Final Project Presentation:

Improvement on Bimanual Grasp Pose Synthesis

Team 3

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Contents

1. Overview of Bimanual Dexterous Grasping

1.1. Overall structure

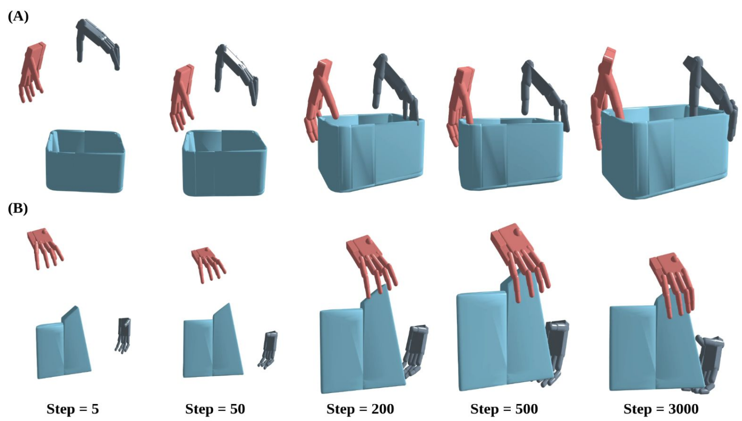
1.2. Generation term in detail

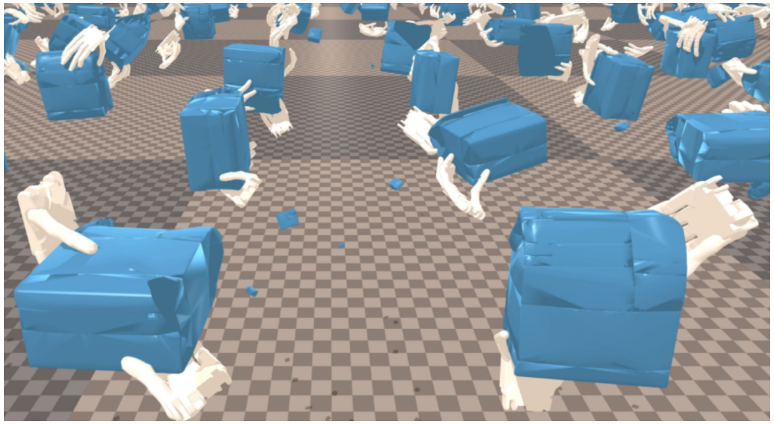
1.1. Overall structure

: Bimanual Grasp Synthesis for Dexterous Robot Hands (ICRA 25)

BimanGrasp Algorithm

- Generate Dataset by **gradient descent of Energy term** from initial state
  Hand-Object Distance, **Force Closure** and **Penetration**





DDPM Algorithm

- Generate pose using diffusion model and
  execute few optimization to avoid penetration

1.2. Generation term in detail

BimanGrasp Algorithm

- Energy term is generated by weighted sum of energy below
- There are some details in optimizer and stochastic acception method

E_{dis}: Hand-object distance	$\sum_{a=1}^{n} d(x_a, O)$
E_{fc}: Force Closure	$\|\|\boldsymbol{Gc}\|\|_2$
E_{vew}: Wrench Ellipse Volume	$\left(\det\left(\mathbf{GG}^T\right)\right)^{-\frac{1}{2}}$
E_{objpen}: Hand-Object Penetration	$\sum_{l\in\{1,2\}} \sum_{p_l\in P(H_l)} \max(\delta - d(p_l, O), 0)$
E_{selfpen}: Hand Self-Penetration	$\sum_{l\in\{1,2\}} \sum_{p,q\in P(H_l)} \max(\delta - d(p, q), 0)$
E_{bimpen}: Inter-Hands Penetration	$\sum_{p\in P(H_1),q\in P(H_2)} \max(\delta - d(p, q), 0)$
E_{joint}: Violation of Joint Limits	$\sum_{i=1}^{44} (\max(\theta_i - \theta_i^{max}, 0) + \max(\theta^{min} - \theta_i, 0))$

