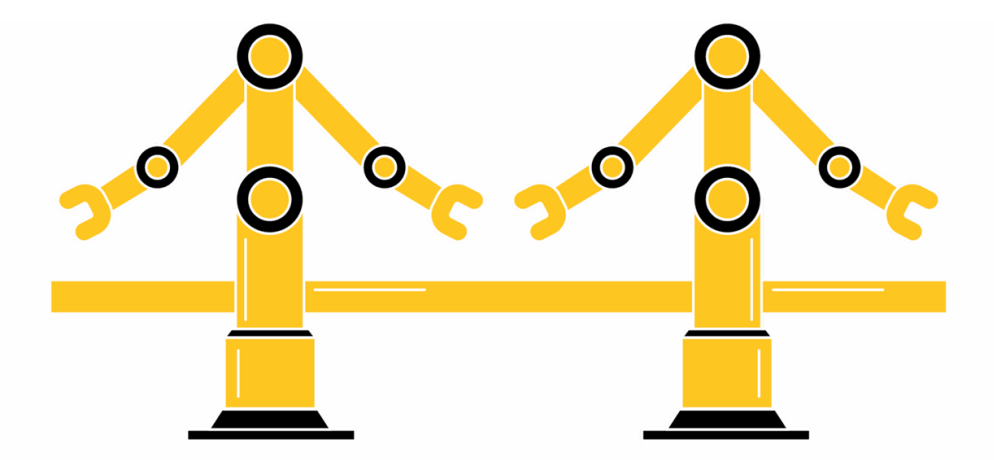


A Micro-Macro Manipulation Framework for Human-Mobile Robot Co-Manipulation Tasks

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IEEE/RSJ IROS 2026 · September 27 – October 1, 2026 · Pittsburgh, PA, USA

