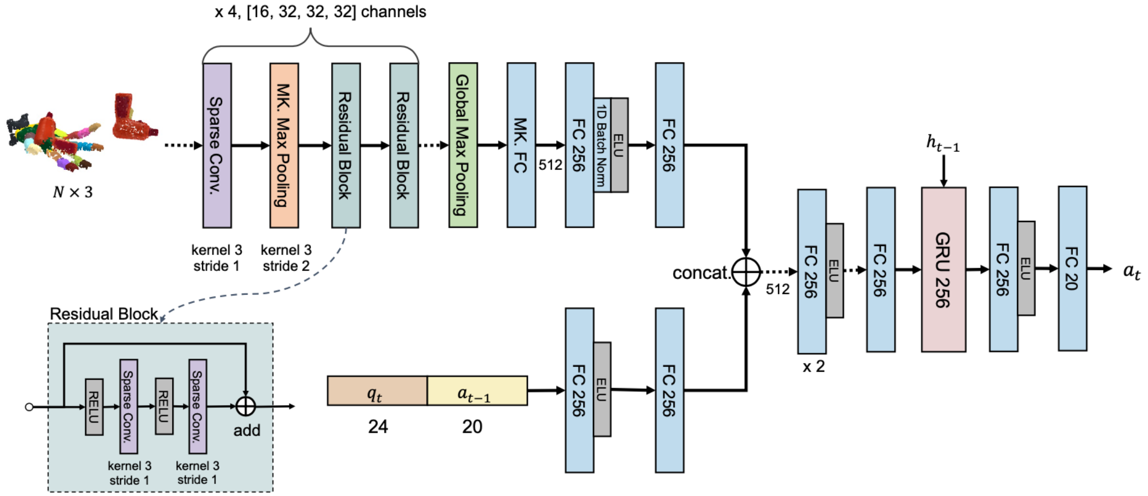
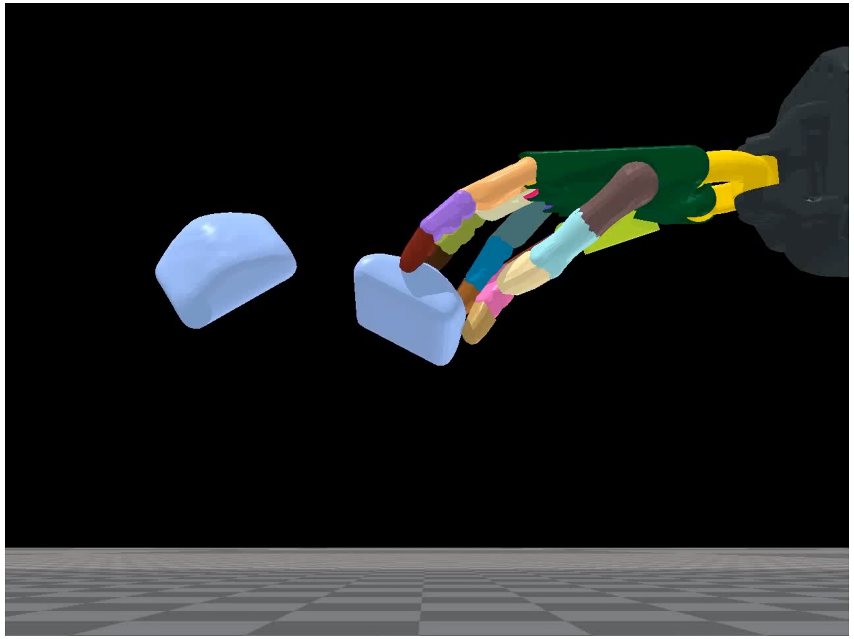


Figure 2: Visual policy architecture. MK stands for Minkowski Engine. q_t is the joint positions and a_t is the action at time step t.

