Framework for Optimizing Morphology and Mounted Pose of Modular Manipulators: A Drilling Task Case Study

ICRA2024 YOKOHAMA | JAPAN

Maolin Lei[1,2], Edoardo Romiti[1], Arturo Laurenzi[1], and Nikos G. Tsagarakis[1]

name.surname@iit.it

(1) Humanoids and Human Centered Mechatronics Research Line, Istituto Italiano Di Tecnologia (IIT) Genoa, Italy.

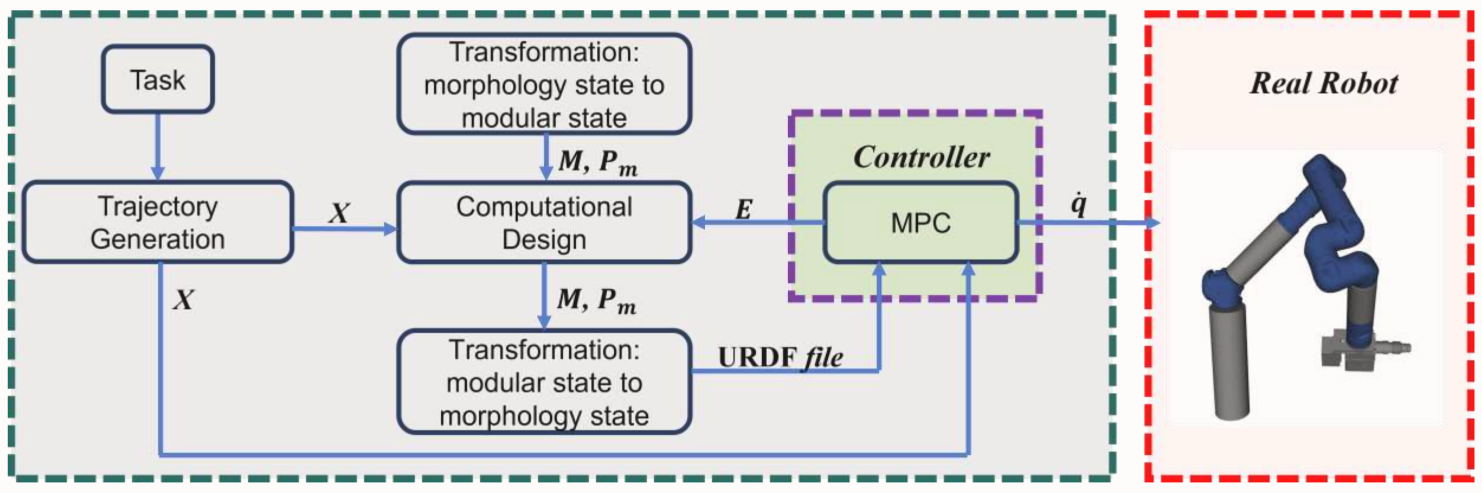
(2) Department of Informatics, Bioengineering, Robotics, and Systems Engineering (DIBRIS), University of Genova, Genoa, Italy

CONCERT iit HHCM HUMANOIDS AND HUMAN CENTERED MECHATRONICS

Abstract: Modular manipulators are an intuitive solution to the increasing need for mass-customized manipulation tasks in construction environment. Specifically, these manipulators, composed of multiple interchangeable body modules, enable rapid and reversible assembly into various morphologies. Task performance significantly depends on the manipulator's **mounted pose and morphology design**, therefore posing the need of methodologies **for selecting suitable modular robot configurations (M) and mounted pose (P_m)** that can address the specific **task requirements and required performance**.

Introduction:

- Manipulation tasks were defined as **trajectories in Cartesian space**, consisting of a series of desired end-effector poses.
- **Model Predictive Control (MPC)** was utilized to control the robot in executing specified trajectories and to apply this controller in real experiments across varied morphologies.
- The execution's performance, assessed through **designated evaluation metrics**, is then leveraged to evaluate and optimize different morphology and mounted pose.



Optimization Formulation:

Optimization Objectives

$$\min \quad F_{\text{eff}} = \frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{d} |\tau(q_{i,j})|$$

minimizing joints *effort* : minimize energy consumption during manipulation

$$\max \quad M_{\text{man}} = \frac{1}{N}\sum_{i=1}^{N} \det(\boldsymbol{J}(\boldsymbol{q}_i)\boldsymbol{J}(\boldsymbol{q}_i)^T)$$

maximizing *manipulability* : address challenges related to singularity

Overall Optimization Formulation

$$\underset{g(\boldsymbol{M}),\mathbf{P}_m}{\text{minimum}} \quad X_e = -we^{-w_f F_{\text{eff}} + w_m M_{\text{man}}}$$

minimizing joints *effort* and **maximizing** *manipulability*

subject to

$$\boldsymbol{q}_i \in [\underline{\boldsymbol{q}}, \quad \overline{\boldsymbol{q}}],$$

$$||FK(\boldsymbol{M}, \boldsymbol{P}_m, \boldsymbol{q}_i)\boldsymbol{T}_{d,i}^{-1}||^2 \le \xi, \ \forall i,$$