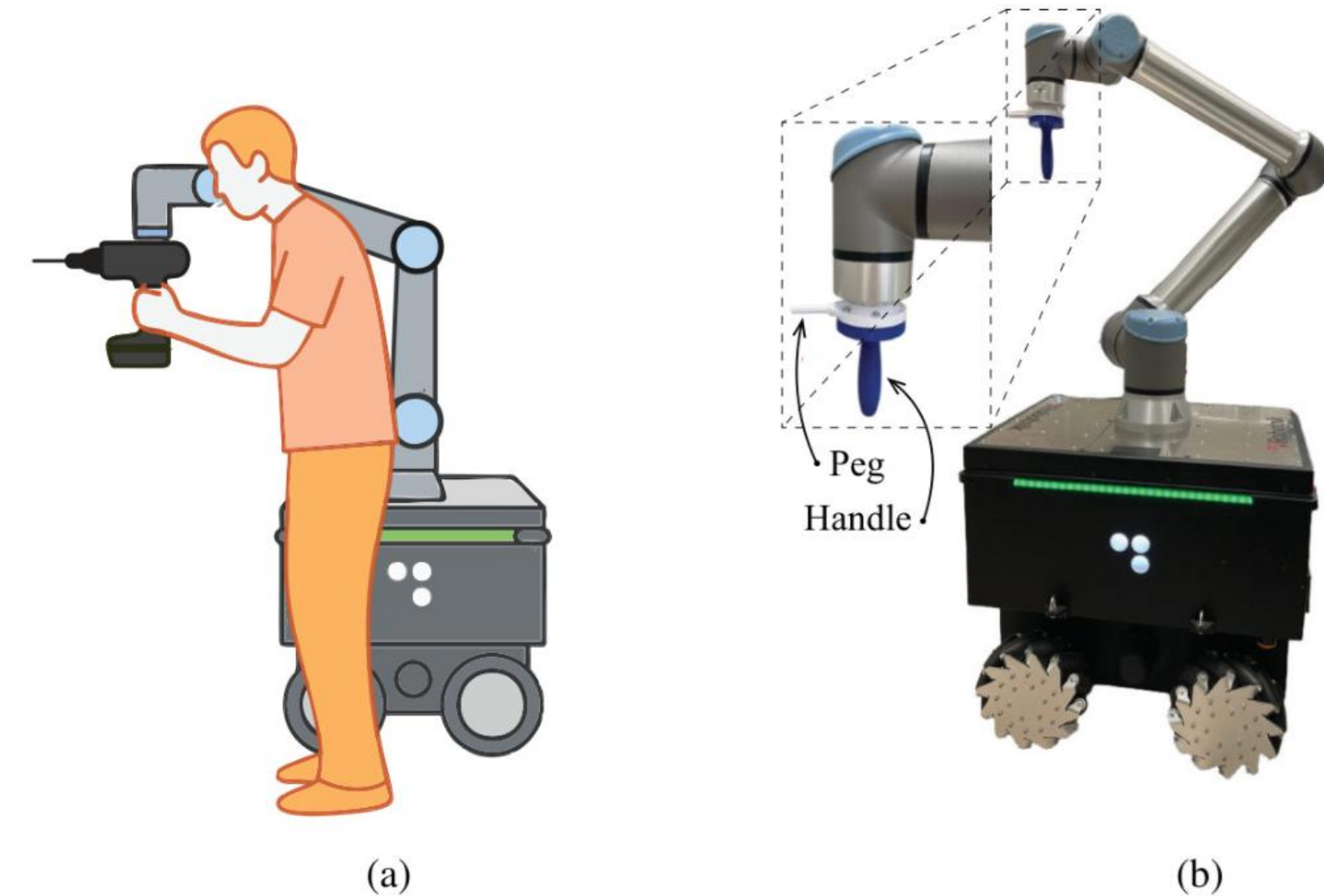


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Motivations

- Mobile manipulators carry heavy loads for long periods and physically assist the operator: co-transportation, robot-assisted walking and navigation, daily-living assistance.
- More DoF than fixed-base arms and more optimization opportunities.
- Existing controllers treat base plus arm as one monolithic redundant robot.



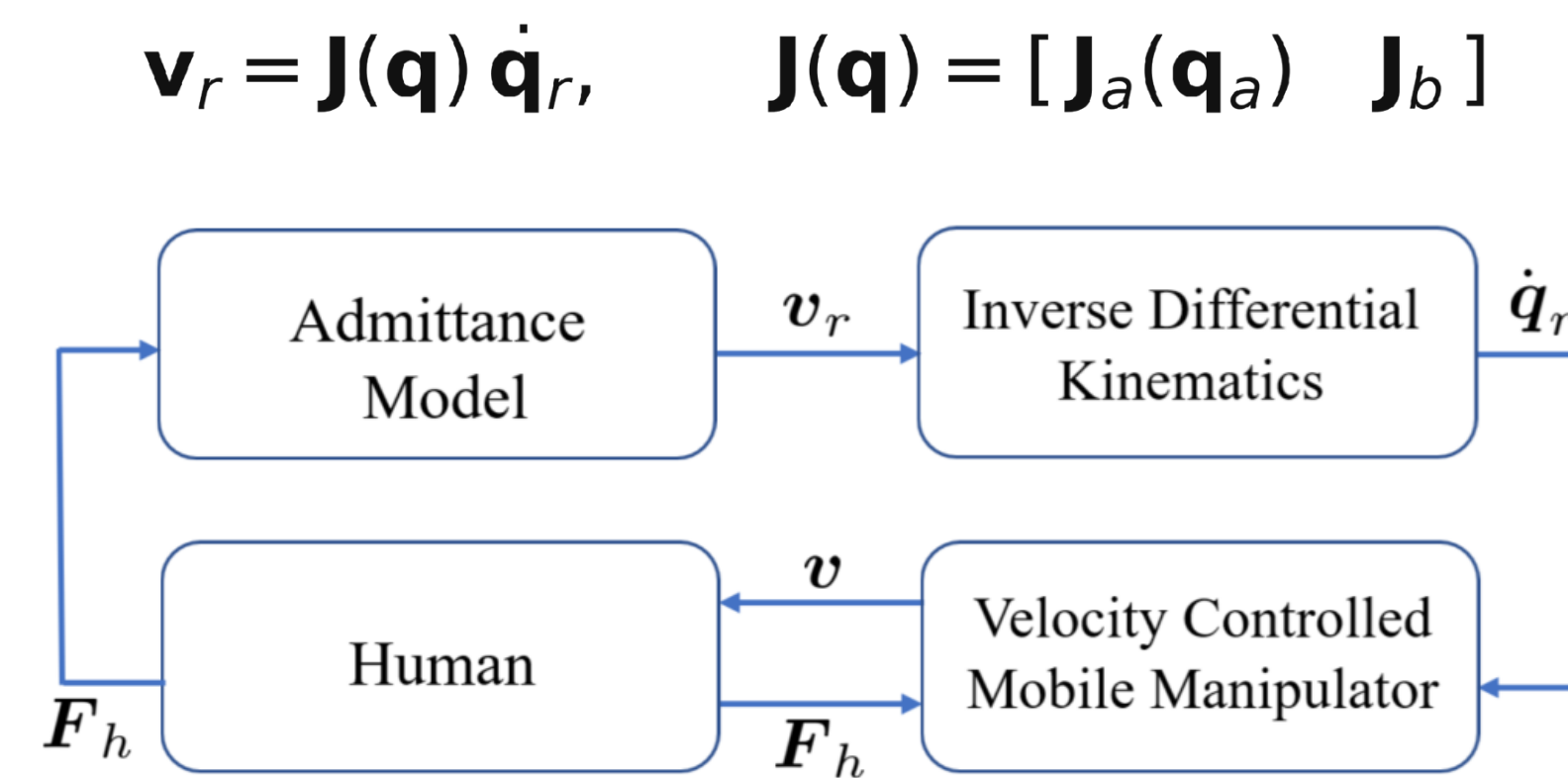
Co-manipulation task (a) and experimental setup (b)