2. Limitation and Solution

2.1. Limitations of the Baseline Paper

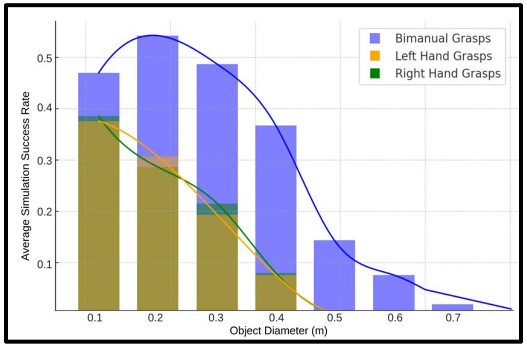
2.2. Proposal 1: Separate Contact Points

2.3. Proposal 2: Consider Gravity and Stability

2.1. Limitations of the Baseline Paper

Recap: Energy terms in Bimanual Grasp Synthesis for Dexterous Robot Hands (ICRA 25)

1. Insufficient Success Rate



Method	$\rho = 5000$	$\rho = 2500$	$\rho = 500$
Both Hands (Optimization)	**41.02%**	**54.03%**	**71.42%**
Uni2Bim (opt)	32.87%	45.26%	56.69%
Left Hand Only	23.38%	41.48%	68.42%
Right Hand Only	21.85%	41.95%	68.48%
Both Hands (Diffusion)	**42.39%**	**54.06%**	**69.87%**

2. Frequent Penetration

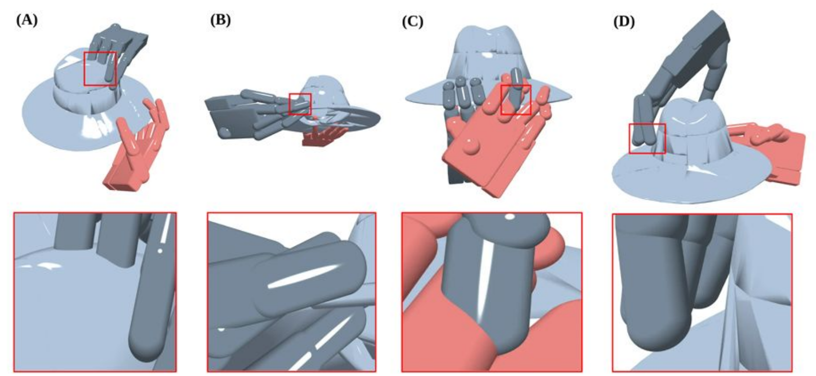


Fig. 9: Visualization of four most common failure patterns: (A) hand-object penetration, (B) hand's self-penetration, (C) inter-hand penetration, and (D) failure to establish contact.

2.1. Limitations of the Baseline Paper

Recap: Energy terms in Bimanual Grasp Synthesis for Dexterous Robot Hands (ICRA 25)

TABLE I: Energy function for grasp search problem. The minimization objective of the algorithm is the weighted sum of all terms.

Term	Formulation
E_{dis}: Hand-object distance	$\sum_{a=1}^{n} d(x_a, O)$
E_{fc}: Force Closure	$\|\|\boldsymbol{Gc}\|\|_2$
E_{vew}: Wrench Ellipse Volume	$\left(\det\left(\mathbf{GG}^T\right)\right)^{-\frac{1}{2}}$
E_{objpen}: Hand-Object Penetration	$\sum_{l\in\{1,2\}} \sum_{p_l \in P(H_l)} \max(\delta - d(p_l, O), 0)$
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E_{bimpen}: Inter-Hands Penetration	$\sum_{p\in P(H_1), q\in P(H_2)} \max(\delta - d(p, q), 0)$
E_{joint}: Violation of Joint Limits	$\sum_{i=1}^{44} (\max(\theta_i - \theta_i^{max}, 0) + \max(\theta^{min} - \theta_i, 0))$

Problems of E_bimpen

- Adding **only** inter-hands penetration energy term may not be sufficient to reflect interaction b/w two hands

2.2. Proposal 1: Separating Contact Points

- Some initial attempts
  1. Friction cone integration
  2. Separate object region with contact points

