High-Level Planning for Object Manipulation with Multi Heterogeneous Robot in Shared Environment

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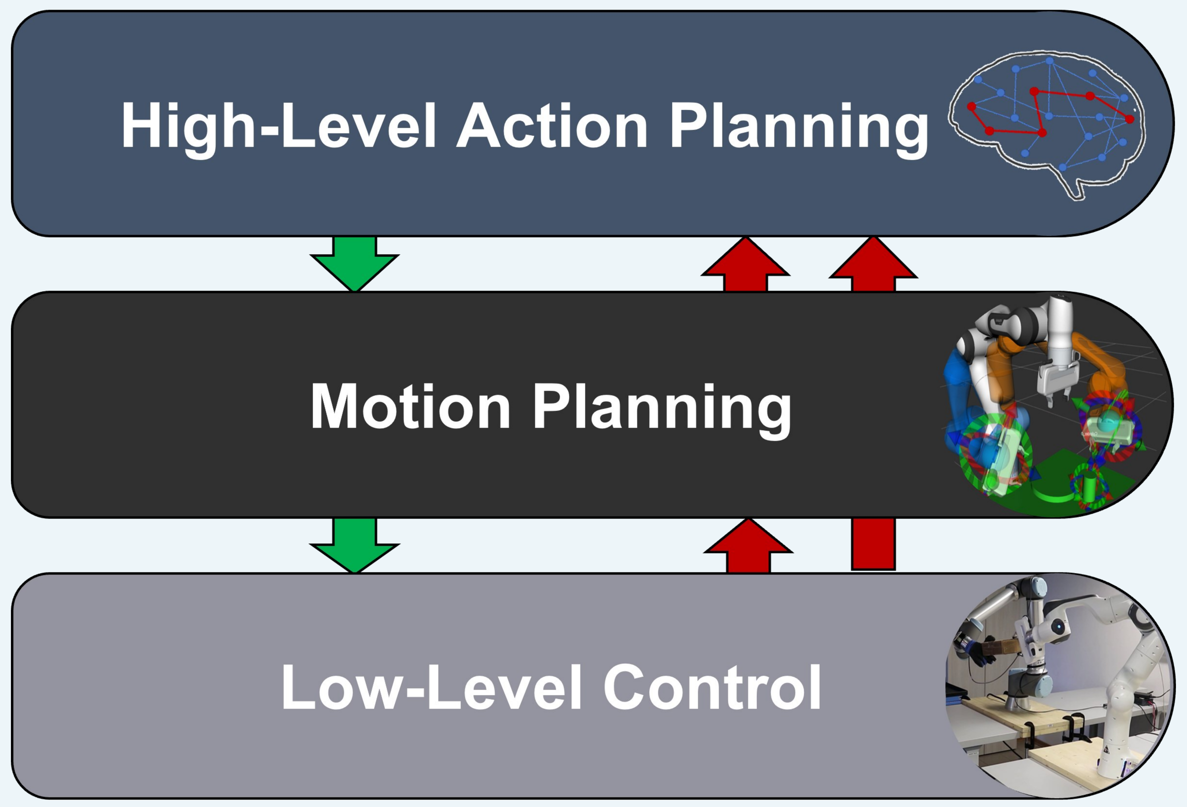
Paper

Abstract

Multi-robot systems are becoming increasingly popular in warehouses since they allow performing complex tasks with greater efficiency. However, this leads to increased complexity in planning and dispatching actions to robots. We tackle such complexity using a hierarchical planning framework. We present a formalization the highest level of this structure.

Hierarchical Structure



Planning Domain

We model the problem through a state-transition system

$$\Sigma = \langle \text{States},\ \text{Actions},\ \phi \rangle$$

The ***States*** representation is carried out by modelling a set of entities, and their specific properties.

We define three basic entities: the **Objects** can be moved in the environment, the set ***Agents*** of autonomous systems and parts of the environment that can be exploited for manipulating the objects, and the ***Sectors*** modelling the regions in which the agents operate.

The ***state variables*** describe the contacts between the objects and the agents, and the sectors in which they are currently located

Planning Problem

The task planning problem is a triple composed by the planning domain, an initial state and the set of goal states.

$$\mathbb{P} = \langle \Sigma, s_0, G_s \rangle$$

The solution is a sequence of high-level actions connecting the initial state to one of the goal states. We use forward search to find a plan π.

$$\pi = \{\nu_1, \ldots, \nu_N\}$$

Plan Refinement

A complete plan skeleton π is first found by our high-level framework, and then passed to lower-level solvers for execution.

The plan is decomposed into a series of subplans, using an automatic procedure based on the identification of “safe” states where to split the original plan.

We use a backtracking strategy to deal with planning failures while refining a subplan. If the low-level planners find an unfeasible action, our high-level planner finds an alternative plan connecting the last feasible state and the final state of the subplan.