Contributions

- ✓ The micro/macro paradigm is applied to admittance-based human–mobile robot co-manipulation.
- ✓ A control architecture based on frequency division between mobile base (macro) and manipulator arm (micro).
- ✓ A cut-off frequency adaptation law and a null-space forcing term give an automatic transition between Locomotion and Manipulation areas.
- ✓ Experimental validation on two tasks with 20 participants

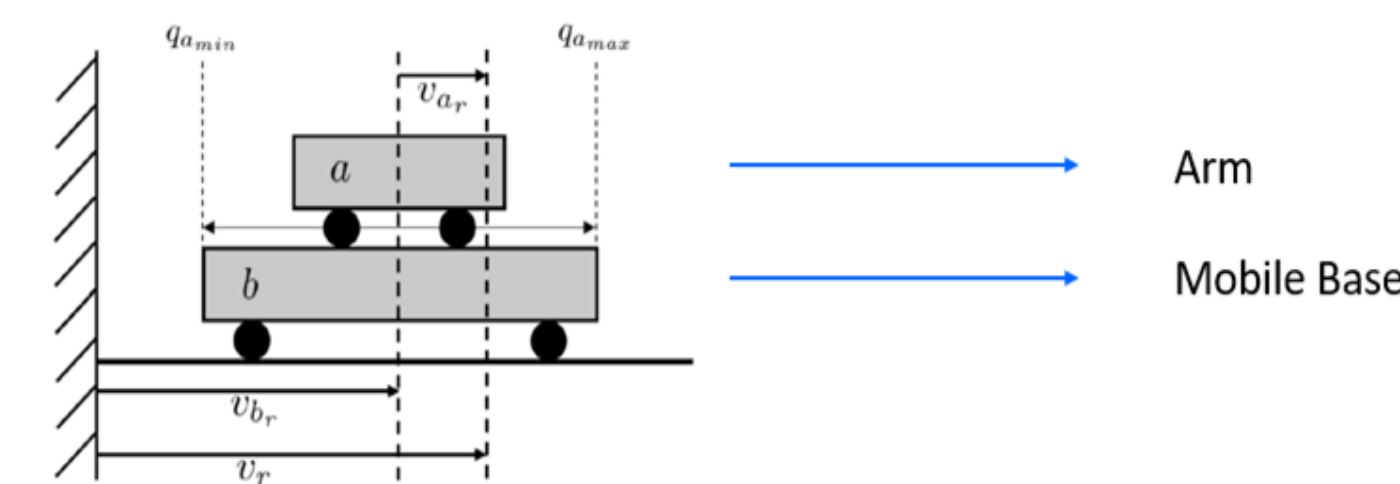
Problem Description and Modelling

- The operator co-manipulates through a handle on the end-effector: a UR10e arm on a Robotnik RB-KAIROS+ omnidirectional base.
- Typically, a virtual admittance model maps the human wrench into a reference twist, then the IDK problem is solved for the whole robot:



Standard admittance-based architecture for pHRI

- **Baseline** [Giammarino et al., 2024]: base and arm are inverted as one redundant system, keeping the operator in a comfortable posture. Their solution is a manual switch between two modes: **LO** (base only active) and **SW** (base + arm, triggered by the user).
- **Micro/macro** paradigm: the heavy, slow mobile base performs macro motions (low-frequency, unbounded); the light, fast **arm** performs micro motions (high-frequency, bounded).



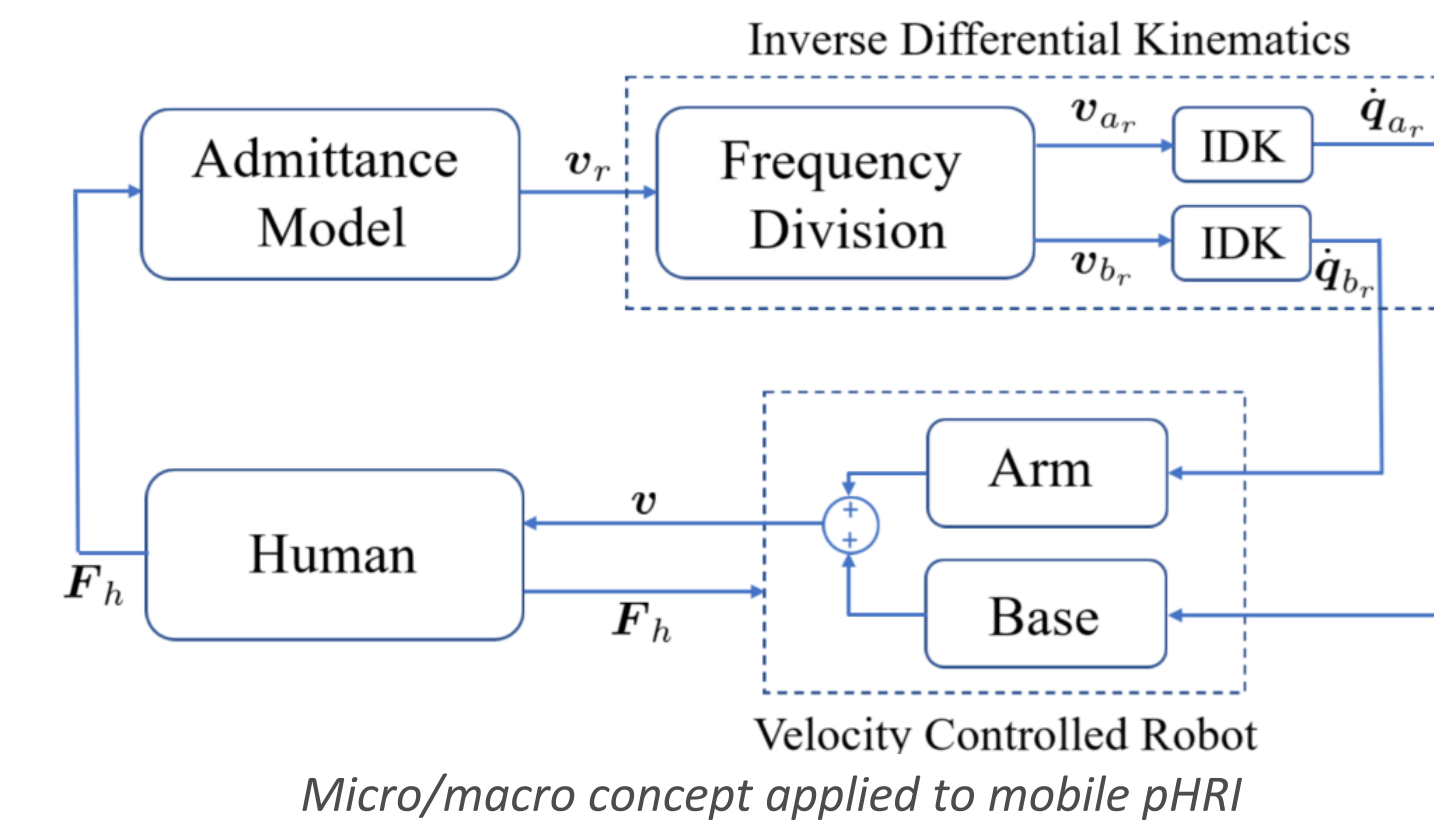
Micro/macro manipulation concept

- With an omnidirectional base, the task velocity is the direct sum of the contributions:

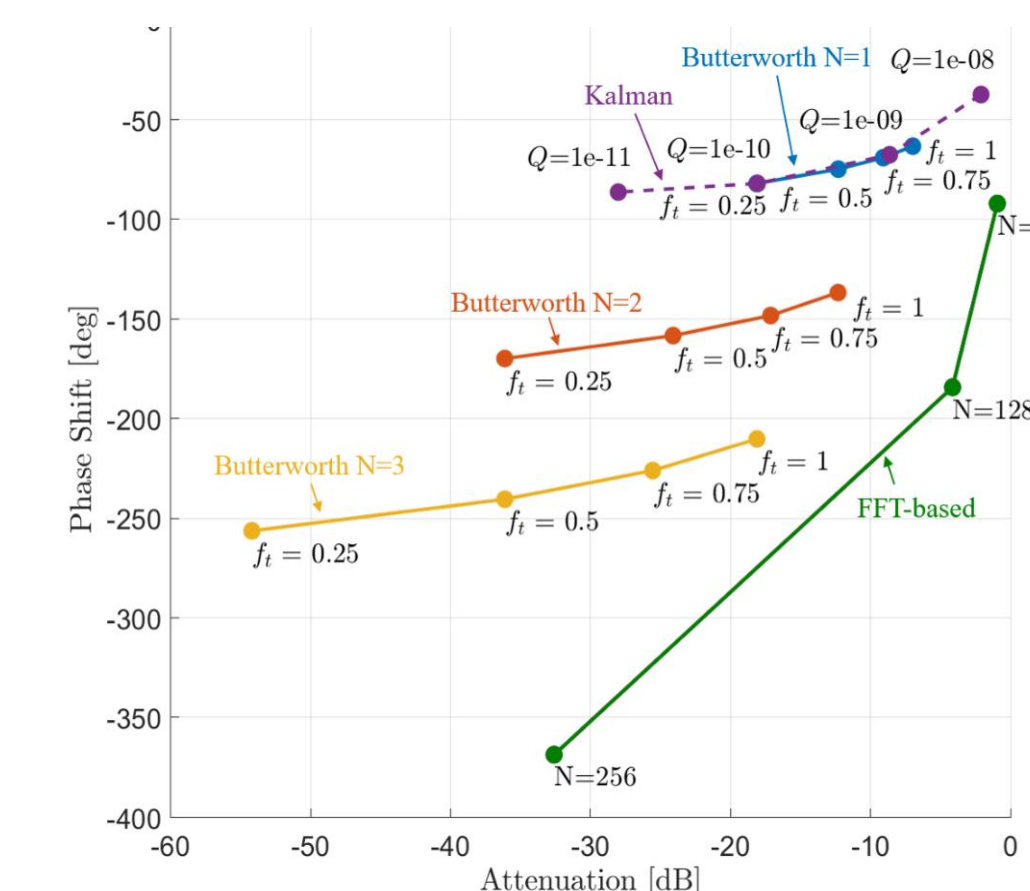
$$\mathbf{v}_{x_r} = \mathbf{v}_{a_{x_r}} + \mathbf{v}_{b_{x_r}} \quad \mathbf{v}_{y_r} = \mathbf{v}_{a_{y_r}} + \mathbf{v}_{b_{y_r}} \quad \omega_{z_r} = \omega_{a_{z_r}} + \omega_{b_{z_r}}$$

Strategy

- The proposed controller (MM) replaces the IDK block with a Frequency Division block: low frequencies → base (macro), high frequencies → arm (micro).