- **Problems**
  - Too much time for generation(Optimization)
  - Hard to balance weights when the energies are complicated
  - **Need to simplify our target energy**

2.2. Proposal 1: Separating Contact Points

- E_contact_separation
  Modified attempts: separate each contact points

Definitions of point sets

$$P_L = \{p_{L,\,1},\ p_{L,\,2},\ \ldots,\ p_{L,\,N_L}\}$$

: contact points of the left hand

$$P_R = \{p_{R,\,1},\ p_{R,\,2},\ \ldots,\ p_{R,\,N_R}\}$$

: contact points of the right hand

Definitions of distances

$$d_{\min} = \min_{p_L \in P_L, p_R \in P_R} d(p_L, p_R)$$

: minimum distance between the two hands

$$d_{LL} = \frac{1}{N_L\,(N_L - 1)/2} \Sigma_{i \neq j,\ p_L \in P_L} d(p_{L,\,i}, p_{L,\,j})$$

: sum of distances between contact points of the left hand

$$d_{RR} = \frac{1}{N_R\,(N_R - 1)/2} \Sigma_{i \neq j,\ p_R \in P_R} d(p_{R,\,i}, p_{R,\,j})$$

: sum of distances between contact points of the right hand

2.2. Proposal 1: Separating Contact Points

- **Modified attempts: separate each contact points**

$$E_{sep} = \begin{cases} (\delta - d_{min})^2 & \text{if } d_{min} < \delta \\ 0 & \text{otherwise} \end{cases}$$

$$\boxed{E_{div} = e^{-\alpha \cdot d_{min}} + \beta \cdot (\text{mean}(d_{LL}) + \text{mean}(d_{RR}))}$$

$\alpha = \text{scaling factor of penalty}$

$\beta = \text{scaling factor of coverage bonus}$

Also consider distribution of contact points in one hand!

2.3. Proposal 2:
Consider Gravity and Stability

- **Motivation:** Current generation doesn't consider gravity, and check validation with 6 direction force. Model always aim for highly controllable grasp rather than stable control

E_gravity_support (sum of upward (z-axis) components of contact normals)

$$\mathrm{ReLU}\left(\mathrm{threshold} - \sum_i n_{i,z}\right)$$

E_vertical_stability (total torque computed from all contact points)

$$\left\|\sum_i (\mathbf{r}_i \times \mathbf{f}_i)\right\|$$

3. Process & Result

3.1. Overall Process

3.2. Result

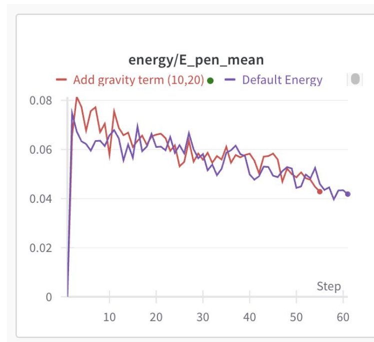
3.1 Overall process

Default Parameter

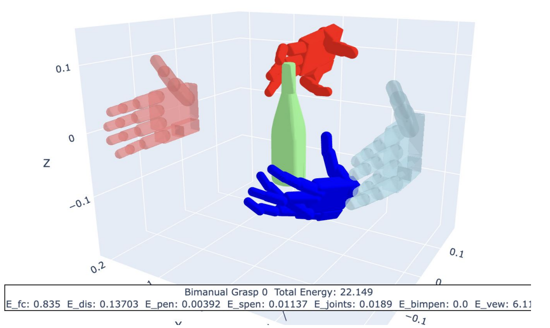
Parameter	Value
n_iter	5000
w_{dis}	150.0
w_{pen}	160.0
w_{spen}	10.0
w_{joints}	40.0
w_{bimpen}	10.0
w_{vew}	1.0
$w_{\text{contact\_sep}}$	0.0
$w_{\text{gravity\_support}}$	0.0
$w_{\text{vertical\_stability}}$	0.0
separation_threshold	0.02

Output (below are example figure)

