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

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

Facing upward and downward (with and without table)

Vision-based student policy

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

Facing upward

Results

| Exp. ID | Dataset | State          | Policy          | 1  | 2  | 3  |
|---------|---------|----------------|-----------------|----|----|----|
| B       | EGAD    | Full state     | RNN             | 95.95 ± 0.8 | 84.27 ± 1.0 | 88.04 ± 0.6 |
|         |         | 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% ± 0.9% and 81.59% ± 0.7%

External Force
Facing downward without table

Results

| Exp. ID | Dataset | State         | Policy            | 1     | 2     | 3     |
|--------|---------|---------------|-------------------|-------|-------|-------|
|        |         |               | Train without DR  | Finetune with DR |
|        |         |               | Test without DR   | Test with DR    |
| K      | EGAD    | Full state    | MLP               | 84.29 ± 0.9  | 38.42 ± 1.5 | 71.44 ± 1.3 |
|        |         |               | RNN               | 82.27 ± 3.3  | 36.55 ± 1.4 | 67.44 ± 2.1 |
| M      | EGAD    | Reduced state | MLP→RNN           | 77.05 ± 1.6  | 29.22 ± 2.6 | 59.23 ± 2.3 |
| N      | EGAD    | Reduced state | 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      | YCB     |               | RNN               | 52.81 ± 1.7  | 26.22 ± 1.0 | 40.44 ± 1.5 |
| Q      | YCB     |               | RNN + g-curr      | 74.74 ± 1.2  | 25.56 ± 2.9 | 54.24 ± 1.4 |
| R      | YCB     | Reduced state | MLP→RNN           | 46.76 ± 2.5  | 25.49 ± 1.4 | 34.14 ± 1.3 |
| S      | YCB     | Reduced state | RNN→RNN           | 45.22 ± 2.1  | 24.45 ± 1.2 | 31.63 ± 1.6 |
| T      | YCB     |               | 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 $\rightarrow$ YCB | YCB $\rightarrow$ 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?