Obstacle Avoidance using Potential Fields

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Overview

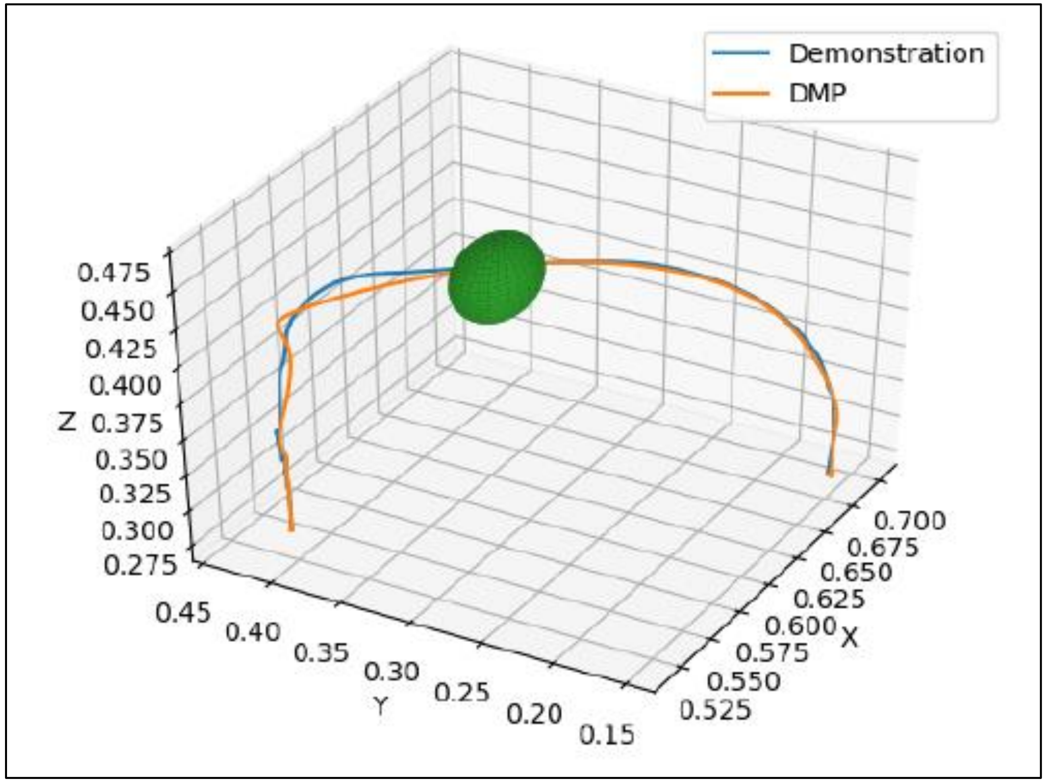
- Obstacle Avoidance using Potential Fields
- Link Collision Avoidance
- Pose Estimation

End-effector Collision Avoidance using Potential Fields

- Spherical obstacles
- DMP

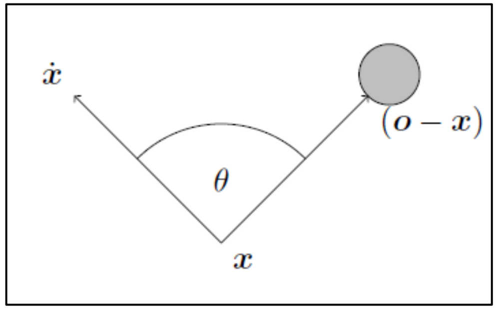
$$\tau \dot{z} = \alpha_z(\beta_z(g - x) - z) + f + C_t,$$