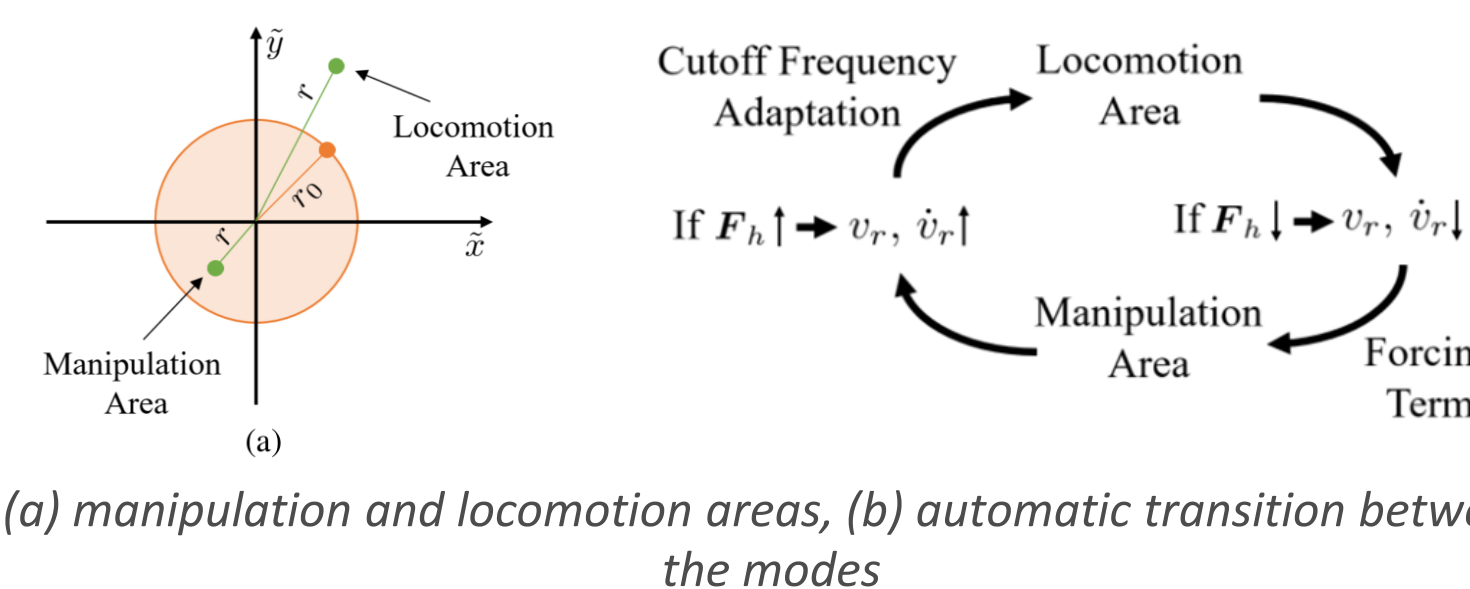


- FFT based, Kalman and Butterworth filters are compared. Phase delay is the critical metric: the considered trade-off is a 1st-order Butterworth, $f_{t0} = 1$ Hz.



