Supplementary Materials for "Disentangled Iterative Surface Fitting for Contact-stable Grasp Planning"

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1 Simulation Experiments

1.1 Grasp Performance Comparison

Preprocessing of Point Cloud Data The point cloud data from publicly available datasets are often very large, making it challenging to directly use all the points for planning computations. Therefore, as an initial step, the loaded point cloud data were voxelized and downsampled. Specifically, downsampling was performed using Open3D [1] with a voxel size of 0.01 [m]. Next, normal vectors for the point cloud data were estimated using Open3D. Additionally, the estimated normal vectors were adjusted to ensure they pointed outward relative to the object's centroid. Subsequently, potential contact regions on the object surface were extracted using the hand plane. A correspondence matching algorithm was then applied to the potential contact regions to extract contact points for grasp planning.

Pre-Convex Shape Approximation of Objects for Physical Simulation When directly loading object model files into the physics simulator for grasping experiments, the object shapes are automatically approximated as convex hulls within the simulator for collision detection purposes. However, this convex hull approximation is often too coarse, resulting in significant deviations from the original 3D object shape and causing issues with executing grasping experiments accurately. To address this, a pre-processing step using CoACD [2] (Collision-Aware Convex Decomposition) was applied to ensure that the original object shape is preserved even after automatic convex approximations are applied within the simulator (in our case, Mujoco 3.2.4). The resolution parameter for the CoACD approximation was set to 50.

Pre-Grasp and Grasp Trajectory Planning While the proposed DISF method provides the final grasp pose, it does not plan the complete grasp trajectory, including the intermediate path from the robot's initial pose to the final grasp pose. Therefore, to execute the planned grasp in practice, an external trajectory planning algorithm is required. In this experiment, based on the grasp pose obtained from DISF, we first compute a pre-grasp pose and move the robot hand's palm from the initial pose to the pre-grasp pose.

The pre-grasp pose is determined based on the final grasp pose $(\mathbf{R}^*, \mathbf{t}^*)$ provided by DISF. The corresponding palm pose in the world coordinate frame is given as $(\mathbf{R}^*_{\text{palm}}, \mathbf{t}^*_{\text{palm}})$. To calculate the pre-grasp pose, we consider a sphere centered at the object grasp position $\mathbf{t}^*_{\text{palm}}$ with a radius γ. The pre-grasp pose $\mathbf{p}_{\text{pre}}$ is defined as the surface point on this sphere aligned with the grasp rotation $\mathbf{R}^*_{\text{palm}}$, computed as:

$$\mathbf{p}_{\text{pre}} = \mathbf{t}^*_{\text{palm}} - \gamma \cdot \mathbf{R}^*_{\text{palm}} \mathbf{n}_z, \tag{1}$$

where γ is the radius of the sphere representing the distance from the grasp position to the pre-grasp position. The pre-grasp orientation remains the same as the grasp orientation, represented by the rotation matrix: $\mathbf{R}_{\text{pre}} = \mathbf{R}^*_{\text{palm}}$. This formulation ensures the pre-grasp pose is aligned with the intended approach direction, facilitating smooth trajectory planning and grasp execution.

After reaching the pre-grasp pose, the robot continues to move towards the final grasp pose $(\mathbf{R}^*_{\text{palm}}, \mathbf{t}^*_{\text{palm}})$. Finally, at the final grasp pose, the gripper open/close command is sent to the robot to complete the grasping process using the optimized gripper displacement δd^*.

Fingertip Displacement Refinement The planned grasp ensures that the gripper surfaces align with the object surfaces according to the object's geometry. However, during actual grasp execution, repulsive forces from the object act against the gripper's grasping force. This can result in the gripper failing to firmly hold the object if the planned gripper opening width is used directly. To address this issue, we introduce an additional refinement to the gripper's opening width when executing the grasp in the physics simulator. Specifically, we add a bias $\hat{\delta d}$ to the planned fingertip displacement δd, resulting in a slightly smaller gripper opening width than the planned value. This adjustment ensures a more secure grasp during execution by compensating for the effects of repulsive forces.

References

1. Q.-Y. Zhou, J. Park, and V. Koltun, "Open3D: A modern library for 3D data processing," *arXiv:1801.09847*, 2018.
2. X. Wei, M. Liu, Z. Ling, and H. Su, "Approximate convex decomposition for 3d meshes with collision-aware concavity and tree search," *ACM Trans. Graph.*, vol. 41, no. 4, pp. 42:1–42:18, 2022. [Online]. Available: https://doi.org/10.1145/3528223.3530103