- graph by wandb

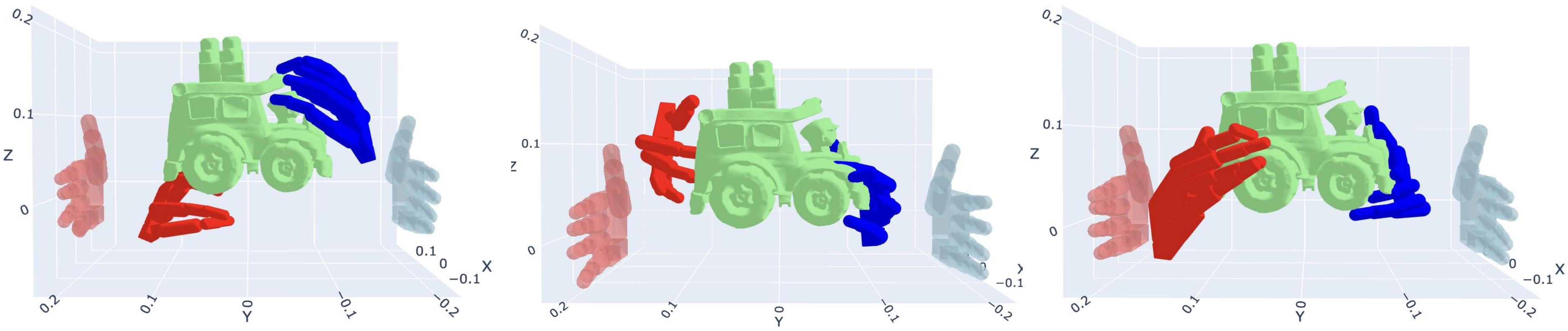


- generated pose with html file



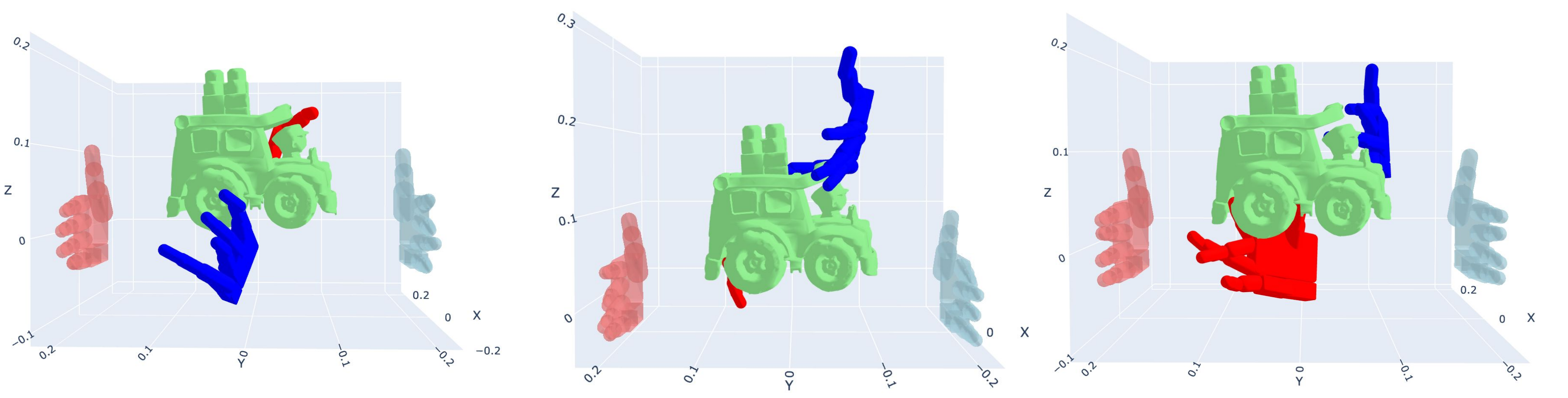
3.2 Result

Default (no additional energy term)