Attenuation vs. phase shift of the three frequency-division methods

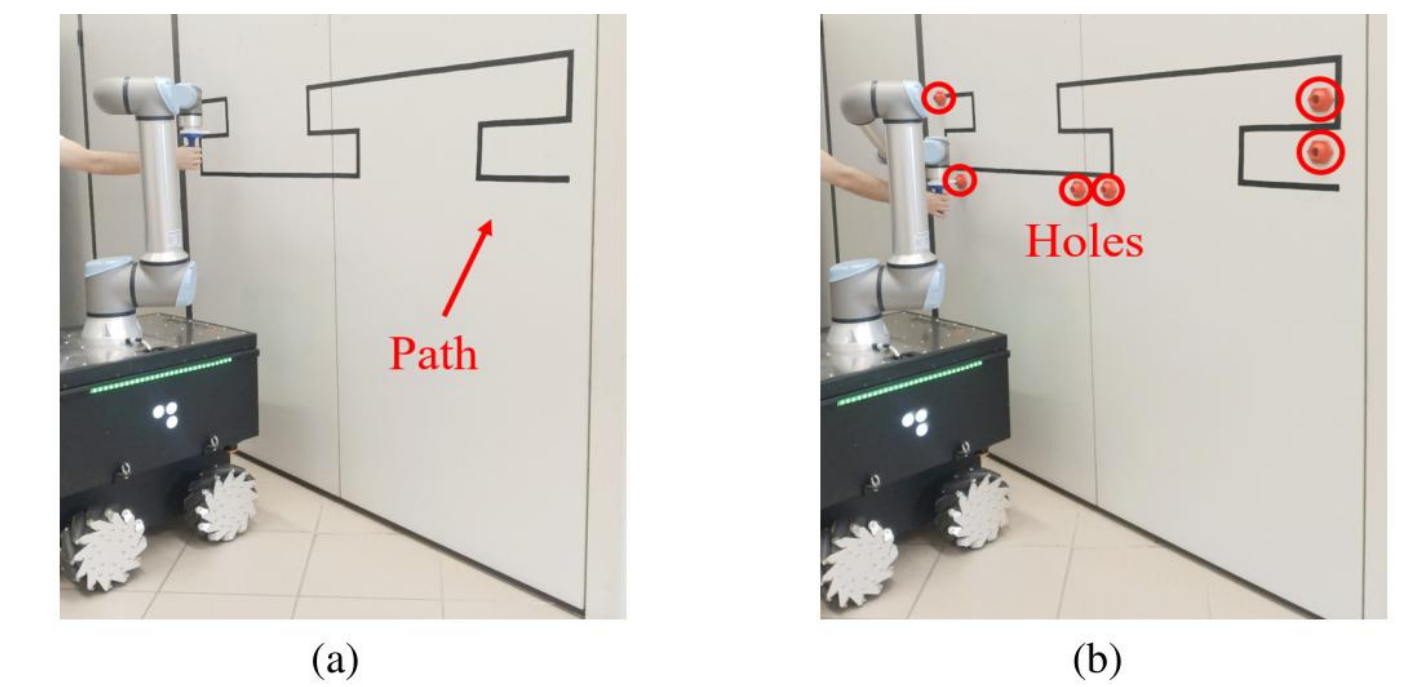
- **Cut-off adaptation**: when the end-effector leaves the manipulation area ($r > r_0$), f_t grows and the base takes over ⇒ locomotion.
- **Forcing term**: a virtual elastic force in the null space of $\mathbf{J}(\mathbf{q})$ pulls the end-effector back to its ergonomic pose ⇒ manipulation.



(a) manipulation and locomotion areas, (b) automatic transition between the modes