Validation

We validated the framework on three different robotic systems:

(A) Two-robot system for picking and palletizing

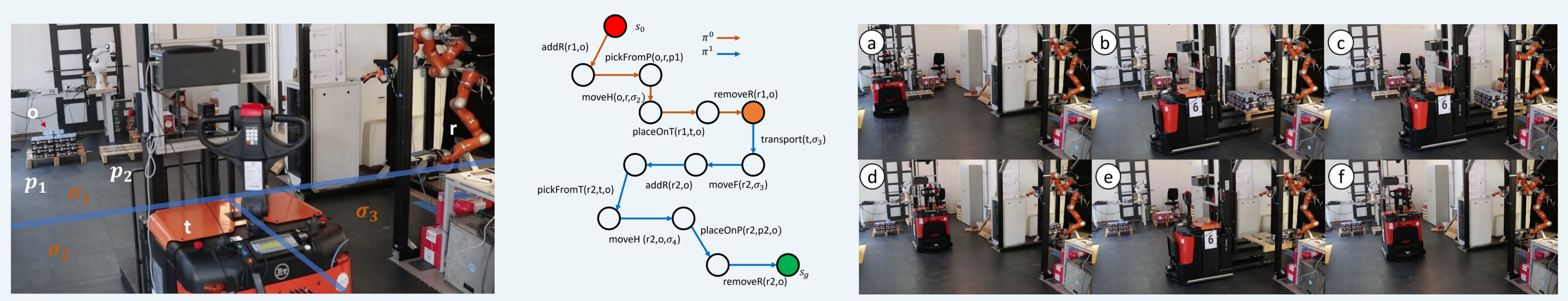
(B) Three-robot system for pick and place

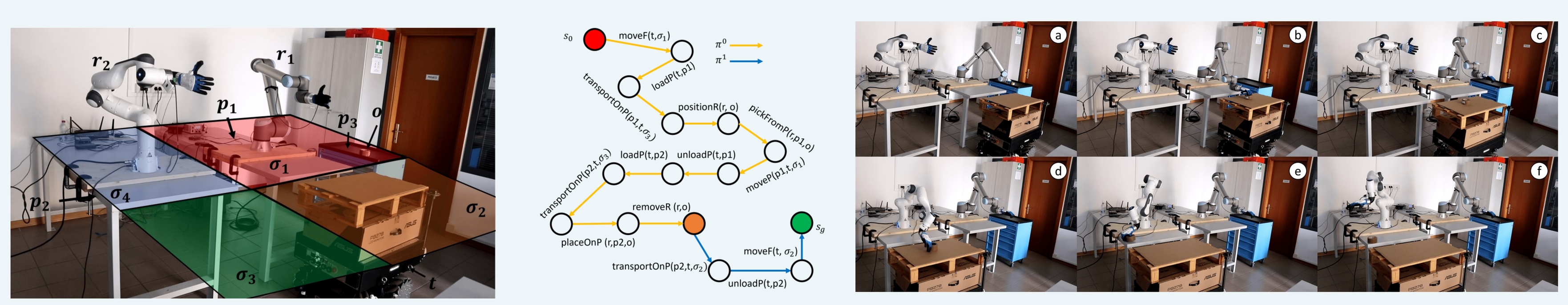
(C) One-robot system for rearrangement

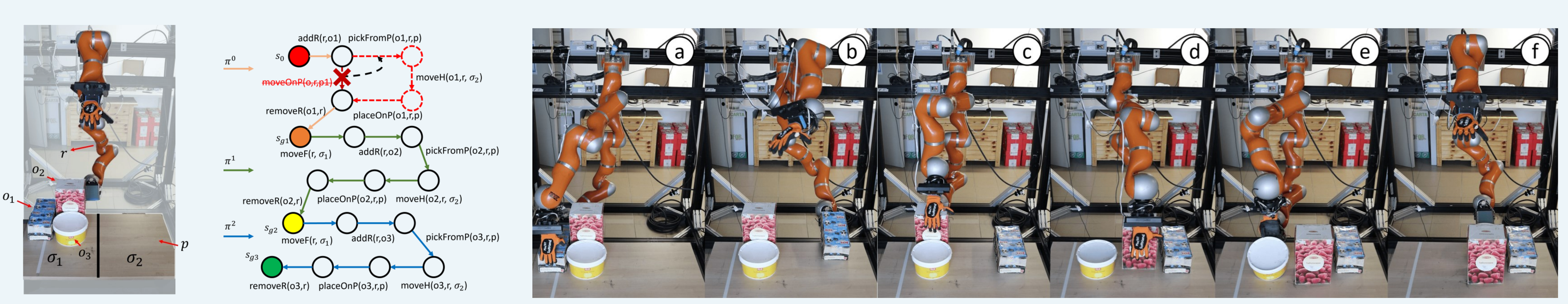
The high-level plans are retrieved using three different search algorithms: i) **Breadth-first**, ii) **Uniform Cost Search**. iii) **A***.

No differences can be noted on the high-level plans of (A) and (B), except for different time. For (C), the breadth-first plan is more expensive.

The use of different low-level algorithms did not produce significant or influence on the higher level.







Conclusion

In this paper, we presented an autonomous high-level planning framework for material handling using multi-robot systems. The produced high-level plan is easy to be refined by state-of-the-art lower-level motion planners. Experiments show the applicability of our approach to real case scenarios. Some aspects, such as a more integrated task and motion planning strategy, and formal guarantees of the high-level algorithm still need further investigation.