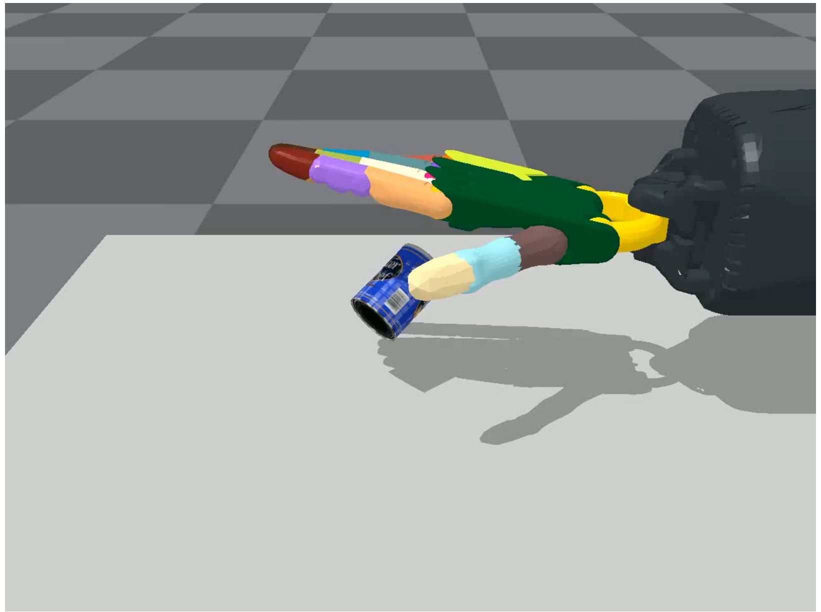
Gravity Curriculum

- Hand facing downward and in air
- Gradually decrease g



Stable Initialization

- Reorient in air
- A separate RNN to lift objects



Experiments

- Dataset

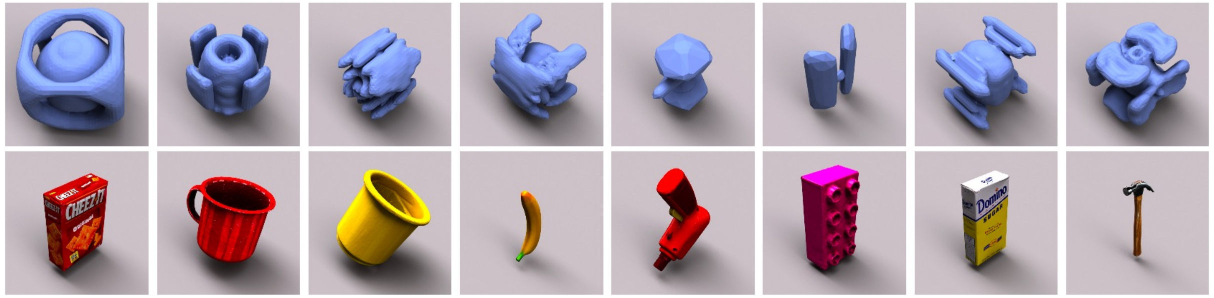


Figure B.2: First row: examples of EGAD objects. Second row: examples of YCB objects.

- Facing upward and downward (with and without table)
- Vision-based student policy

Facing upward

- Results

				1	2	3
Exp. ID	Dataset	State	Policy	Train without DR		Train with DR
				Test without DR	Test with DR	Test with DR
B	EGAD	Full state	RNN	95.95 ± 0.8	84.27 ± 1.0	88.04 ± 0.6
E		Reduced state	RNN→RNN	91.96 ± 1.5	78.30 ± 1.2	80.29 ± 0.9
G	YCB	Full state	RNN	80.40 ± 1.6	65.16 ± 1.0	72.34 ± 0.9
J		Reduced state	RNN→RNN	81.04 ± 0.5	64.93 ± 0.2	65.86 ± 0.7

