Robust Dexterous Throwing against Release Uncertainty

EPFL LASA Learning Algorithms and Systems Laboratory

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DARKO Dynamic Agile Production Robots That Learn and Optimise Knowledge and Operations

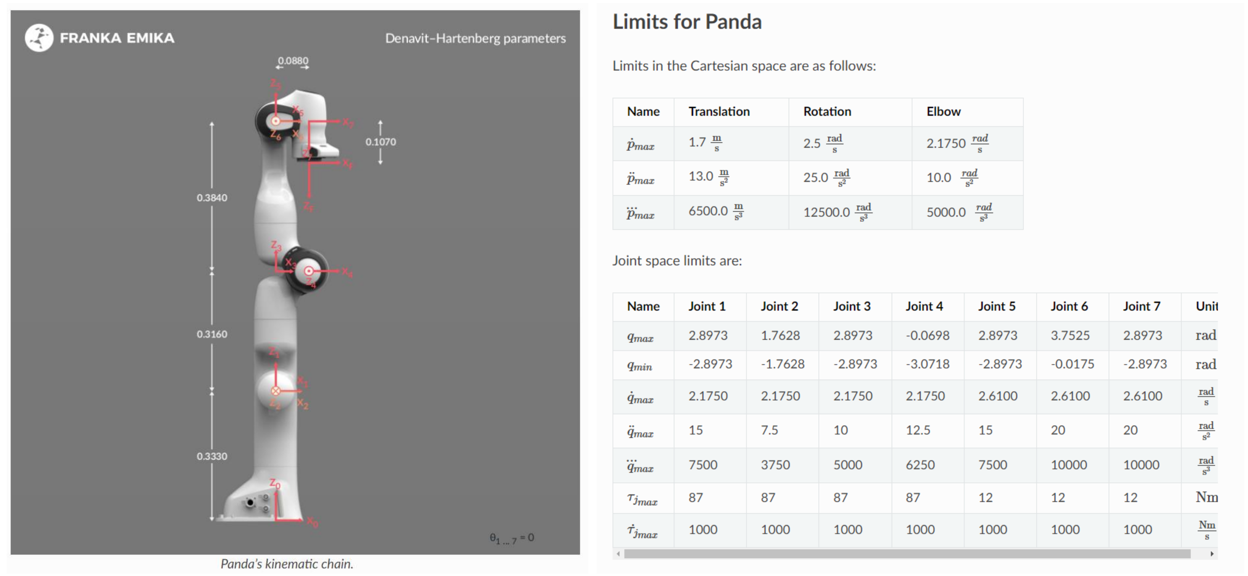
Introduction

Human can throw different objects in various ways, adaptive to unstructured environments. Can we design reliable and efficient algorithms for robots to do so?

Challenges

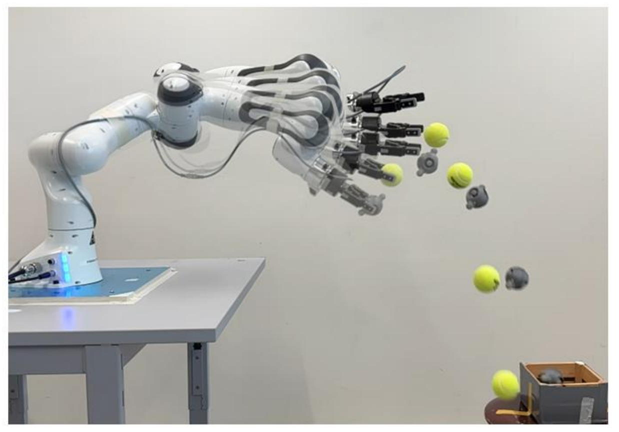
Dexterous throwing - nonconvex feasible set

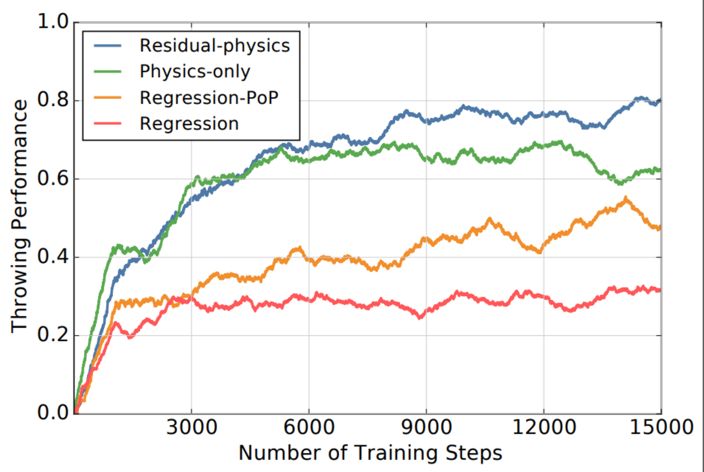
- Complex geometry of the 7-DoF robot
- Restrictive dynamic limits