$$\tau \dot{x} = z,$$

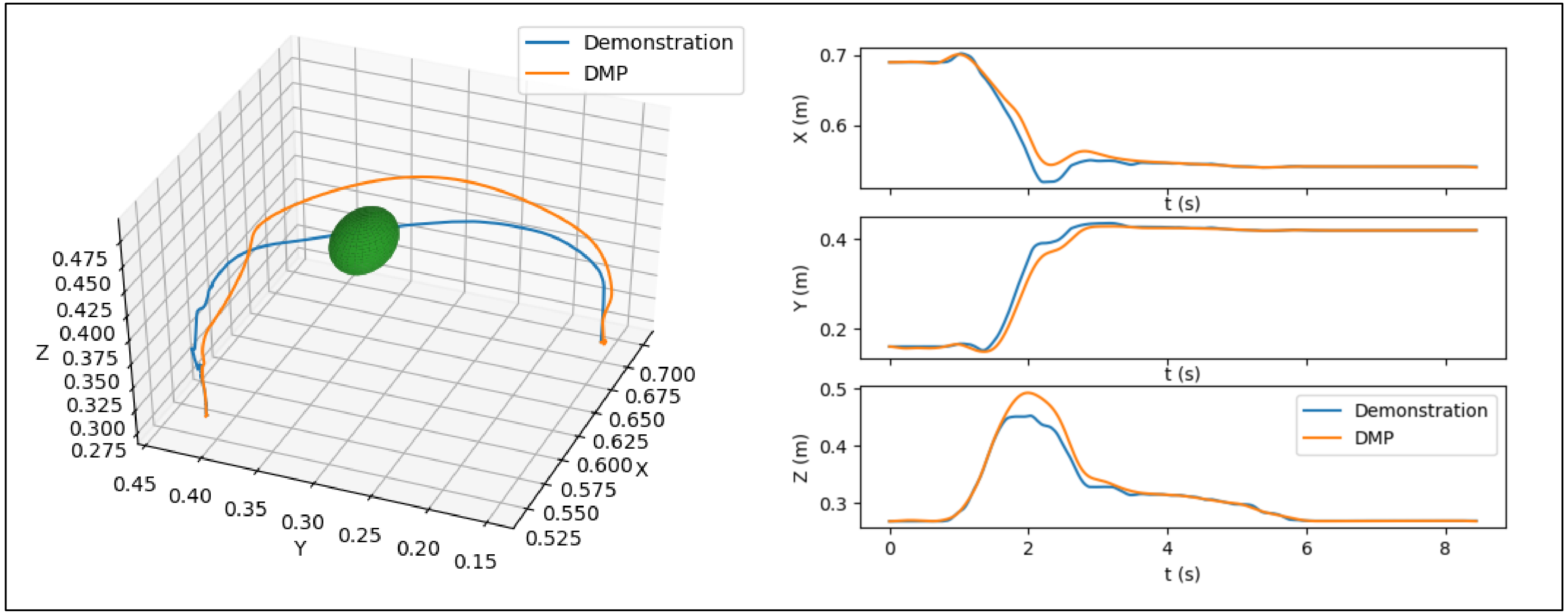


[5] Akshara Rai et al. “Learning coupling terms for obstacle avoidance”.