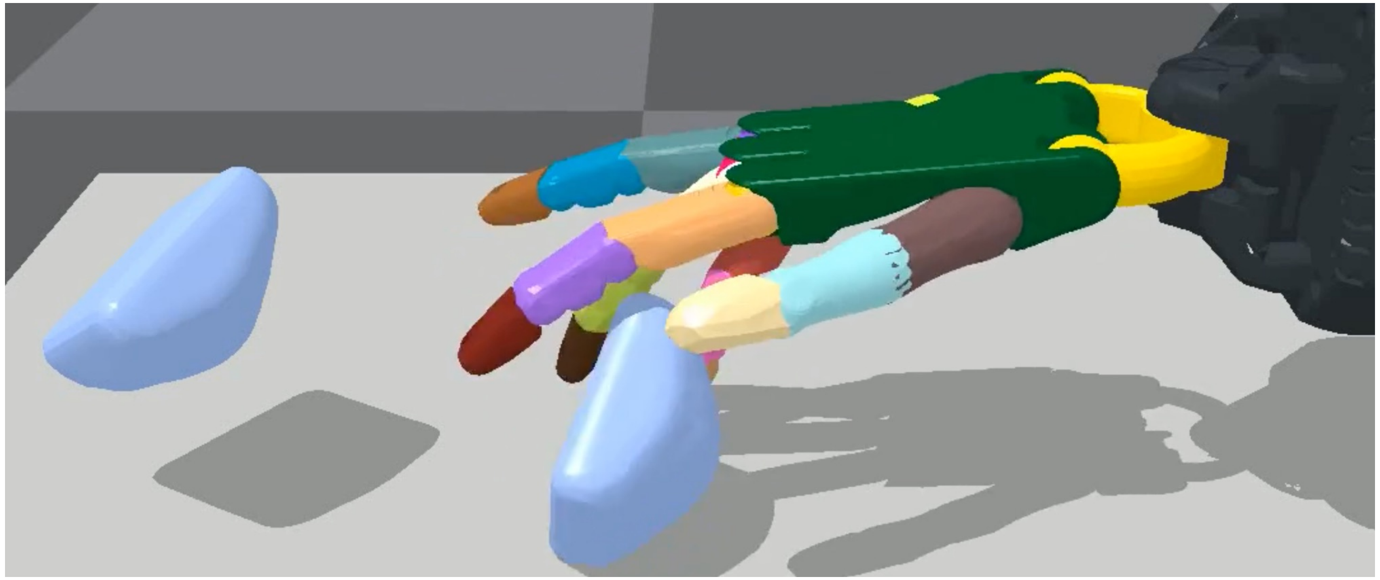
- Throw and Catch
- Failure

Facing downward with table

- Results

  MLP policy for EGAD and YCB is 95.31% $\pm$ 0.9% and 81.59% $\pm$ 0.7%

- External Force



Facing downward without table

- Results

				1	2	3
Exp. ID	Dataset	State	Policy	Train without DR		Finetune with DR
				Test without DR	Test with DR	Test with DR
K	EGAD	Full state	MLP	**84.29 ± 0.9**	**38.42 ± 1.5**	**71.44 ± 1.3**
L			RNN	82.27 ± 3.3	36.55 ± 1.4	67.44 ± 2.1
M		Reduced state	MLP→RNN	**77.05 ± 1.6**	29.22 ± 2.6	59.23 ± 2.3
N			RNN→RNN	74.10 ± 2.3	**37.01 ± 1.5**	**62.64 ± 2.9**
O	YCB	Full state	MLP	58.95 ± 2.0	26.04 ± 1.9	44.84 ± 1.3
P			RNN	52.81 ± 1.7	**26.22 ± 1.0**	40.44 ± 1.5
Q			RNN + g-curr	**74.74 ± 1.2**	25.56 ± 2.9	**54.24 ± 1.4**
R		Reduced state	MLP→RNN	46.76 ± 2.5	**25.49 ± 1.4**	34.14 ± 1.3
S			RNN→RNN	45.22 ± 2.1	24.45 ± 1.2	31.63 ± 1.6
T			RNN + g-curr→ RNN	**67.33 ± 1.9**	19.77 ± 2.8	**48.58 ± 2.3**

- Also Throw and Catch

Zero-shot Transfer

- Results

	EGAD → YCB	YCB → EGAD
U.FS	68.82 ± 1.7	96.41 ± 1.2
U.RS	59.64 ± 1.8	96.38 ± 1.3
D.FS	62.73 ± 2.2	85.45 ± 2.9
D.RS	55.30 ± 1.3	77.91 ± 2.1

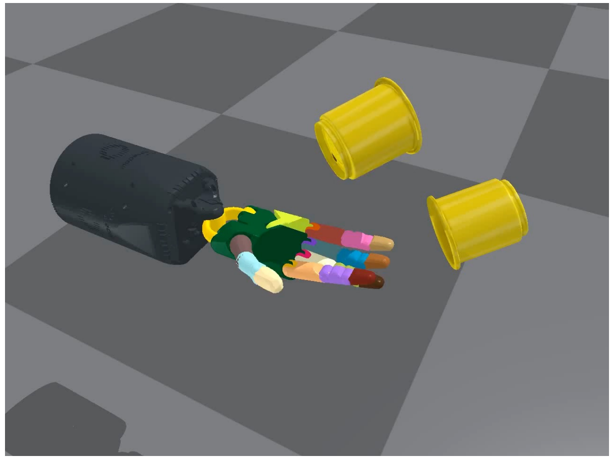
- Shape-agnostic

Vision-based

- Constraints

- Results

	Object	Success rate (%)
	025_mug	89.67 ± 1.2
	065-d_cups	68.32 ± 1.9
	072-b_toy_airplane	84.52 ± 1.4
	073-a_lego_duplo	58.16 ± 3.1
	073-c_lego_duplo	50.21 ± 3.7
	073-e_lego_duplo	66.57 ± 3.1



Comment

- Highly Dynamic
- Reduced State can be obtained?
- Shape-agnostic?