SPONGE: Sequence Planning with Deformable-ON-Rigid Contact Prediction from Geometric Features

Tran Nguyen Le[1], Fares J.Abu-Dakka[2], and Ville Kyrki[1]

[1]Intelligent Robotics Group, Aalto University, Finland [2] MIRMI, Technische Universität München, Germany

Contacts:
tran.nguyenle@aalto.fi

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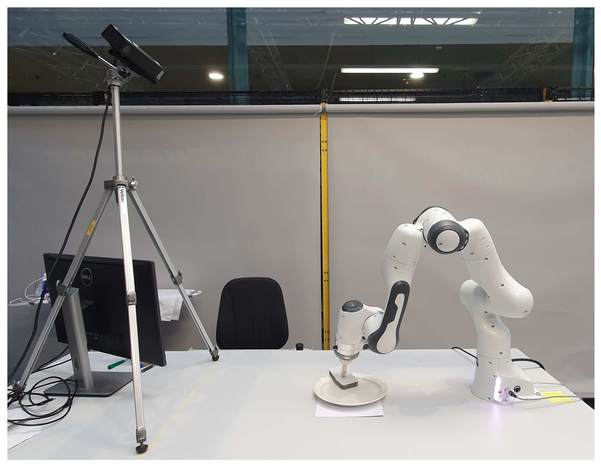
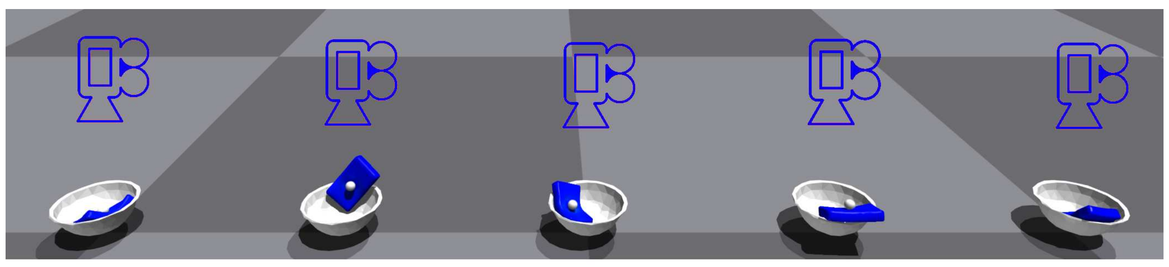
Motivation

- Successful manipulation of deformable objects can lead to numerous practical applications in areas ranging from surgical manipulation to domestic tasks such as assistive dressing or cleaning dishes.
- Planning manipulation tasks involving interactions between deformable and rigid objects, such as wiping a curved surface with a deformable tool, is trivial for humans, but is difficult for robots due to the challenge in predicting such interactions.



- The question of **how to predict the interaction between deformable and rigid objects** and **exploit such interactions** for **planning** remains open.