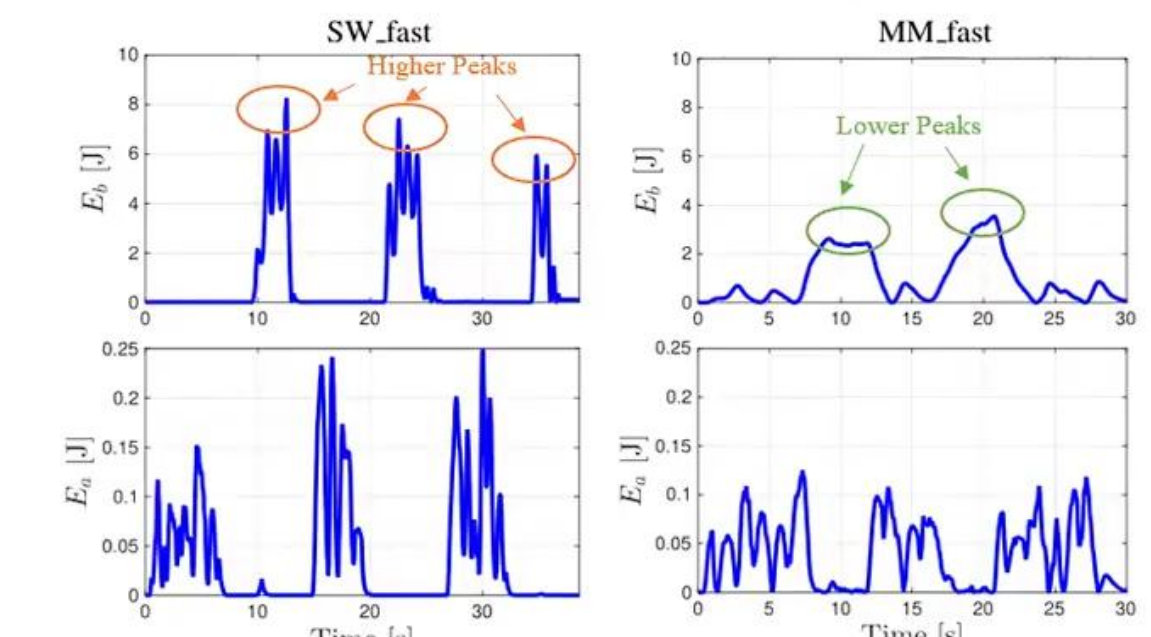
Results

- Two tasks, 20 participants. MM (proposed) vs. SW (baseline with manual switch) and LO (locomotion only).



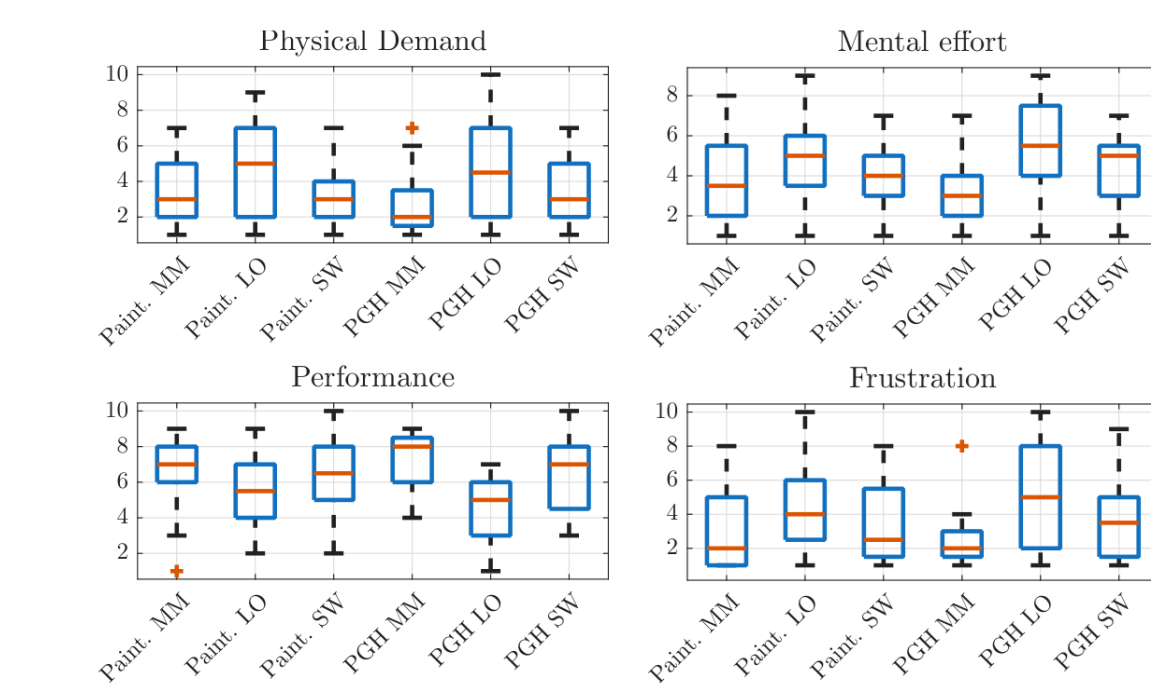
(a) painting-like task, (b) peg-in-hole (drilling)

- At similar execution time, MM_slow and SW_fast have comparable metrics.
- At free speed (MM_fast vs. SW_fast): potential execution time reduction thanks to the absence of a switching operation, since the latter inherently introduces a certain delay.



Stored energies E_b , E_a — painting-like task (SW fast vs. MM fast)

- SW causes much higher kinetic-energy peaks on the mobile base, a potential safety concern.



Questionnaire results for the two tasks

- Evaluation questionnaire: MM resulted the least demanding and the least frustrating one, especially in high precision tasks such as peg-in-hole.