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MIN Faculty
Department of Informatics

A Data-Efficient Approach to Precise and Controlled Pushing

Bauza, M., Hogan, F. R., & Rodriguez, A

Tom Schmolzi

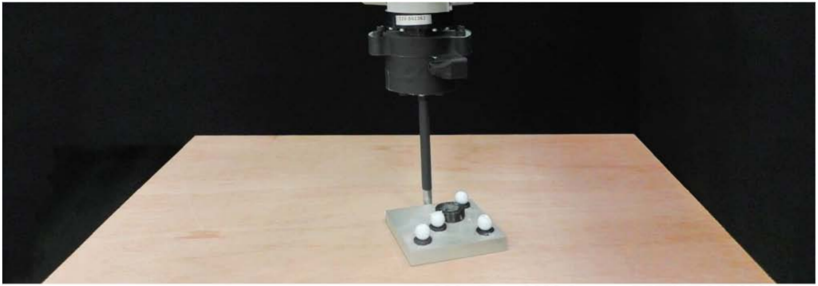
University of Hamburg
Faculty of Mathematics, Informatics and Natural Sciences
Department of Informatics

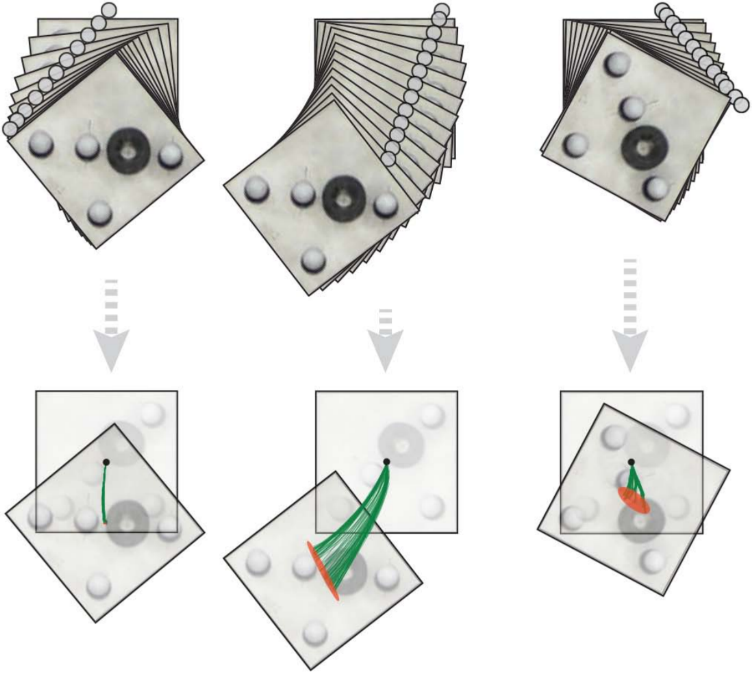
Technical Aspects of Multimodal Systems

1. December 2022

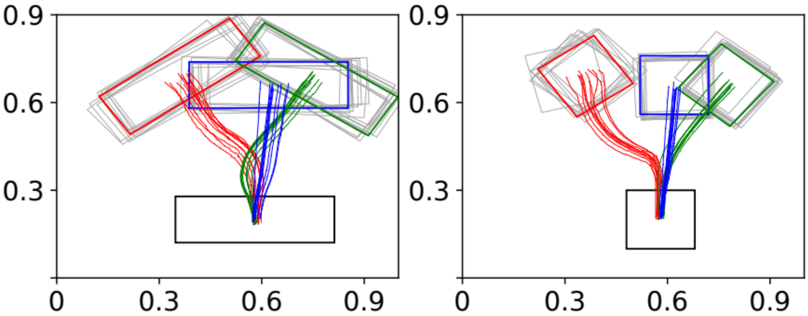
Outline

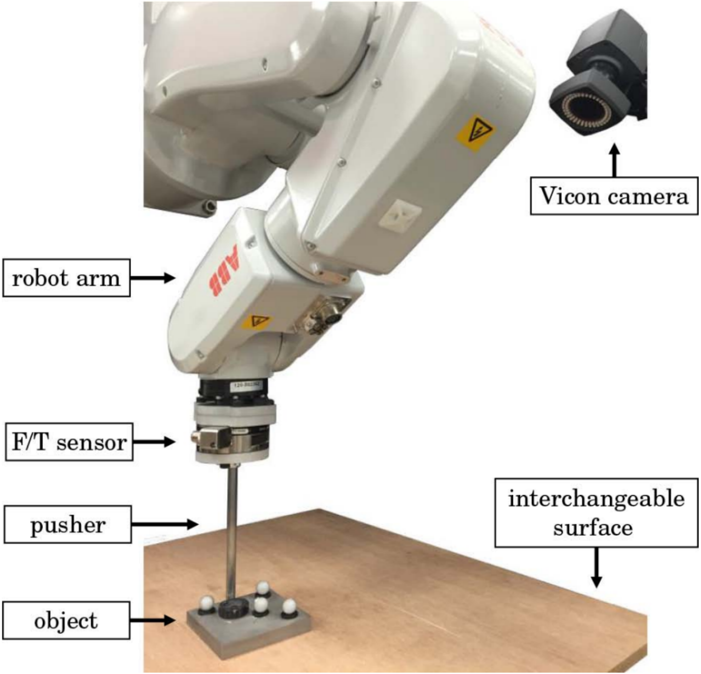
Motivation



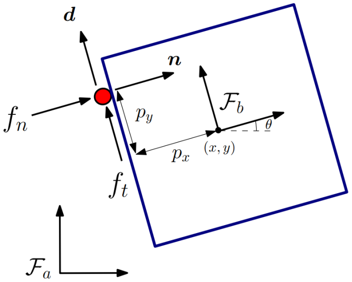


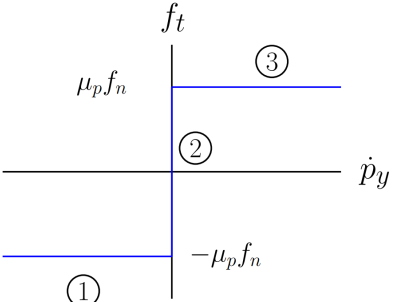
Variance




Vicon camera
robot arm
F/T sensor
