DexDeform: Dexterous Deformable Object Manipulation with Human Demonstrations and Differentiable Physics

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Motivation

- The recent success of dexterous manipulation has been widely observed on tasks with rigid objects.
- However, a substantial portion of human dexterous skills comes from interactions with deformable objects.
- Therefore, in order to develop control policy for robotic dexterity, we need to consider deformable scenarios.

Problem Statement:

Dexterous Deformable Object Manipulation

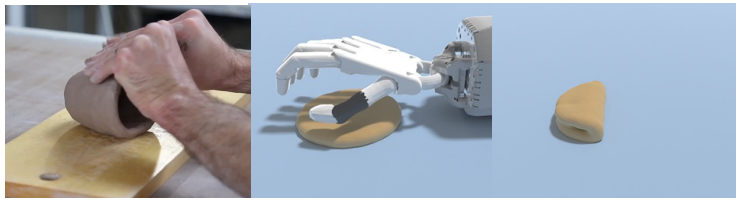


Figure 1: Given current observation, plan dexterous actions to achieve the goal shape (described in point cloud).

Contributions

- An **initial investigation** on **dexterous deformable manipulation**.
- A platform that supports **differentiable simulation** and **human teleoperation**, supporting easy collection of demonstrations.
- A skill-learning framework that **plans actions based on abstractions**, and **bootstrap skills with differentiable physics.**
- Our approach outperforms the baselines and successfully accomplishes six challenging tasks.

DexDeform provides a simulation platform

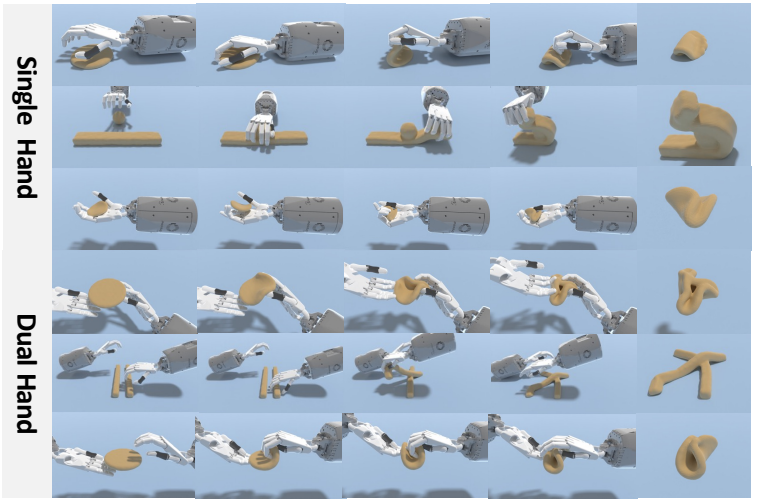
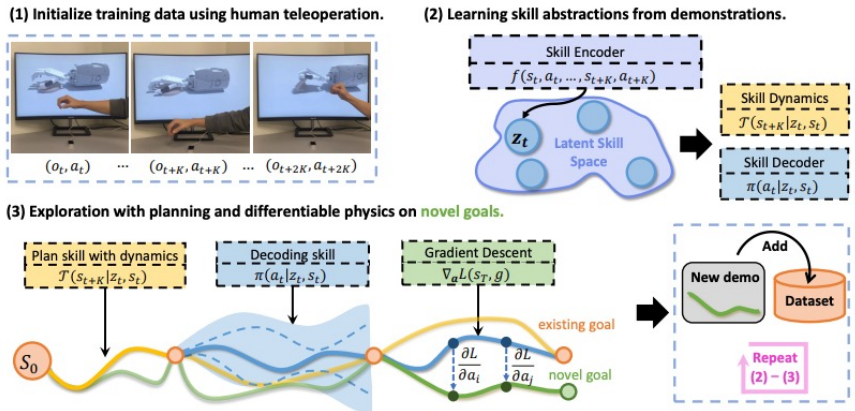
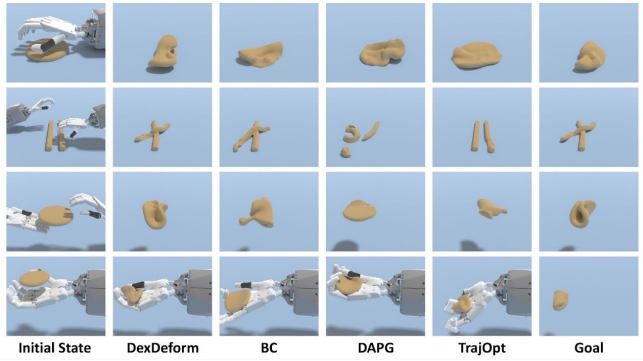


Figure 2: Our framework covers tasks with a single-hand and dual hand tasks. Rightmost column represents goals.

Framework Overview



Qualitative Evaluation



Quantitative Evaluation

Env	Folding	Rope	Bun
TrajOpt	0.032 ± 0.061	0.079 ± 0.026	0.000 ± 0.000
PPO	0.361 ± 0.173	0.460 ± 0.257	0.069 ± 0.117
DAPG	0.538 ± 0.308	0.246 ± 0.626	0.460 ± 0.079
BC	0.685 ± 0.388	0.557 ± 0.377	0.379 ± 0.258
DexDeform	$\mathbf{0.970 \pm 0.021}$	$\mathbf{0.972 \pm 0.010}$	$\mathbf{0.874 \pm 0.078}$
Env	**Dumpling**	**Wrap**	**Flip**
TrajOpt	0.000 ± 0.000	0.000 ± 0.000	0.195 ± 0.275
PPO	0.000 ± 0.000	0.000 ± 0.000	0.223 ± 0.328
DAPG	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
BC	0.506 ± 0.314	0.134 ± 0.595	0.253 ± 0.359
DexDeform	$\mathbf{0.888 \pm 0.055}$	$\mathbf{0.845 \pm 0.050}$	$\mathbf{0.842 \pm 0.057}$

Conclusions

- We perform the first investigation of the learning-based dexterous manipulation of deformable object**.**
- We build a platform that integrates low-cost teleoperation with a soft-body simulation that is differentiable.
- We propose a skill learning framework that learns from demonstrations and bootstrap skills with differentiable physics trajectory optimization.