Potential Field as a Function of Steering Angle



$$C_t = \gamma_0 R \dot{x} \theta e^{-\beta_0 |\theta|}$$

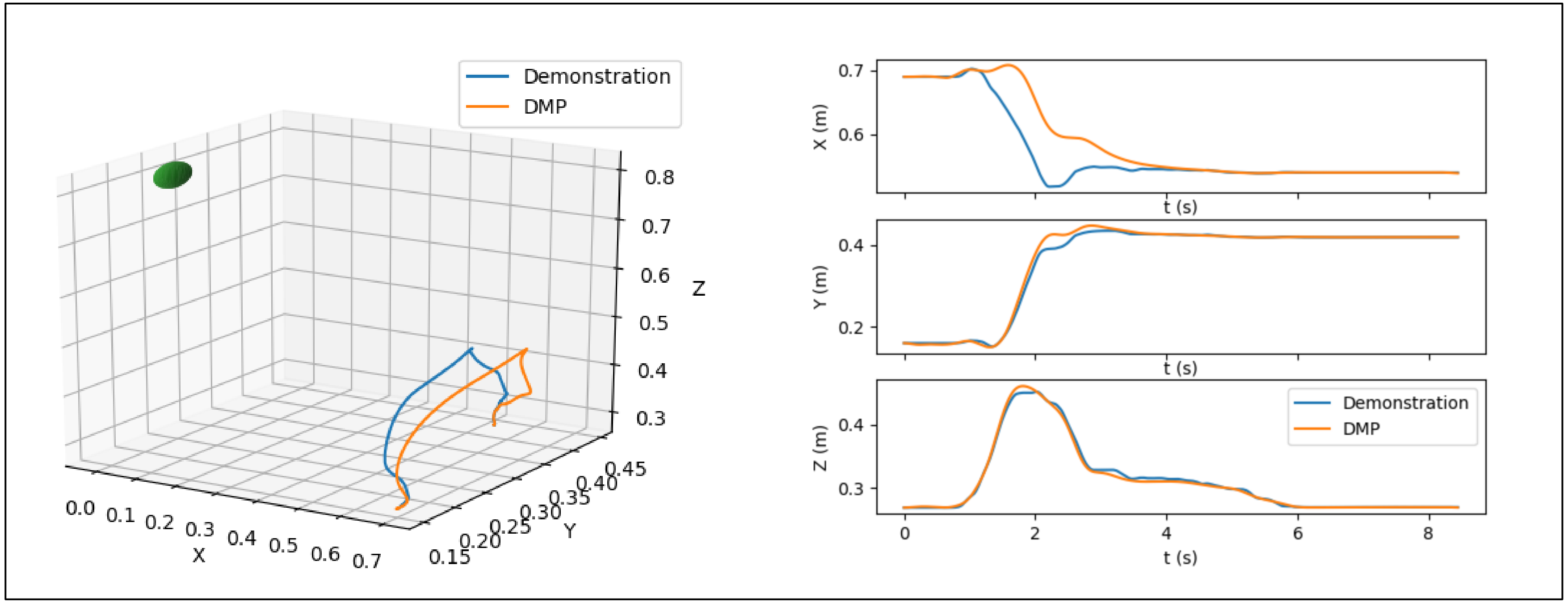


[4] W. Warren, B. Fajen, and D. Belcher. “Behavioral dynamics of steering, obstacle avoidance, and route selection”.
[5] Akshara Rai et al. “Learning coupling terms for obstacle avoidance”.

Potential Field as a Function of Steering Angle

Problems

- Obstacle far away
- $\theta = 0$



$$C_t = \gamma_0 R \dot{x} \theta e^{-\beta_0 |\theta|}$$

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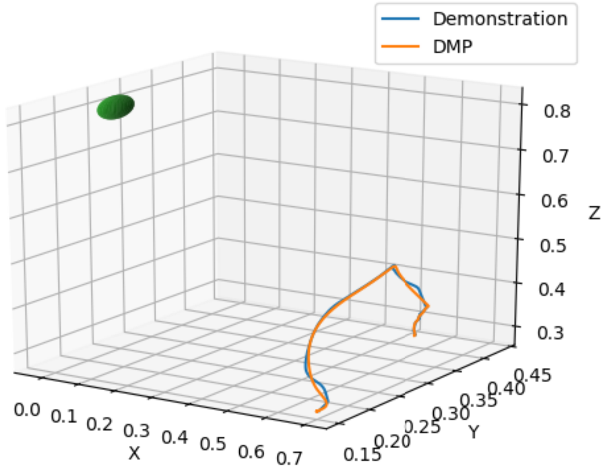
Coupling terms DMP