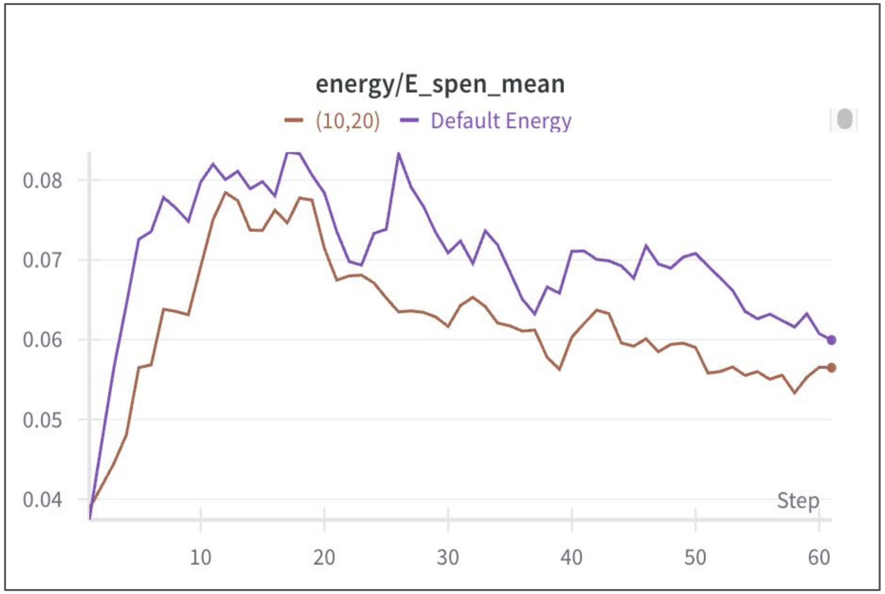
w_gravity_support : 10.0 & w_contact_sep : 5.0