pusher
interchangeable surface
object

Analytical Model

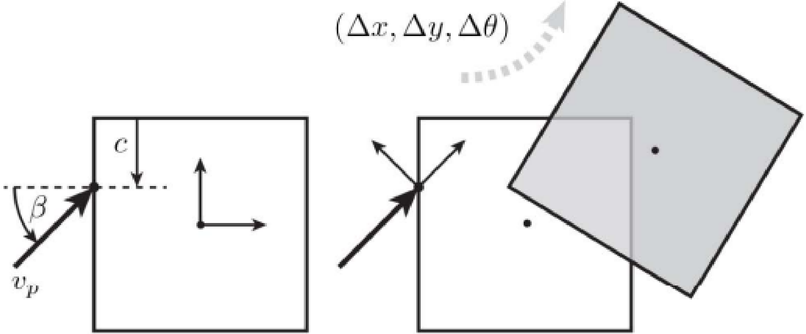




Bauza, Maria, Francois R. Hogan, and Alberto Rodriguez. "A data-efficient approach to precise and controlled pushing." In Conference on Robot Learning, pp. 336-345. PMLR, 2018.

Inputs : $[f_n \; f_t \; \dot{p}_y]^T$ *Outputs* : $\Delta\mathrm{x} = [\Delta x \; \Delta y \; \Delta\theta]^T$

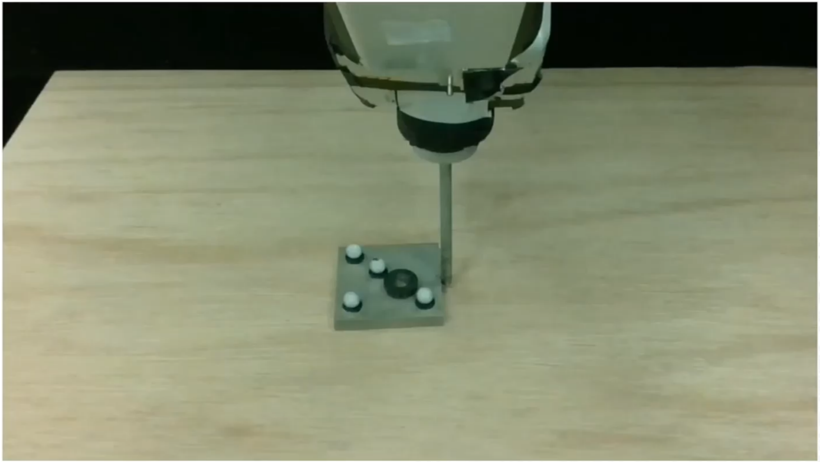
Data Driven Model



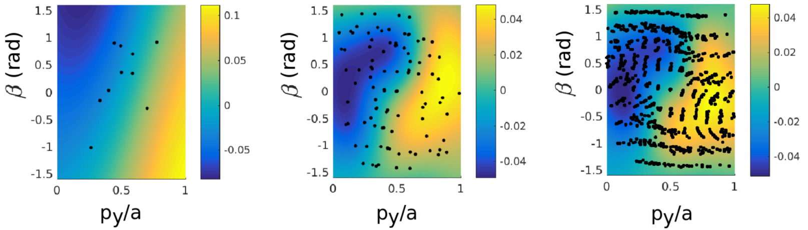
Bauza, Maria, and Alberto Rodriguez. "A probabilistic data-driven model for planar pushing." In 2017 IEEE International Conference on Robotics and Automation (ICRA), pp. 3008-3015. IEEE, 2017.