$$\mathrm{C}(\boldsymbol{p}_r) \ge d_{\text{safe}}, \ \forall \boldsymbol{p}_r \in \text{Robot},$$

$$\forall i \quad ||\tau_i(\mathbf{q}_i, \dot{\mathbf{q}}_i, \ddot{\mathbf{q}}_i)|| < \tau_{\text{max,i}},$$

joint limits
tracking threshold
collision avoidance
dynamic constraints

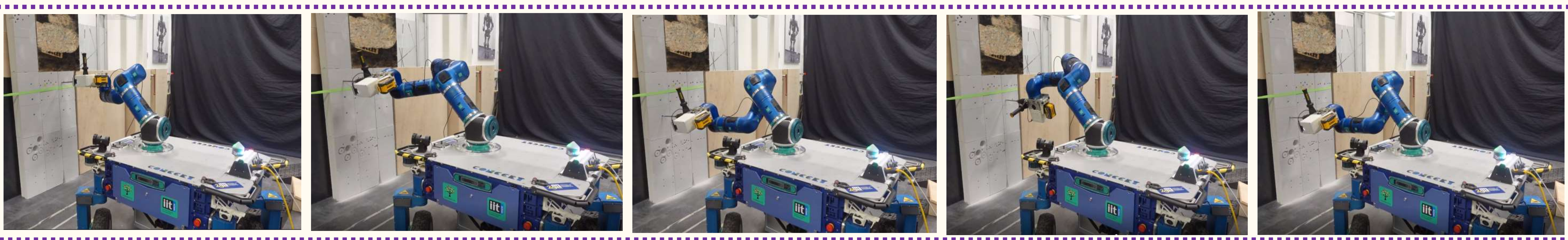
ensure the manipulator's **practical applicability**

Optimization and Experiments Results:

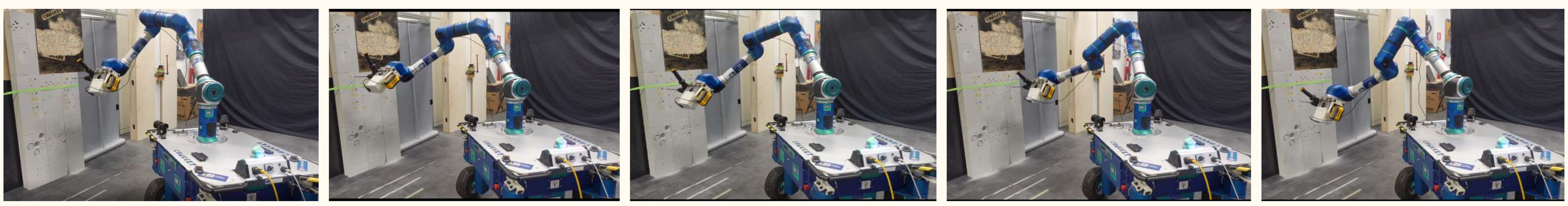
CONCERT mobile modular manipulator equipped with a **10kg drilling end-effector continuously is able to executed drilling tasks at various locations**. Despite the heavy payload in executing such tasks and two drilling points close to the base link's horizontal level, the computational results still **ensure collision-free** with the mounted platform and **satisfy dynamic constraints** of the robot.

Optimization Objective	Morphology	Mounted Pose	$[w_m, w_f]$	M_{man}	F_{eff}
maximizing manipulability and **minimizing** joint effort	C-1	[-0.15, 0.21, 1.57]	[1.00,0.01]	0.41	198.7
solely **maximizing** manipulability	C-2	[0.29, -0.03, 2.2]	[1.00,0.00]	**0.83**	329.5
solely **minimizing** joint effort	C-3	[0.13, 0.09, 1.57]	[0.00,0.01]	0.35	**186.6**

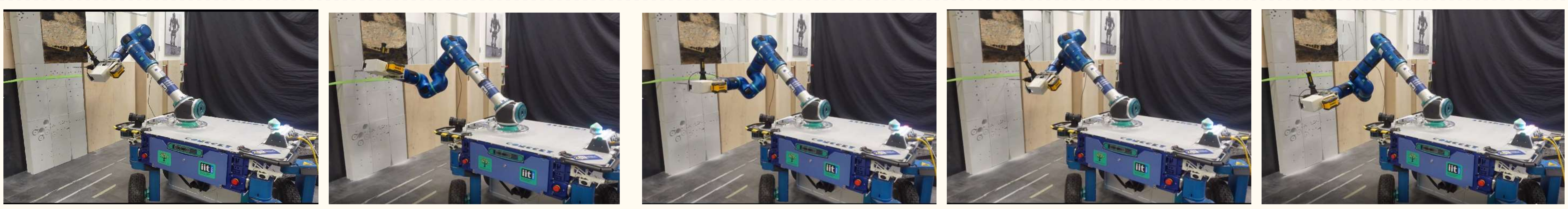
C-1



C-2



C-3



Acknowledge: This paper was supported by the European Union's Horizon 2020 Research and Innovation Program under Project CONCERT with grant number 101016007.