Efficient and High-quality Prehensile Rearrangement in Cluttered and Confined Spaces

Presenter: Rui Wang

DATA-INSPIRE TRIPODS Institute

10/15/2021
Rearrangement in cluttered and confined spaces vs. Rearrangement in tabletop setup

1. **Clutter**: The robot cannot directly access all objects – **the swept volume of the robot may cause robot-object collisions**

2. **Limited/Confined manipulation space**: Once an object is grasped, it cannot be lifted high enough – cannot waive object-object collisions

3. Must take both **robot-object constraints** and **object-object constraints** into account.

---

1. Allow the robot to reach the majority of objects at any point in time by using top-down grasps – **simplify robot-object interactions**

2. Once an object is grasped, it can be lifted sufficiently high relative to other objects – **assume no object-object collisions**

3. The only hard constraints arise from **the potential between the start and goal poses of objects**
Search for an ordering with which object are rearranged to successfully fulfill the task

Monotone: Objects need to be moved at most once to solve the problem. Non-monotone: At least one object needs to be moved to a buffer before moved to its goal.

Complexity: $O(n!)$: Does not scale well with the number of objects

Search for an ordering with which object are rearranged to successfully fulfill the task.

Monotone: Objects need to be moved at most once to solve the problem. Non-monotone: At least one object needs to be moved to a buffer before moved to its goal.

Complexity: $O(n!)$ : Does not scale well with the number of objects.

Observation: Instead of searching the space of all object permutations $O(n!)$ to solve monotone instances, it is sufficient to search the space of object arrangements $O(2^n)$.

**Observation:** Even in the reduced arrangement space, there is a lot of redundancy.

Some branches of the search tree will not lead to a solution, as they violate constraints enforced in cluttered and confined spaces.

Don’t move $o_4$ when $o_1$ is at the goal!!

Don’t move $o_1$ when $o_4$ is at the start...

$$\overline{A}[o_1] = \{\alpha \mid \alpha[o_4] = \alpha_c[o_4]\}$$
Another example

Denote $C^j_4$ as the colliding object set, where the goals of these objects hinder the grasping of $o_4$ for the j-th configuration.

$$C^1_4 = \{o_2\}, C^2_4 = \{o_1\}, C^3_4 = \{o_3, o_5\}$$

$$C^1_4 \times C^2_4 \times C^3_4$$

$$c^1 = \{o_1, o_2, o_3\}$$

$$c^2 = \{o_1, o_2, o_5\}$$

Don’t move $o_4$ when $o_2, o_1, o_3$ are all at their goals!!!

Don’t move $o_1$ when $o_4$ is at start while $o_2, o_3$ are both at their goals....

$$\widetilde{H}[o_1] = \{\alpha \mid \alpha[o_4] = \alpha_c[o_4], \alpha[o_2] = \alpha_F[o_2], \alpha[o_3] = \alpha_F[o_3]\}$$
Algorithm 1: CIRS($\alpha_C$, $\alpha_F$, $\mathcal{O}$, $K$)
1. $A_{invalid} = \text{DETECTINVALIDITY}(\alpha_C, \alpha_F, \mathcal{O}, K)$
2. return $\text{CIDFS}_\text{DP}(\emptyset, \alpha_C, \alpha_F, A_{invalid})$

Algorithm 2: DETECTINVALIDITY($\alpha_C$, $\alpha_F$, $\mathcal{O}$, $K$)
1. for $o_i \in \mathcal{O}$ do
2. | $A_{invalid}[o_i] = \emptyset$
3. for $o_i \in \mathcal{O}$ do
4. | $[q^1, \cdots, q^K], [C^1_i, \cdots, C^K_i] =$
5. | $\text{GENERATEARMCONFIGURATIONS}(\alpha_C, \alpha_F, K)$
6. for $c^j \in \{C^1_i \times \cdots \times C^K_i\}$ do
7. | $\tilde{A} = \text{ELICITARRANGEMENTS}(c^j)$
8. | $A_{invalid}.\text{ADD}(\tilde{A})$
9. return $A_{invalid}$

Algorithm 3: CIDFS$_\text{DP}$(T, $\alpha_C$, $\alpha_F$, $A_{invalid}$)
1. for $o \in \mathcal{O}\setminus\mathcal{O}($$\alpha_C$) do
2. | if $\alpha_C \in A_{invalid}[o]$ then continue
3. | $\alpha_{new}[\mathcal{O}\setminus\{o\}] = \alpha_C[\mathcal{O}\setminus\{o\}]$
4. | $\alpha_{new}[o] = \alpha_F[o]$
5. if $\alpha_{new} \notin T$ then
6. | $\pi \leftarrow \text{MOTIONPLANNING}(\alpha_C, \alpha_{new}, o)$
7. | if $\pi \neq \emptyset$ then
8. | $T[\alpha_{new}].\text{parent} \leftarrow \alpha_C$
9. | if $\alpha_{new} \neq \alpha_F$ then
10. | $T = \text{CIDFS}_\text{DP}(T, \alpha_{new}, \alpha_F, A_{invalid})$
11. | if $\alpha_F \in T$ then return $T$
12. return $T$
Experimental results
Other contributions in the current line of work

1. Propose a non-monotone global framework for solving non-monotone problems with high-quality solutions, i.e., fewer actions in total to fulfill a task.

2. Propose a pre-processing tool (labeled roadmap) which significantly speeds up online motion planning query.
Future Work

1. Generalize all the possible constraints to save more computational time.

2. Learn failure cases during the search.

3. See if we can come up with a better default object ordering with which the search uses as a heuristic.

Demonstration

Yinglong Miao
Reference

2. https://www.astechprojects.co.uk/company-profile-media-gallery/
Thanks for Listening!

Acknowledgments
We would like to acknowledge the support of NSF awards 1934924 (HDR TRIPods)