$$Inputs : [p_y \ \beta]^T \qquad Outputs : \Delta\mathrm{x}_b = [\Delta x_b \ \Delta y_b \ \Delta\theta_b]^T$$

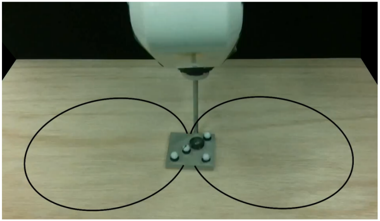
Data Collection (Video)

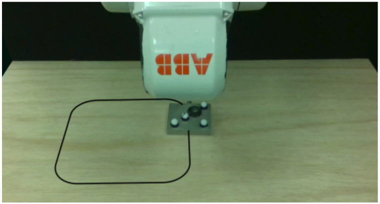


Data Driven Model

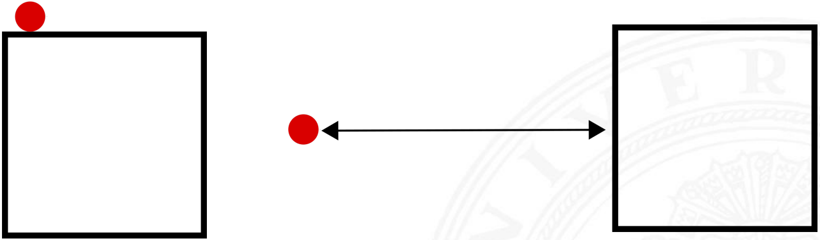


Goal Path





Pertubations



Tangential pertubations

Normal pertubations

Controller Design

- Applicable for both models
- Prediction using the models
- Closed loop

Model Predictive Control

$$
\begin{aligned}
\min_{\bar{x}_i, \bar{u}_i} \quad & \bar{x}_N^T Q_N \bar{x}_N + \sum_{i=0}^{N-1} (\bar{x}_{i+1}^T Q \bar{x}_{i+1} + \bar{u}_i^T R \bar{u}_i) \\
\text{subject to} \quad & \bar{x}_{i+1} = \bar{x}_i + h[A_i \bar{x}_i + B_i \bar{u}_i] \\
& x_i \in \mathcal{X} \\
& u_i \in \mathcal{U}
\end{aligned}
$$

Experiment Parameters

Analytical Model

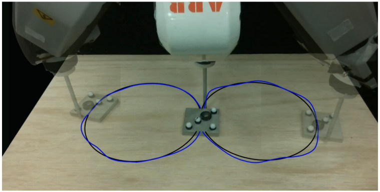
$$Q = [6000, 3000, 10, 0]$$
$$x = [x\ y\ \theta\ p_y]^T$$
$$R = [0.1, 0.001, 0.001]$$
$$u_m = [f_n\ f_t\ \dot{p}_y]^T$$

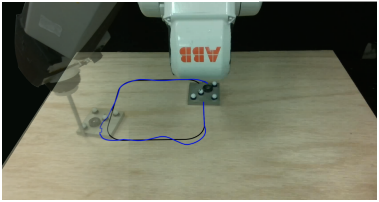
Data Driven Model

$$Q = [6000, 3000, 10, 3000]$$
$$x = [x\ y\ \theta\ p_y]^T$$
$$R = [0.1, 0.001]$$
$$u_m = [v_n\ v_t]^T$$

$$Q_N = Q;\ \ N = 35;\ \ h = 0.01s$$

Result Path

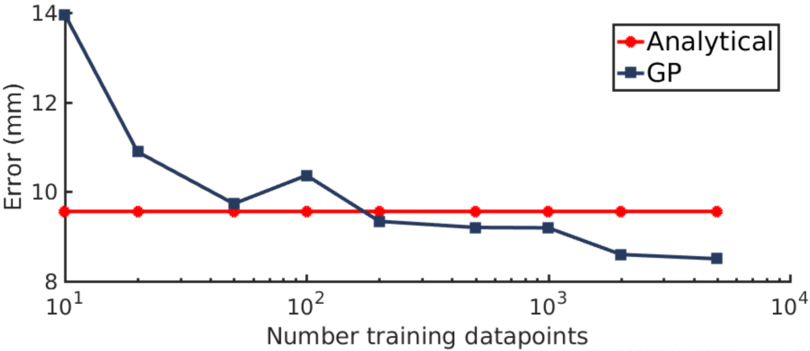




Model Comparison

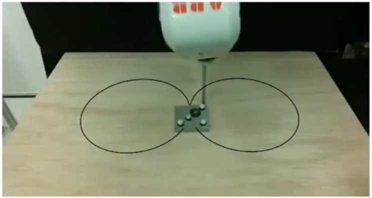
Trajectory	Error (Analytical)	Error (Data-Driven)
8-track no perturbation, v= 80mm/s	9.56 mm	8.50 mm
8-track no perturbation, v= 20mm/s	2.89 mm	6.53 mm
8-track normal perturbation, v= 80mm/s	11.10 mm	8.52 mm
8-track tangential perturbation, v= 80m/s	12.37 mm	9.28 mm
Square trajectory, v= 50mm/s	4.95 mm	6.60 mm