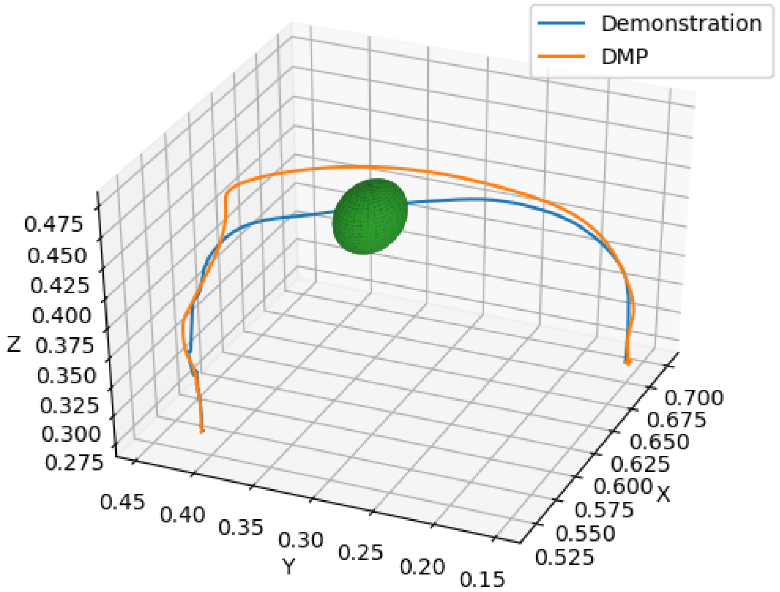
$$C_t = \gamma_1 R\dot{\boldsymbol{x}}\phi_1 + \gamma_2 R\dot{\boldsymbol{x}}\phi_2 + \gamma_3 R\dot{\boldsymbol{x}}\phi_3$$

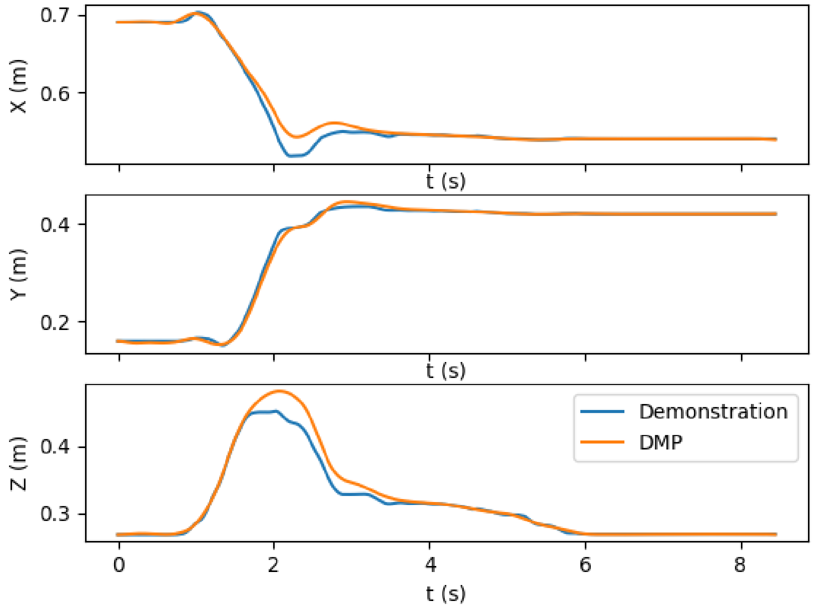
$$\phi_1 = \theta e^{-\beta_0|\theta|} \cdot e^{-kd}$$