Release uncertainty – intricate contact mechanics

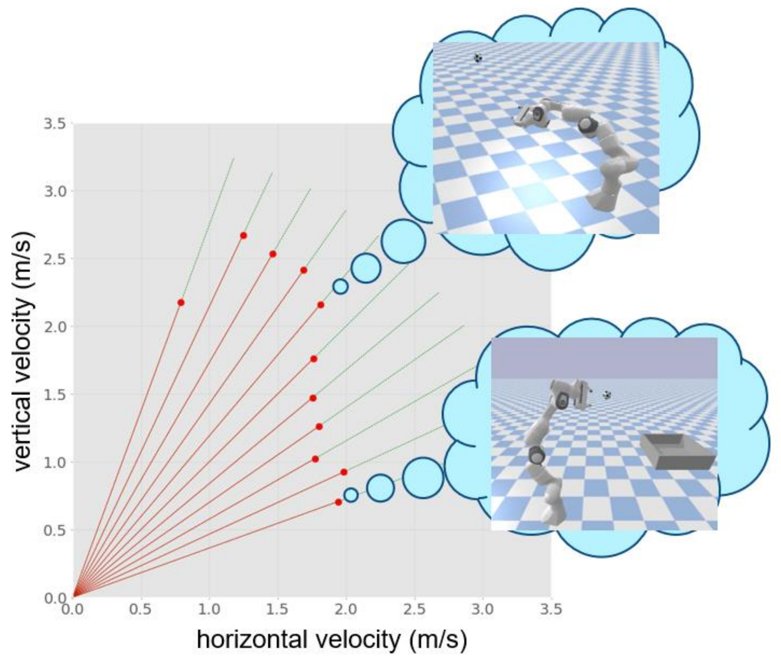
- Objects differ in friction and deformation
- Same throwing motion could lead to different landing outcomes
- End-to-end learning is not scalable to diverse configurations

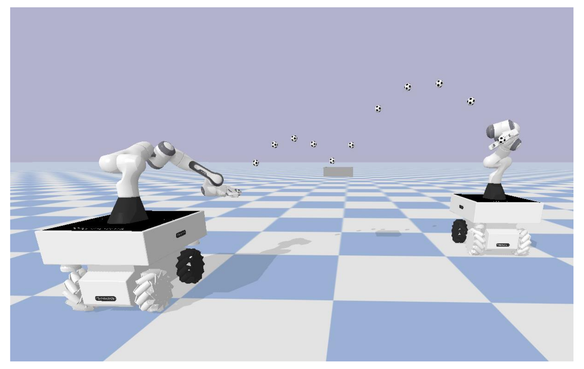




End-to-end learning for planar throwing [1]

Velocity Hedgehog – Dictionary of Diverse Throwing Configurations [2]





