Loco-Manipulation Tasks for Self-Relocatable Space Robots

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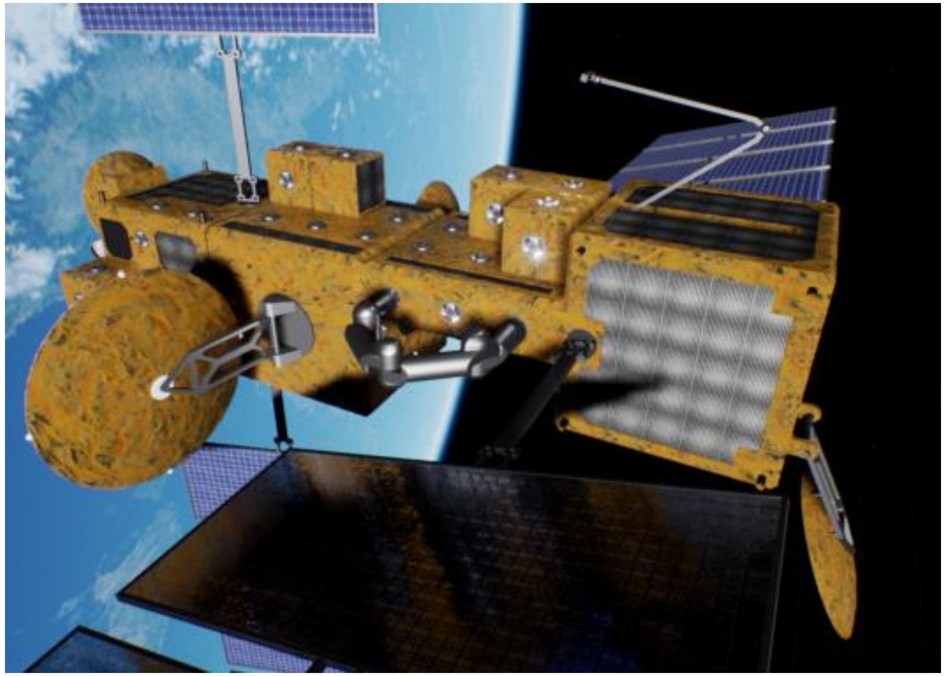
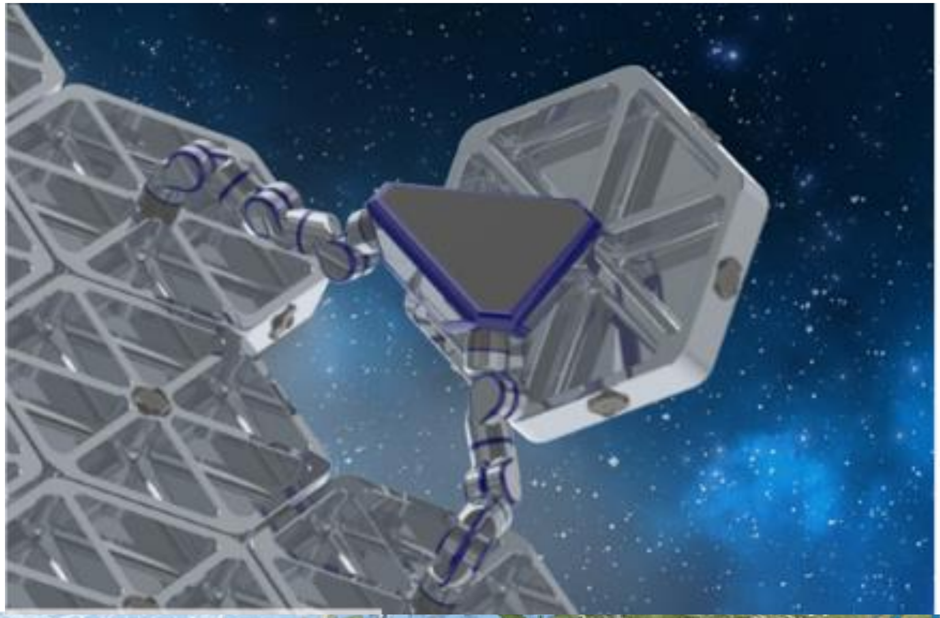
In-Space Assembly

- Key technology for creating large structures in space
- Requires autonomous robotics
- Efficient exploitation of loco-manipulation abilities requires suitable planning tools
- Whole-body motion, intermittent contacts, are features similar to multi-contact loco-manipulation in humanoid robots