$$\phi_2 = \theta e^{-\beta_0|\theta_p|} \cdot e^{-kd_p}$$

$$\phi_3 = e^{-kd}$$



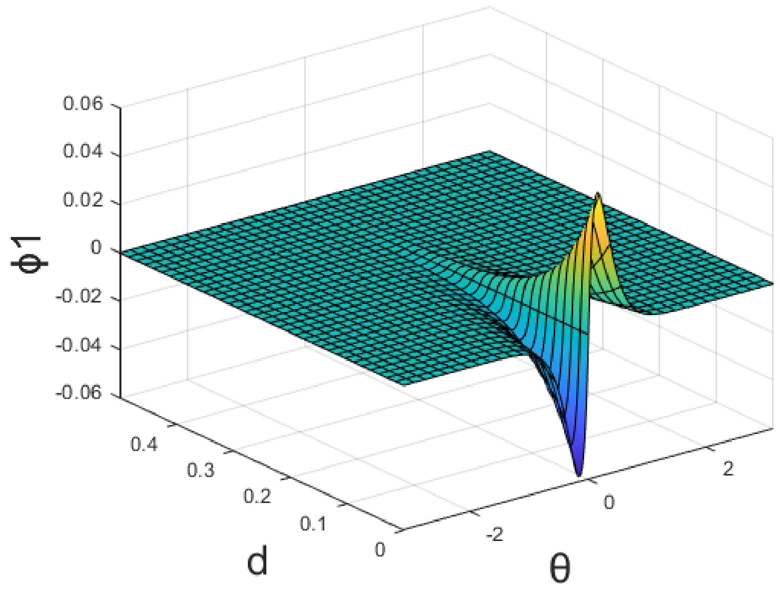


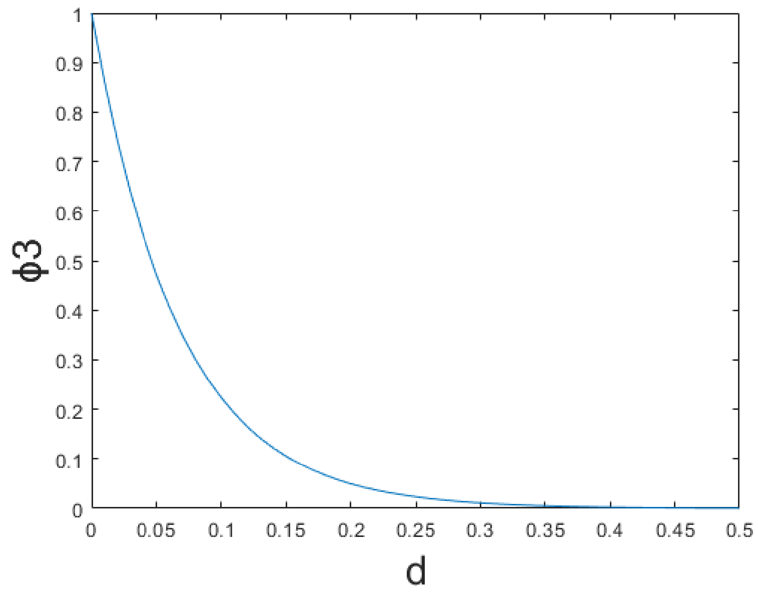


[5] Akshara Rai et al. “Learning coupling terms for obstacle avoidance”.