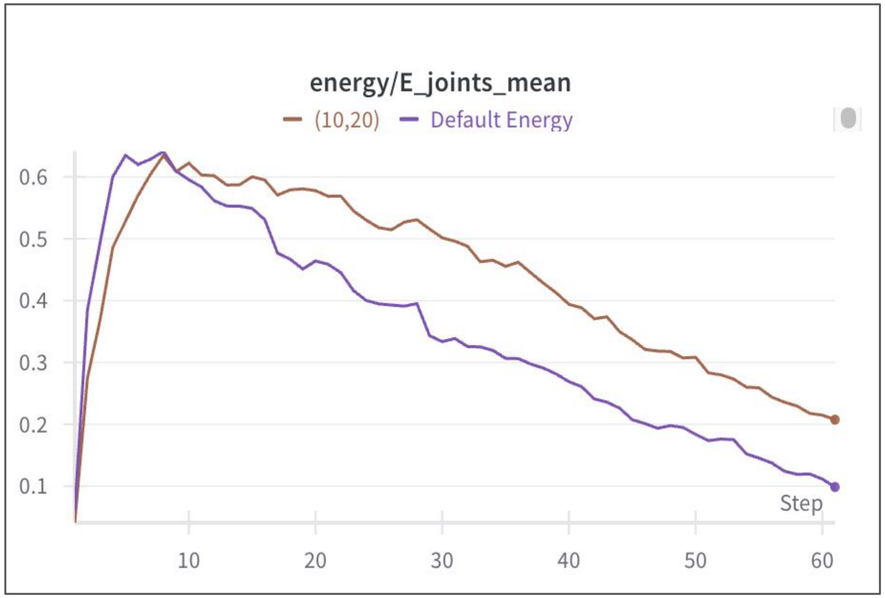
w_vertical_stability: 20.0



3.2 Result

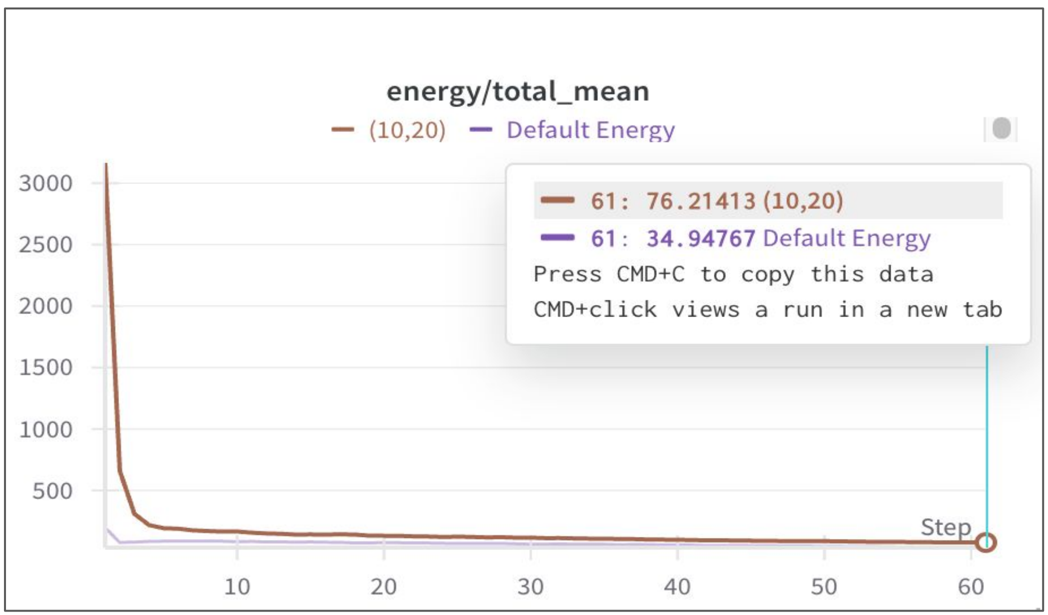
- **Contact Separation** could obtain less penetration result
- Furthermore, just increasing weight of previous term could not make wide gripping pose
- Previous penetration term has stricter restraint and it only increases rejection by optimizer

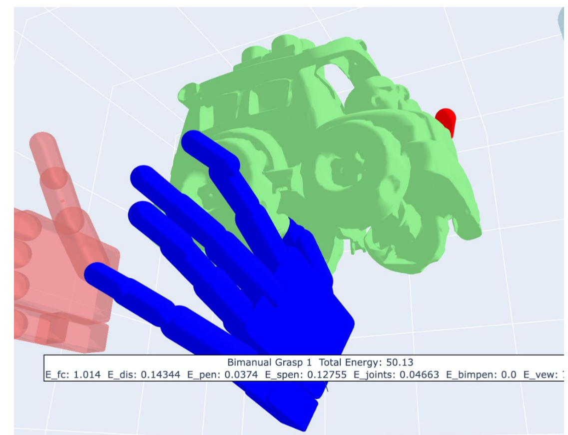


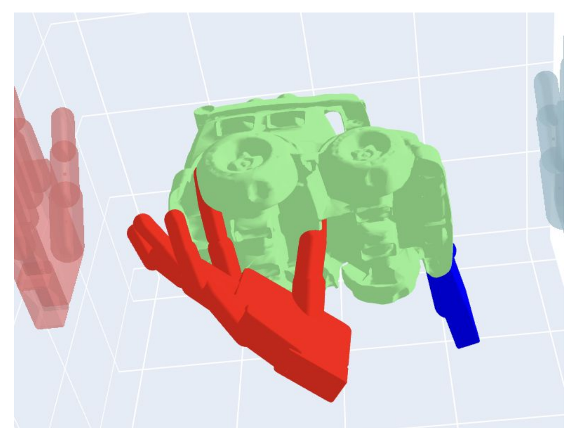


3.2 Result

- **Gravity support** could generate pose with hand under object in small batch size 100
- Even though energy term is added, total mean has not much increase







4. Conclusion

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Summary

1. Previous methods have limitations on low performance and frequent penetration
2. We propose two methods:
    a. **Separation Energy** between Contact Points
    b. **Gravity** Consideration and **Vertical Stability** Energy

Limitations So Far

1. Haven't achieved much success for validation process yet.
2. Tried <10 objects
3. Hard to optimize for small & concave objects
4. Time consuming (Almost double compared with unimanual)

Future Directions

1. Fine tune & Elaborate codes to achieve success in IsaacGym
2. Try on more objects
3. Compare performance with the baseline method

Thank you

Q&A