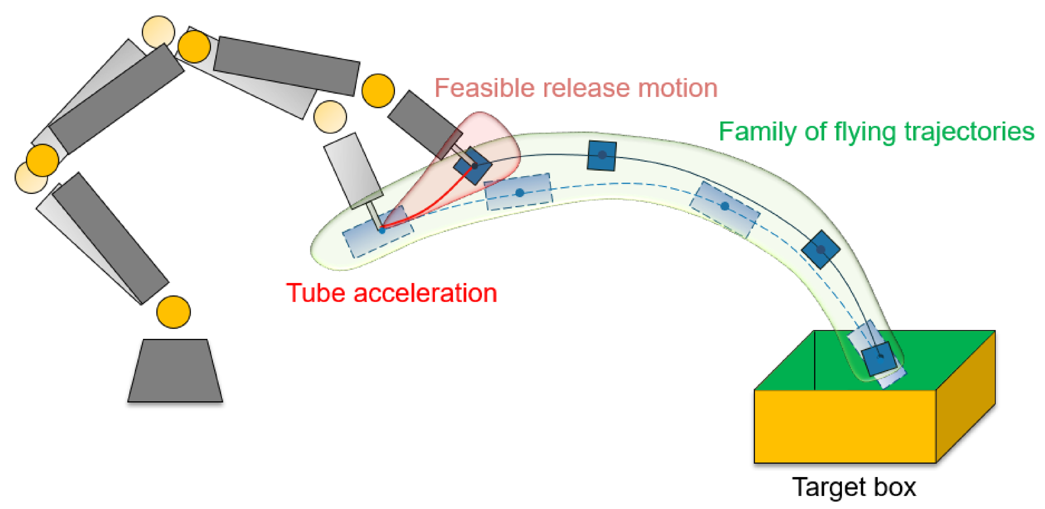
Offline: build throwing dictionary

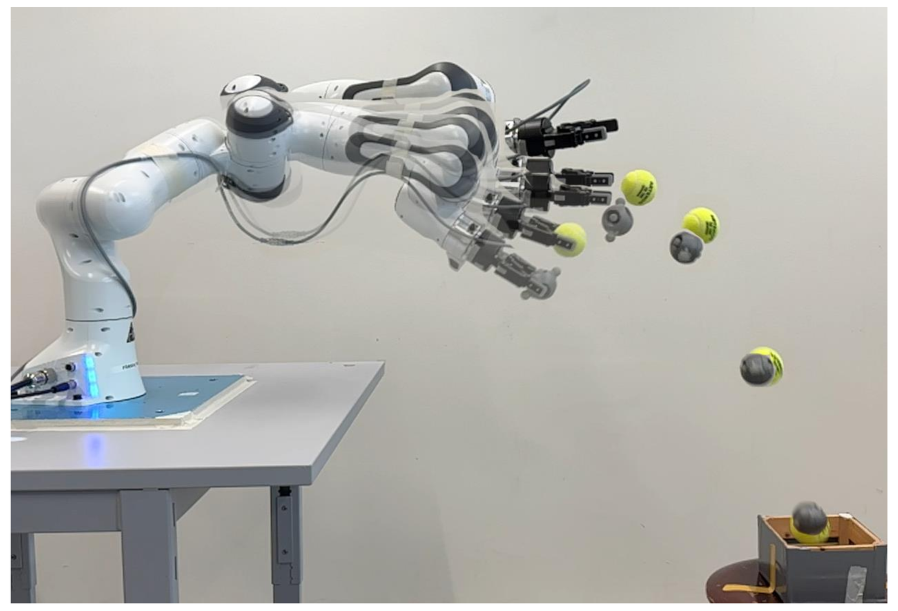
- Keys: 100k pairs of (end-effector position, throwing direction)
- Value of each key:
  - maximum feasible Cartesian velocity v_{max}
  - the joint configuration enabling v_{max}
- Extracted from 1 million joint configurations (7 hours)

Online: search over 100k entries

- **20 ms** running time
- Thousands of qualitatively different solutions

Tube Acceleration - Robust Release Motion



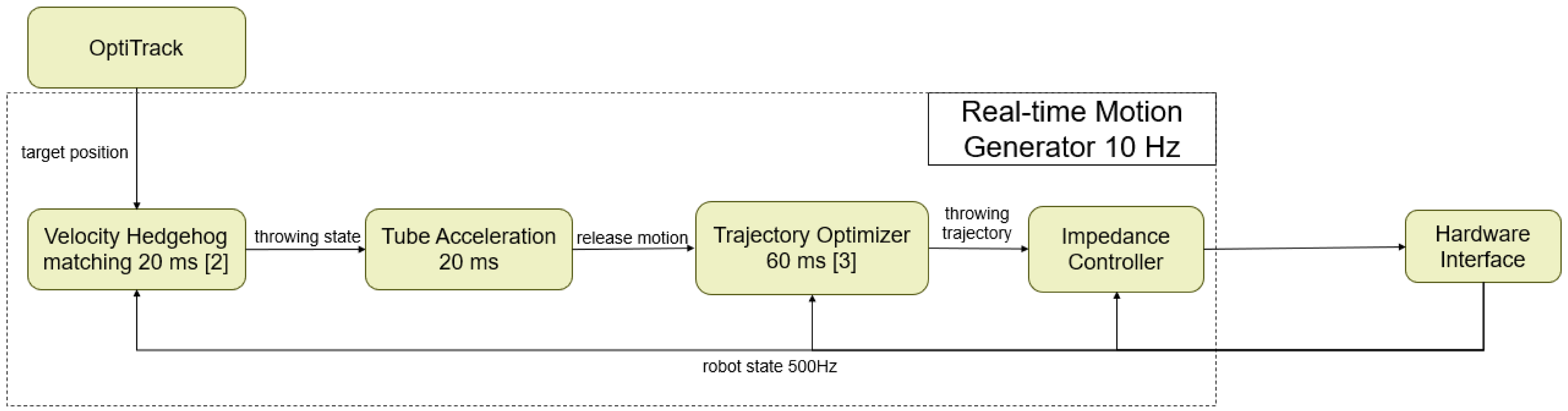


Idea: design robot motion to traverse the family of valid throwing configurations during gripper opening (100 ms)

