Quantifying Action Uncertainty with Inaccurate Stochastic Dynamics through Conformalized Nonholonomic Lie groups

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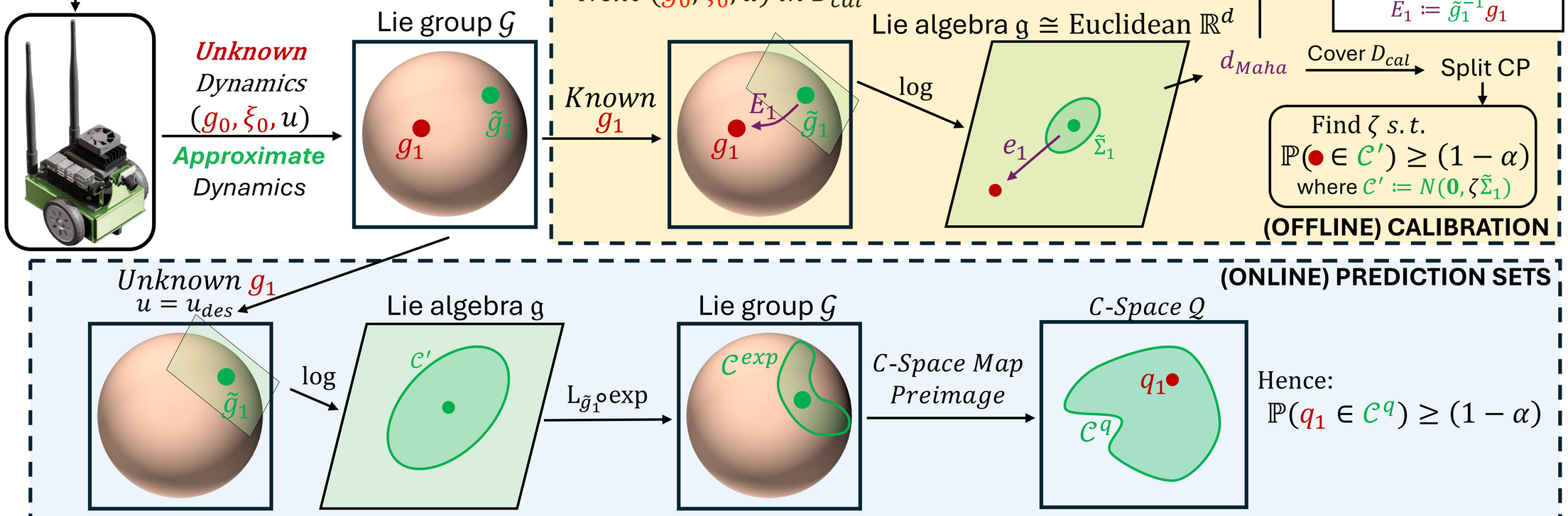
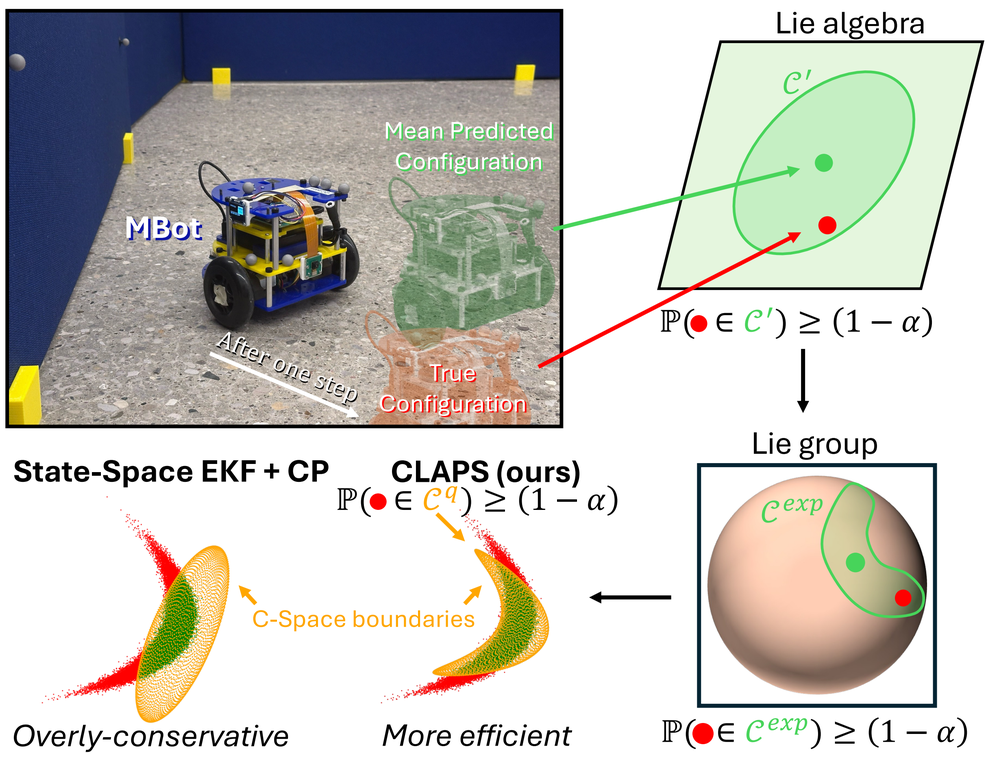
Given an approximate Lie-algebraic Gaussian dynamics model $\tilde{f}$ and a transitions dataset $\mathrm{D}_{cal}=\{(s_t, a_t, s_{t+1})\}$, we:

- provide a state-action-dependent post-hoc calibration layer over existing Lie-algebraic Gaussian uncertainty estimators
- extend conformal guarantees from Euclidean configuration spaces to *SE(2)*, improving volume-efficiency

Method: CLAPS



Hardware Validation



State Space Dynamics to Lie group form

State Space Dynamics

Configuration Update $\frac{d}{dt} q = \dot{q}$

Forced Lagrange-d'Alembert $\frac{d}{dt}\frac{\partial L}{\partial \dot{q}} = \frac{\partial L}{\partial \dot{q}} + B(q)u + A(q)\lambda, \quad A(q)\dot{q} = 0$

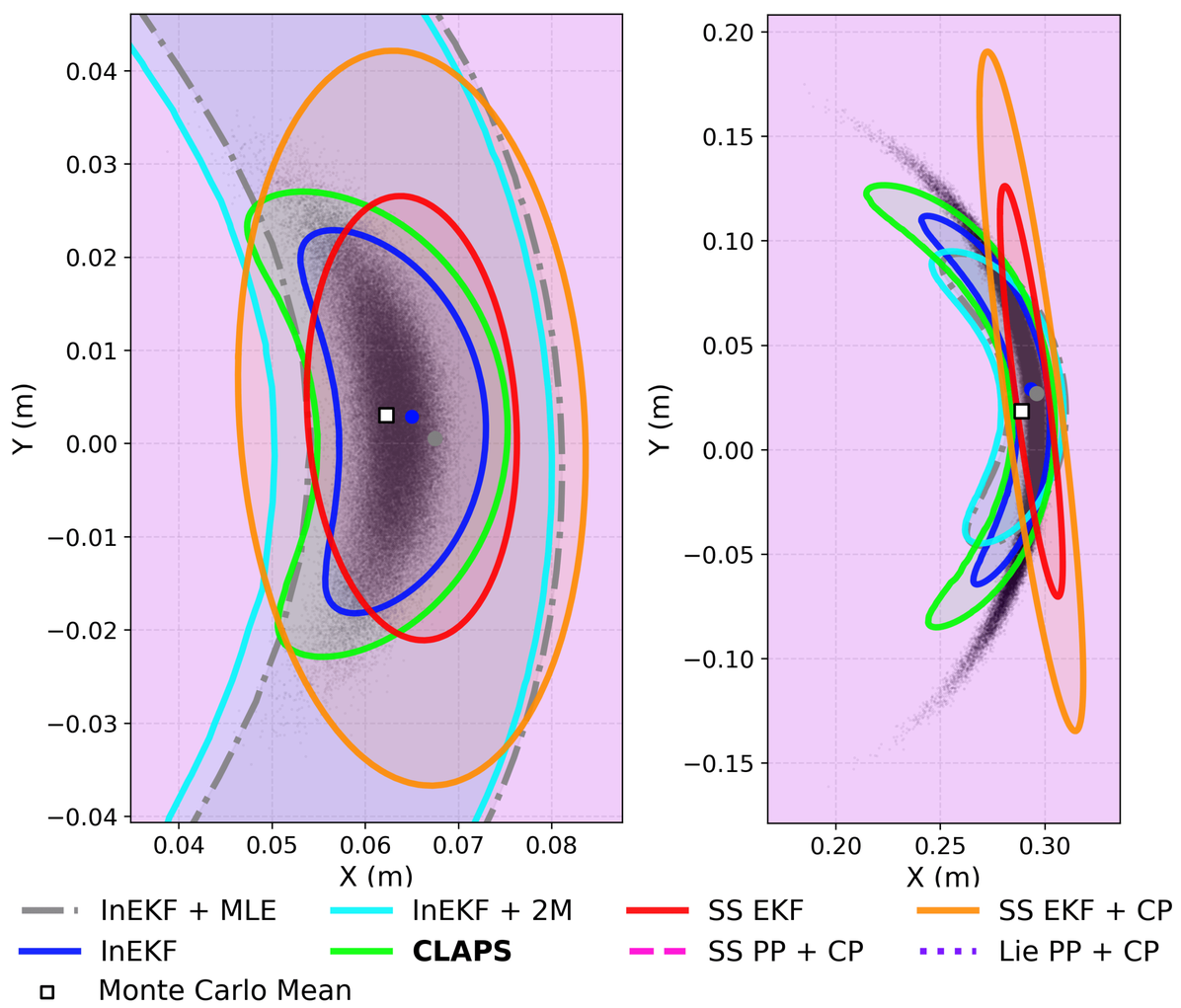
Configuration q / g — Velocity $\dot{q}$ / ξ — Force Map $B(q)$ / $\mathcal{B}$
Control input u (shared) — Nonholonomic Constraint $A(q)$ / $\mathcal{A}$

Lie group Dynamics

Reconstruction Eq. $\frac{d}{dt} g = g\xi^{\wedge}$

Forced Euler-Poincaré-Suslov $\frac{d}{dt}\frac{\partial l}{\partial \xi} = \mathrm{ad}^*_{\xi}\left(\frac{\partial l}{\partial \xi}\right) + \mathcal{B}u + \mathcal{A}\lambda, \quad \mathcal{A}\xi = 0$

Workspace Footprint of C-space regions



JetBot (Simulation) Results (over 625 validation trials)

Algorithm	Marginal Coverage (%)	Avg. Volume Ratio ↓	Avg. Workspace IoU with Particles (%) ↑	Provable Guarantees?
SS EKF	78.7	0.63	35.0	✗
InEKF	82.7	0.47	41.8	✗
InEKF+2M	89.2	3.06	40.0	✗
InEKF+MLE	90.3	2.80	42.3	✗
SS PP + CP	89.9	2137	0.20	✓
Lie PP + CP	89.9	2138	0.20	✓
SS EKF + CP	91.2	2.86	30.4	✓
CLAPS	90.0	**1.00**	**48.4**	✓

red if coverage does not achieve (<) the user-set probability $(1-\alpha) = 0.9$.
The average volume ratio is reported relative to **CLAPS**.

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