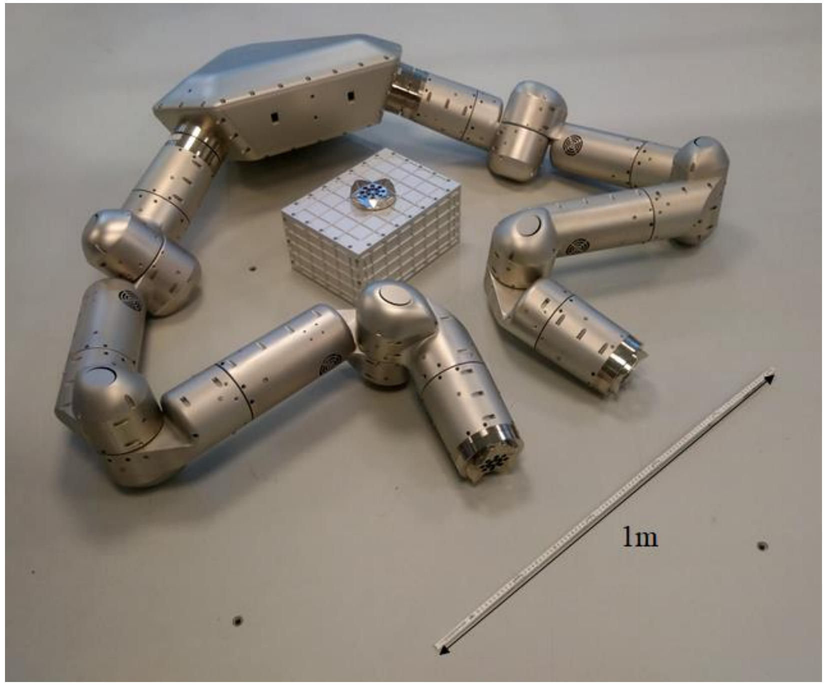




Background

Active HOTDOCK

Passive HOTDOCK



Walking Manipulator (WM)