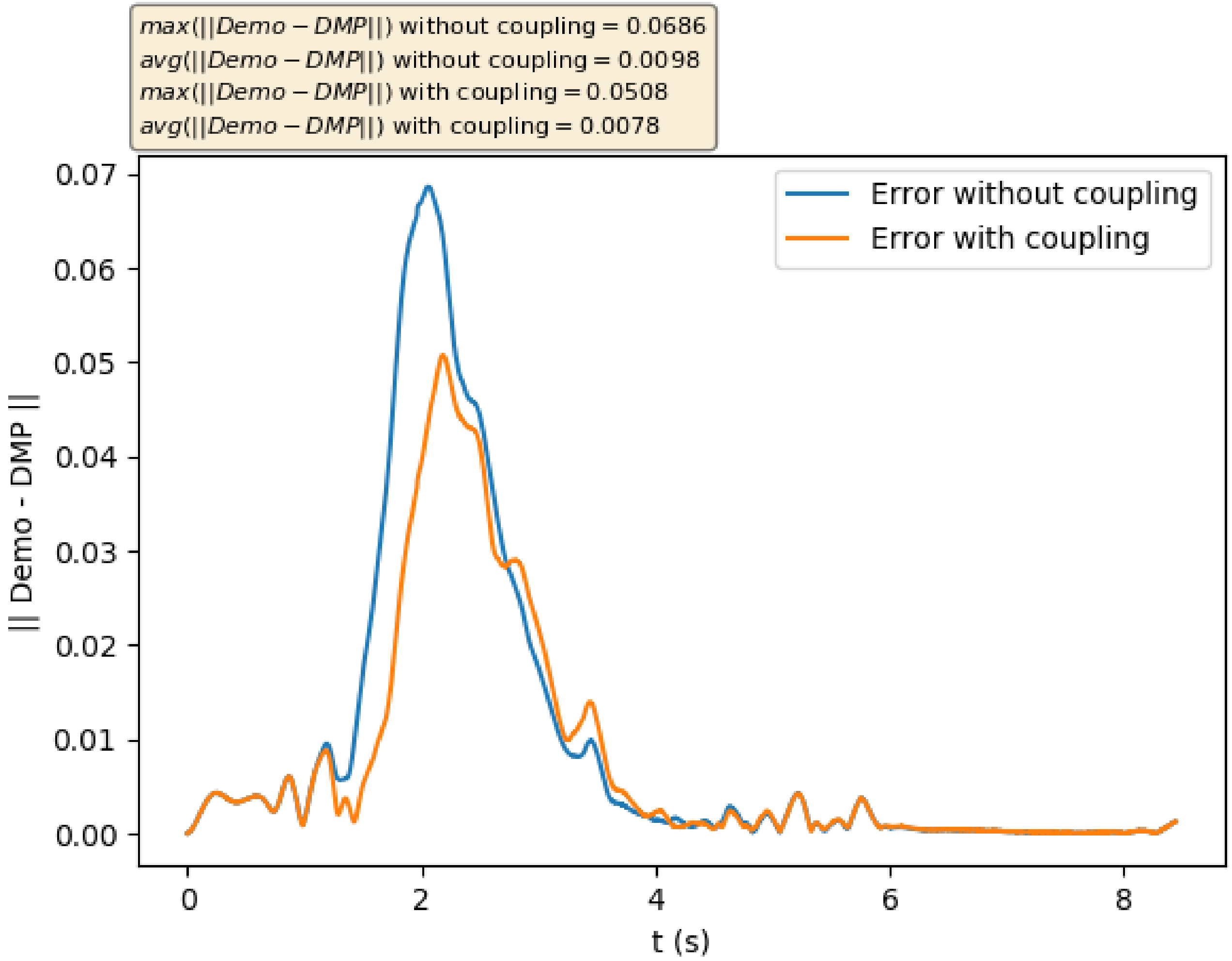
Coupling terms DMP

- Choosing distance scaling constant k
  - $\uparrow k \rightarrow$ less impact of obstacles
  - $\downarrow k \rightarrow$ high impact of obstacles
  - $k = 15$
- Correct weights of three terms
  - γ_1, γ_2 and γ_3