Insight: object flying flowmap: initial state → landing position is quasi-linear (bounded Hessian)

- Constant joint acceleration – tube acceleration during release window can drive the robot stay in valid throwing configurations
- Tube acceleration can be found via convex optimization within **20 ms** and with bounded error

System Architecture

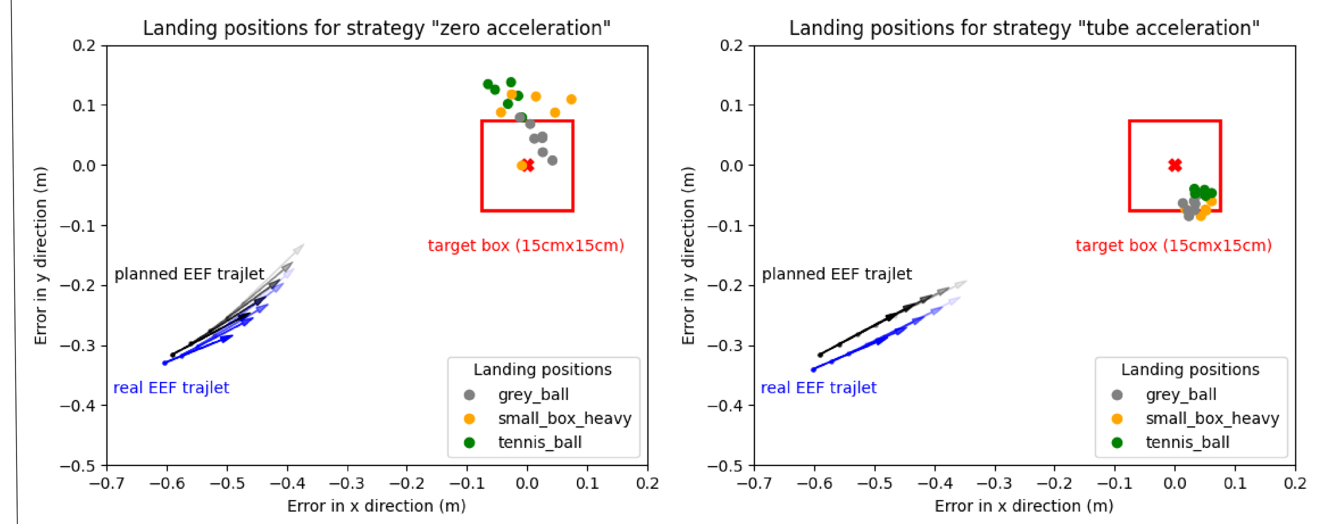


Real Throwing Experiments

Thrown objects

Object	grey_ball	small_box_heavy	tennis_ball
Weight (g)	120	100	70
Size (mm)	80×60×60	80×65×60	75×75×75

Population of landing positions



Statistics of landing errors

	Mean (mm)		Std. (mm)	
Object	Tube	Zero	Tube	Zero
grey_ball	74.52	**53.70**	**9.51**	15.60
small_box_heavy	**87.12**	95.30	**7.47**	44.57
tennis_ball	**66.23**	121.07	**9.55**	25.97
overall	**75.88**	88.11	**12.04**	40.74

Conclusion

- Dexterous throwing configurations can be found quickly via Velocity Hedgehog
- Release uncertainty can be suppressed by robust throwing motion design
- Fast and reliable algorithms enable adaptive robot throwing

Reference

[1] Zeng et al., "*TossingBot: Learning to Throw Arbitrary Objects with Residual Physics*", RSS 2019.

[2] Yang Liu, Aradhana Nayak and Aude Billard, "*A Solution to Adaptive Mobile Manipulator Throwing*", IROS 2022.

[3] Petr Listov and Colin Jones, "*PolyMPC: An efficient and extensible tool for real-time nonlinear model predictive tracking and path following for fast mechatronic systems*", Optimal Control Applications and Methods 2020.

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