Results

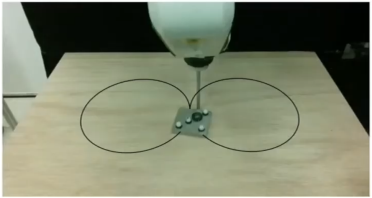

Analytical
GP
Error (mm)
14
12
10
8
10^1
10^2
10^3
10^4
Number training datapoints

Results (Video)

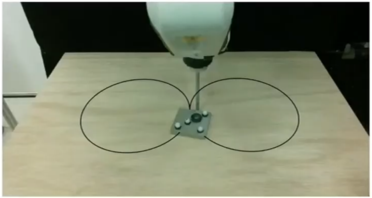
5000 points



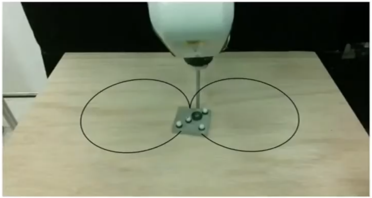
1000 points



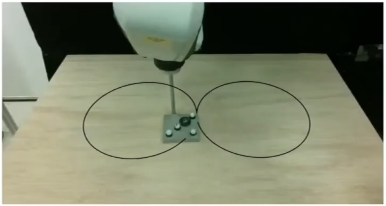
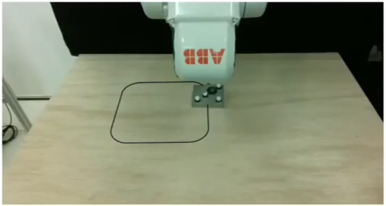
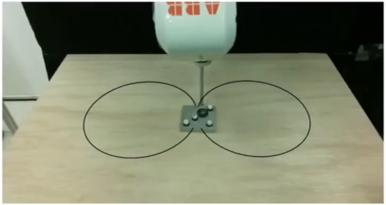
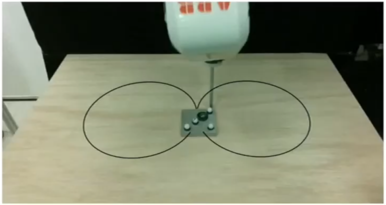
100 points



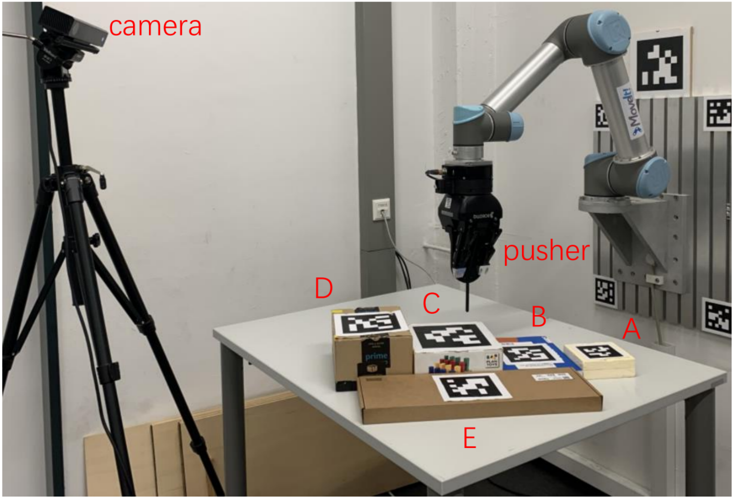
10 points



Robustness (Video)

Other Approaches



Cong, Lin, Michael Grner, Philipp Ruppel, Hongzhuo Liang, Norman Hendrich, and Jianwei Zhang. "Self-adapting recurrent models for object pushing from learning in simulation." In 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 5304-5310. IEEE, 2020.

Future Work

- What happens in no contact situations?
- Side Switching
- Online learning
- Higher Degrees of Freedom

Contributions

- Stable model from 10 random datapoints
- GP model and MPC
- Model in velocity space softens hybridness

References

[1] Maria Bauza, Francois R Hogan, and Alberto Rodriguez.
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[3] Maria Bauza and Alberto Rodriguez.
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[7] Jiaji Zhou, Robert Paolini, J Andrew Bagnell, and Matthew T Mason.
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