MOSAR

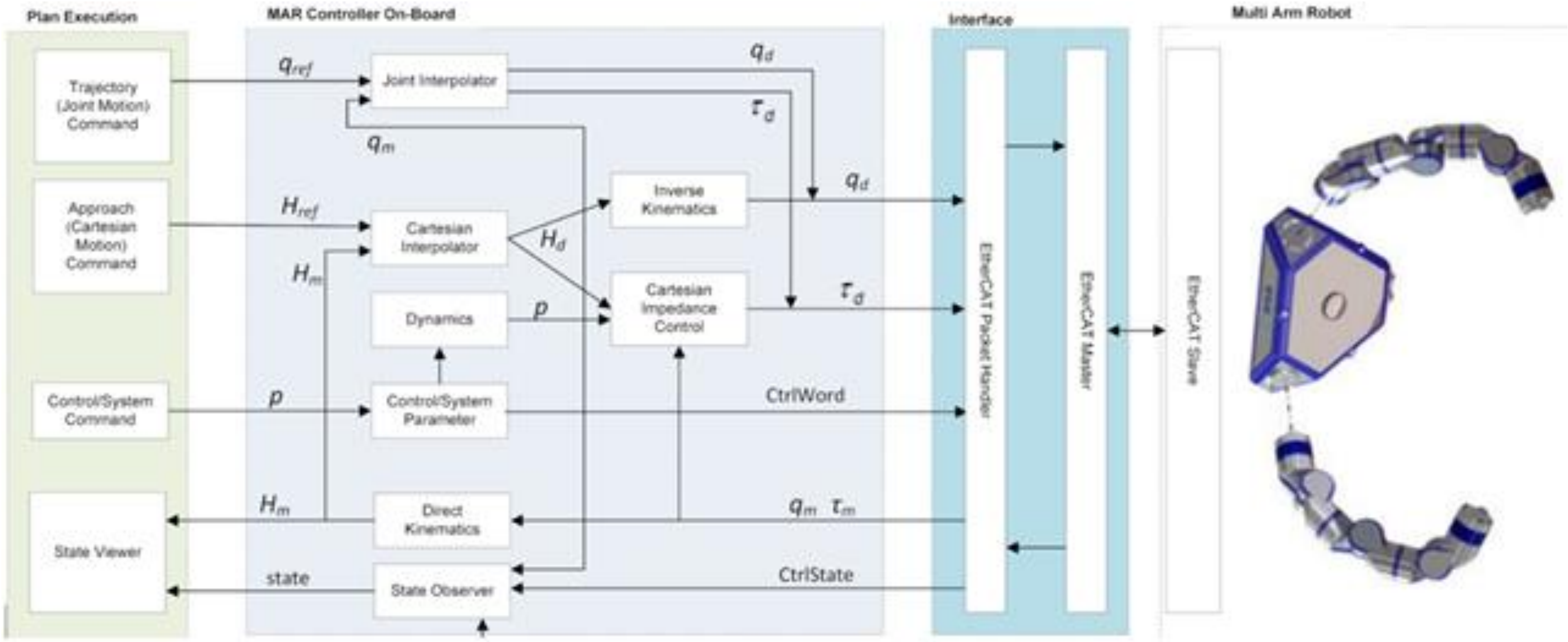
2019-2021

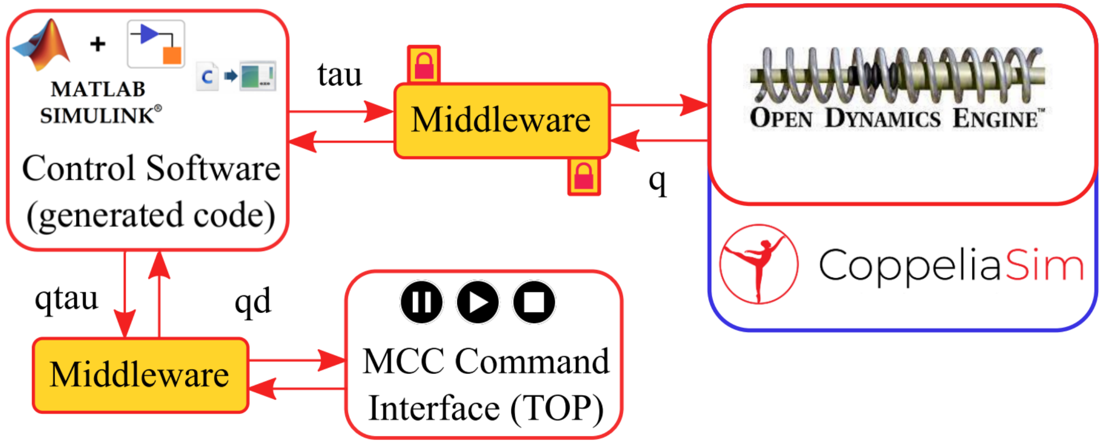
Multi-Arm Robot (MAR)

MIRROR

2020-2022

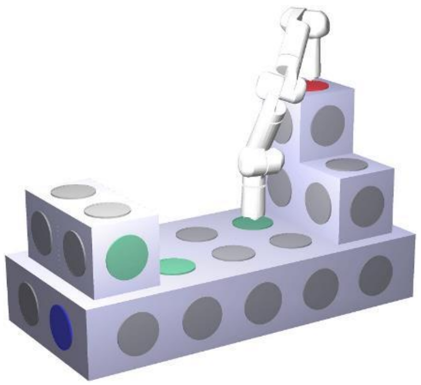
Control and Co-simulation frameworks

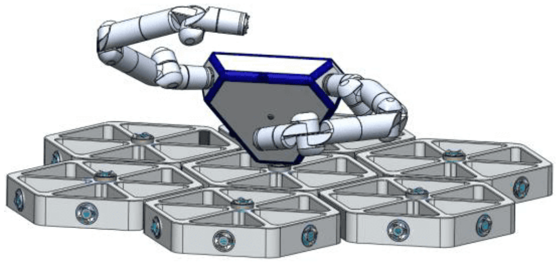


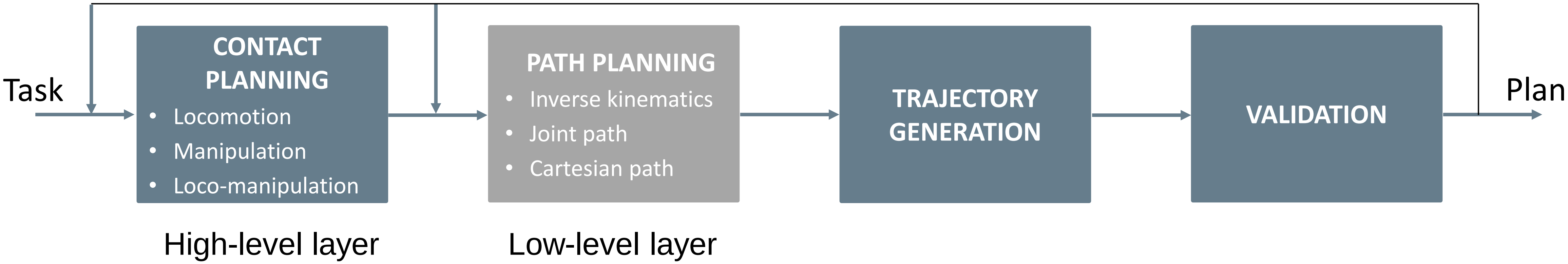


Planning Scenarios

- Locomotion
- Manipulation
- Loco-manipulation







Constraints for a valid plan:

- **Geometric:** collision avoidance,
- **Kinematic:** joint range, velocity and acceleration limits,
- **Dynamic:** joint torque limits and limits of the coupling devices.

Graph representation:

- Nodes: robot contact states
- Edges: transitions between states

Planning Approach

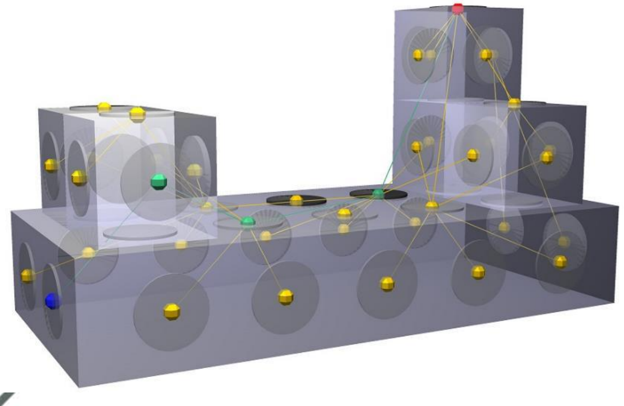
Locomotion

State of the robot: $s = \{\, b, r_b, q \,\}$.

Locomotion: graph search performed with breadth-first search + queue reordering, minimizing a weighted sum:

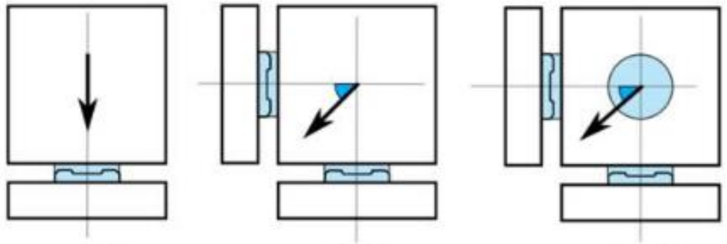
$$node\ cost = \frac{|b_i - b_{target}|}{|b_{parent} - b_{target}|}$$

$$edge\ cost = \max \frac{\tau_i}{\tau_{lim_i}}$$



Manipulation

Poses of the end effector corresponding to approach/contact/lift-off of the pick & place task:



The axial symmetry of the SI allows 4 different grasping modes r_t. Optimization is performed to evaluate feasibility and cost of the grasping alternatives:

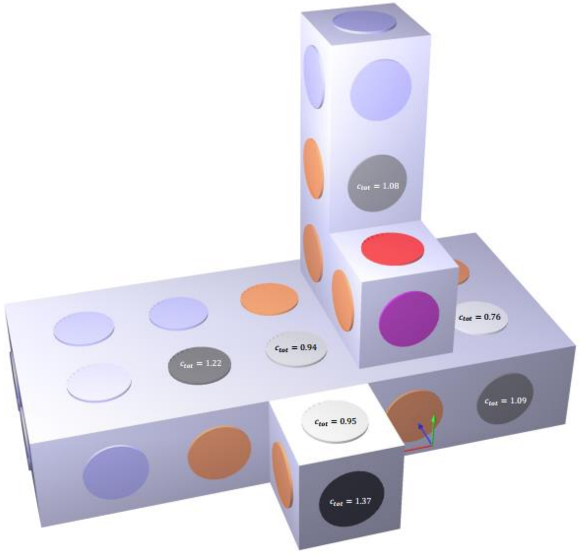
$$\min_{r_t \in R_t} c_m(r_t) = \max \frac{\tau_i}{\tau_{lim_i}}$$

Loco-manipulation

Candidate manipulation plans are searched by optimizing:

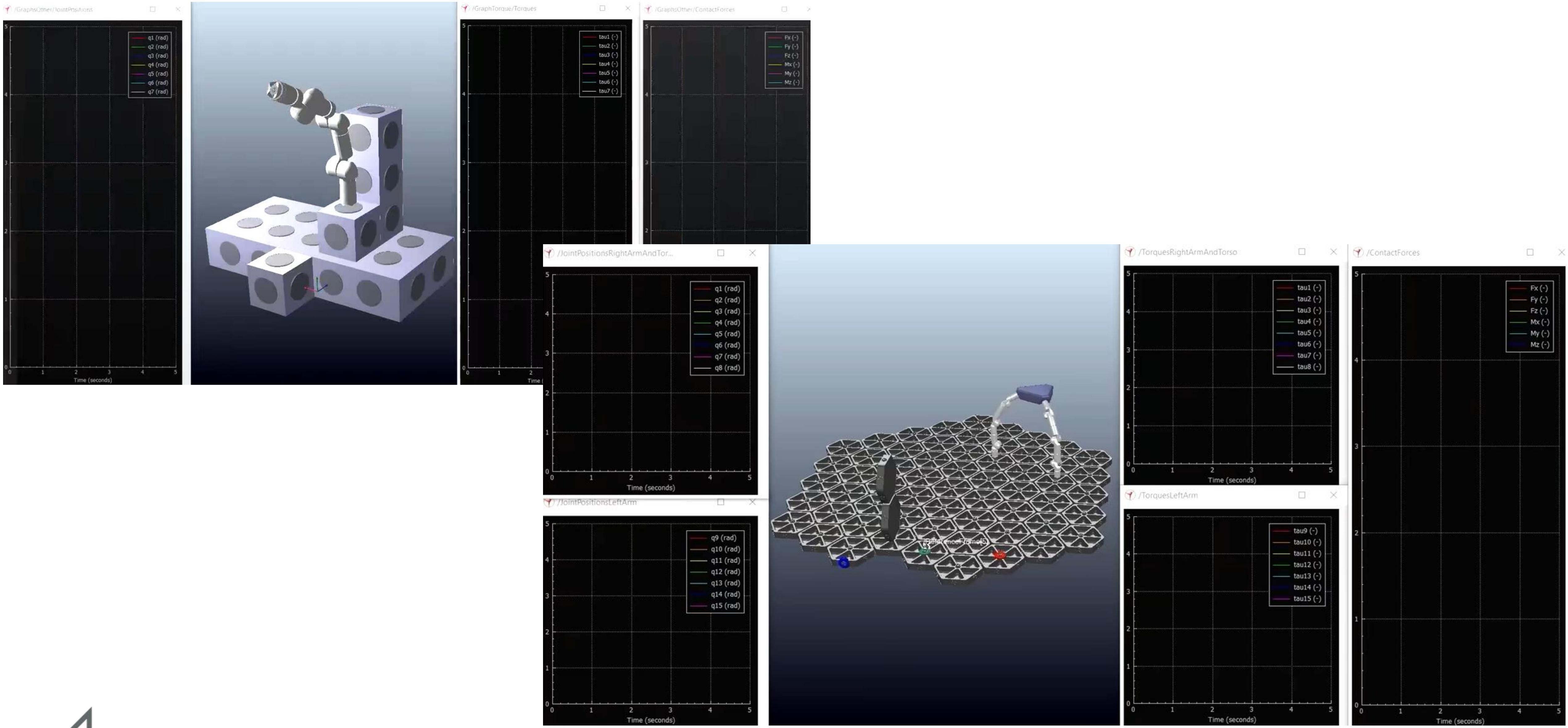
$$\min_{b, r_b, r_t} c_{tot}(b, r_b, r_t) = w_l c_l(b) + w_m c_m(b, r_b, r_t$$

A locomotion plan is searched from the starting state to the support associated to a candidate manipulation plan.



DLR

Results


/GraphTorque/Torques
/JointPositionsRightArmAndTor...
/JointPositionsLeftArm
/TorquesRightArmAndTorso
/TorquesLeftArm
/ContactForces
q1 (rad)
q2 (rad)
q3 (rad)
q4 (rad)
q5 (rad)
q6 (rad)
q7 (rad)
q8 (rad)
q9 (rad)
q10 (rad)
q11 (rad)
q12 (rad)
q13 (rad)
q14 (rad)
q15 (rad)
tau1 (-)
tau2 (-)
tau3 (-)
tau4 (-)
tau5 (-)
tau6 (-)
tau7 (-)
tau8 (-)
tau9 (-)
tau10 (-)
tau11 (-)
tau12 (-)
tau13 (-)
tau14 (-)
tau15 (-)
Fx (-)
Fy (-)
Fz (-)
Mx (-)
My (-)
Mz (-)
Time (seconds)