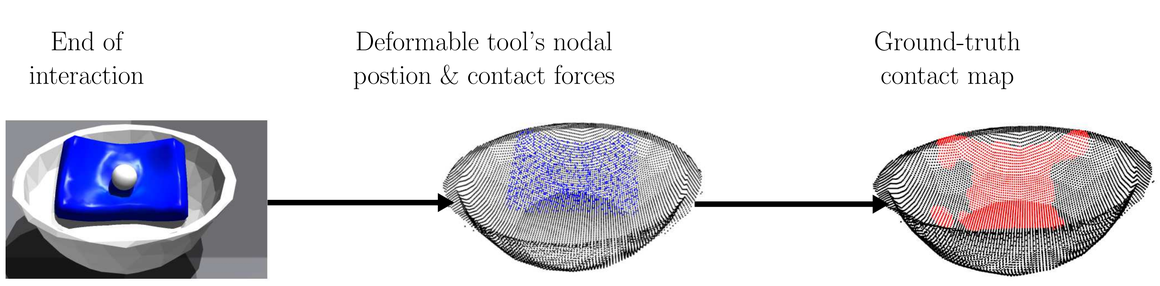
SPONGESim Simulation Environment



End of interaction

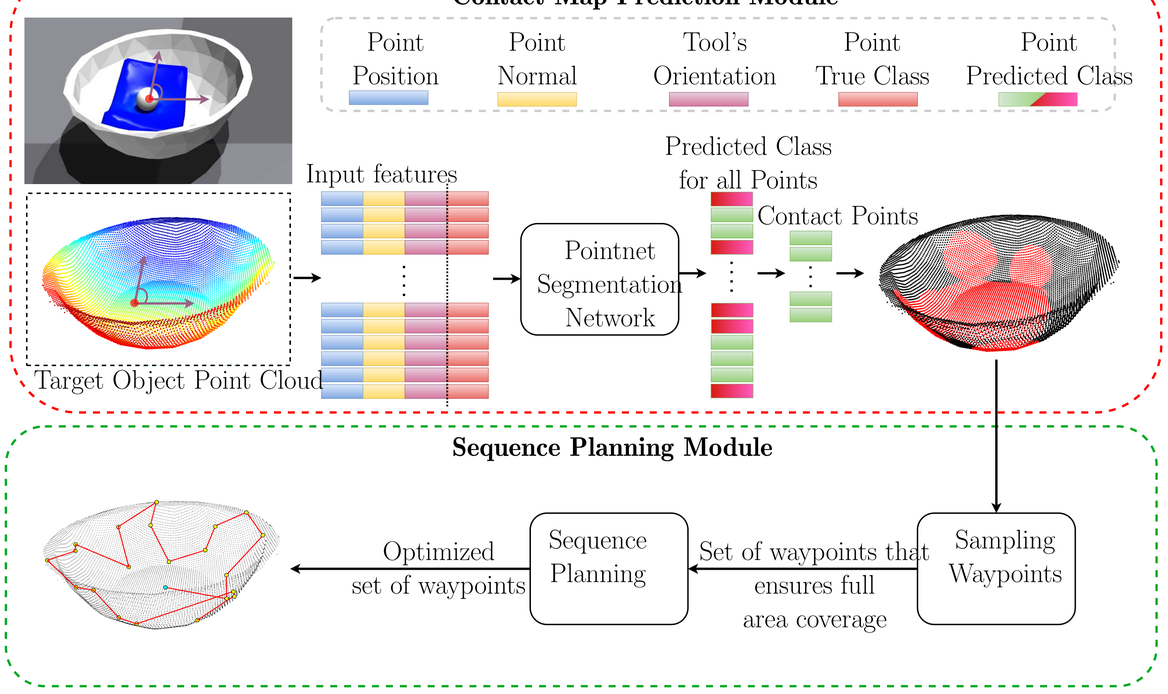
Deformable tool's nodal postion & contact forces

Ground-truth contact map



- SPONGESim is developed using NVIDIA Isaac Gym physics-based simulator that features the GPU-accelerated finite element method (FEM) to represents volumetric deformable bodies as a graph of connected tetrahedrons.
- Tens of thousands of unique contact interactions between deformable and rigid objects were conducted in parallel environments.

SPONGE Framework



Contact Map Prediction Module

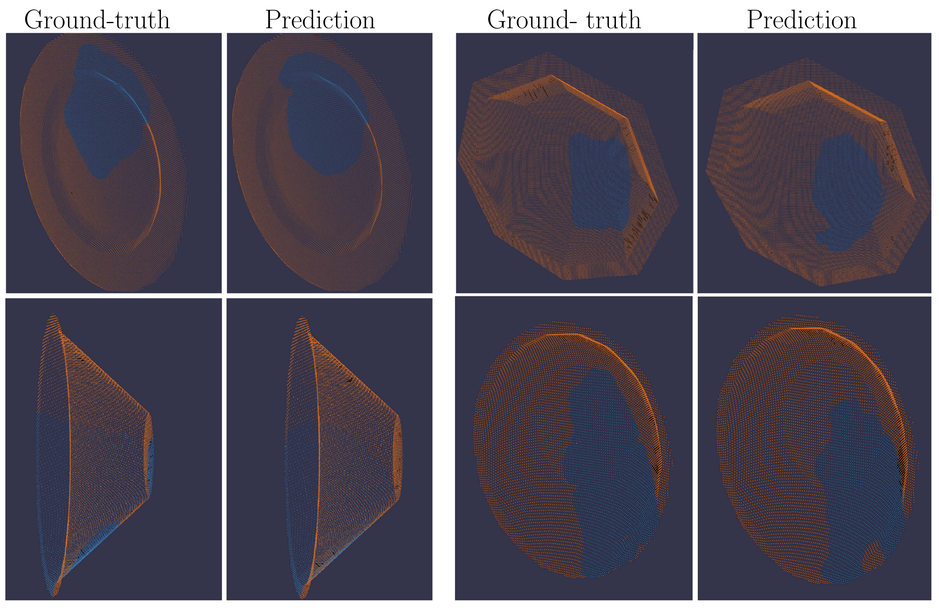
- Input: Target objects point cloud and the pose of the deformable tool.
- Output: Contact map between the deformable tool and the target objects.

Sequence Planning Module

- Input: A set of contact points that ensure the full coverage of the target object.
- Output: The optimal trajectory with minimal travel distance.

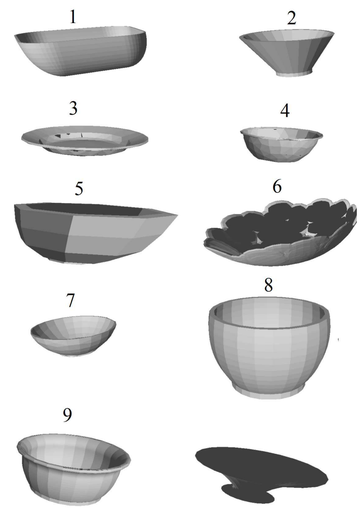
Result: Contact Map Prediction

We access the performance of the proposed prediction model based on the contact prediction **F1 score** on the test dataset, which is approximately **0.95**.



Result: Planning in Simulation

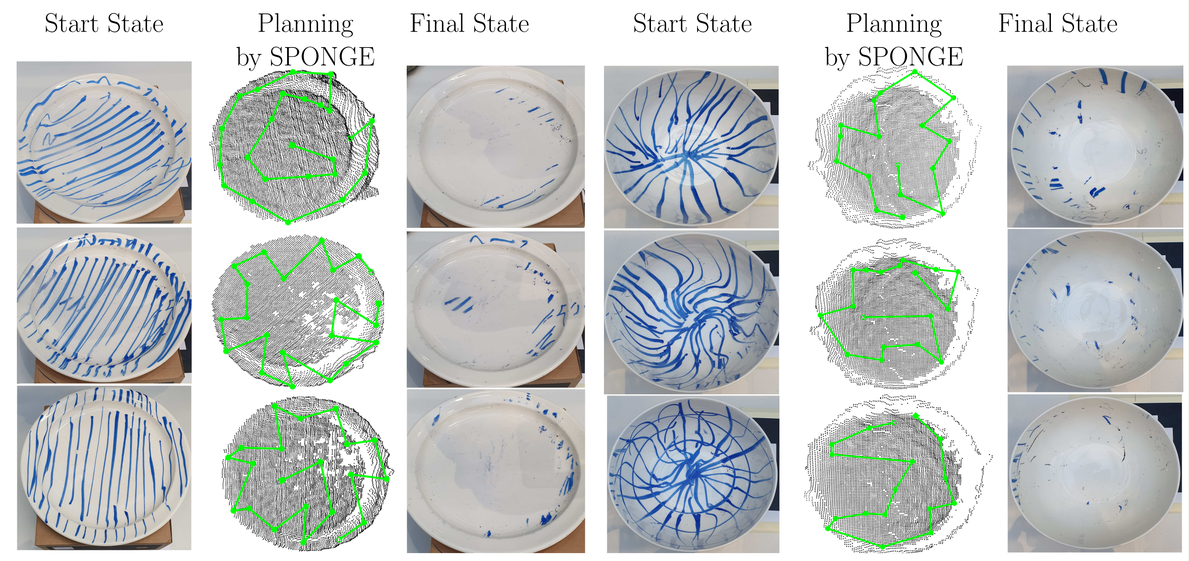
We quantify the quality of the trajectory by the **area coverage (*i.e.*, proportion of the contact points to the total population of point clouds)**. For each object, we randomly initialized its starting position 20 times and evaluated the best trajectory.



Object	Area Coverage	Number of Waypoints
1	89.5	19.3
2	97.3	13.3
3	100	18.1
4	96.2	14.1
5	87.6	23.6
6	97.9	22.3
7	98.7	12.4
8	88.5	32.7
9	92.1	22.4
10	94.6	20.2
All ↑	94.27	-

Result: Real Robot Deployment

The performance of the proposed pipeline is evaluated based on the **remaining amount of blue marker writings** after the execution of the trajectories.



Conclusions and Future work

- We presented a planning pipeline for manipulation tasks involving the interaction between deformable and rigid objects, which we explicitly demonstrate in the dish cleaning task with a deformable sponge.
- Despite the good results, some limitations of the proposed pipeline are:
  - The lack of real-time knowledge of the en route contact map while traversing between two contact points.
  - The counter-intuitive trajectories compared to those of humans.
  - The lack of reacting and adapting trajectories to uncertainties such as incorrect contact map prediction, or displacement of the target object during execution procedure.