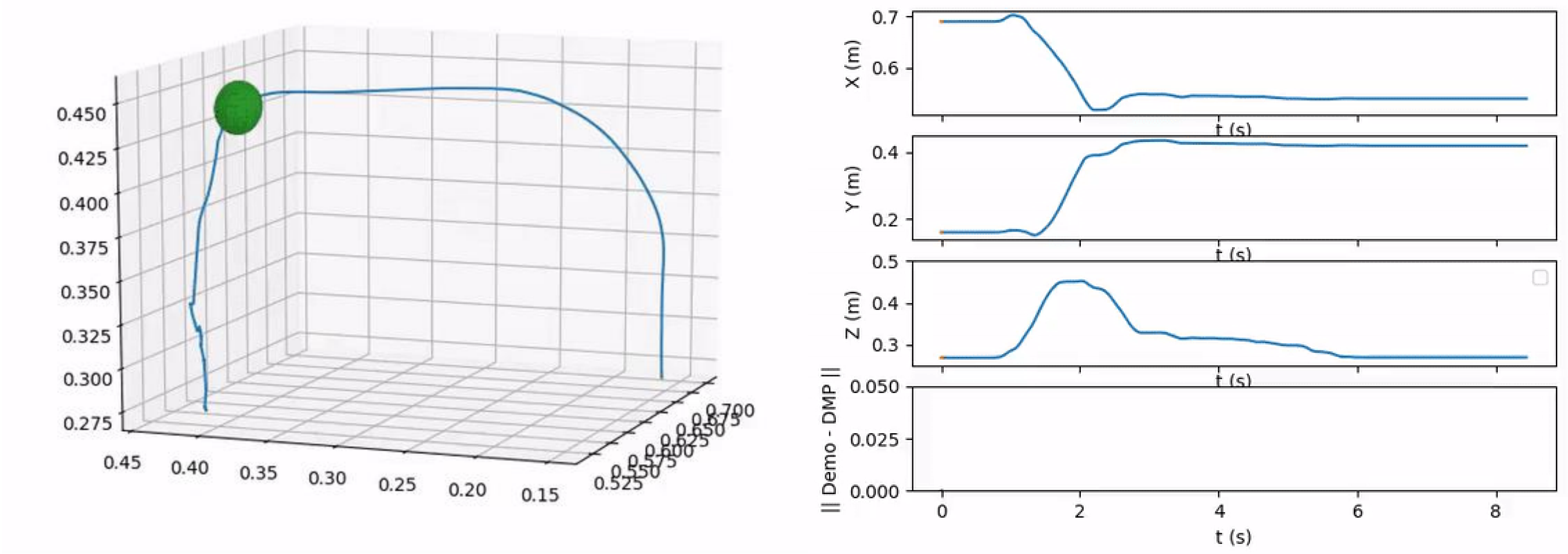


Coupling terms DMP



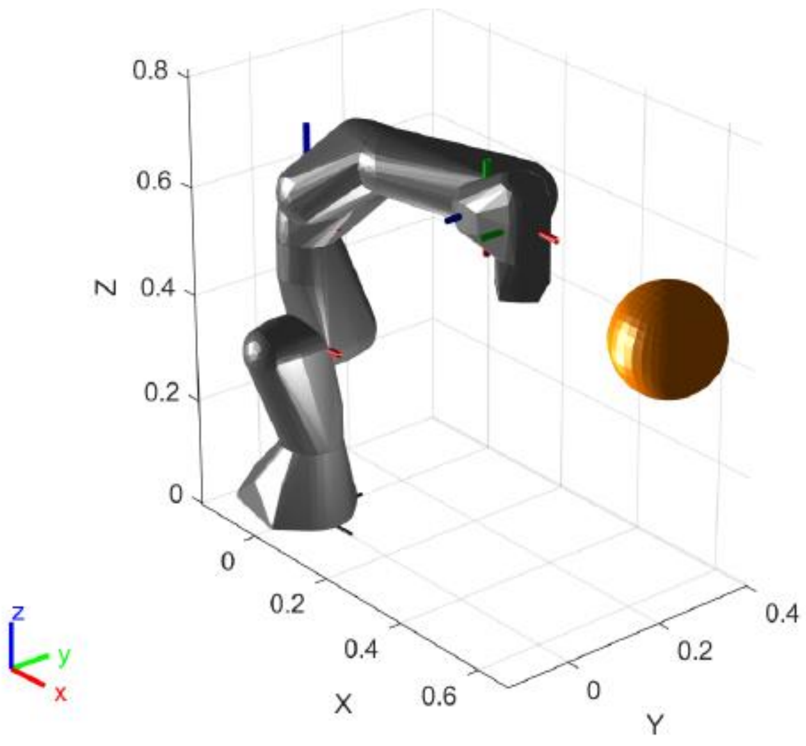
Online obstacle avoidance

- Evaluating position of obstacle

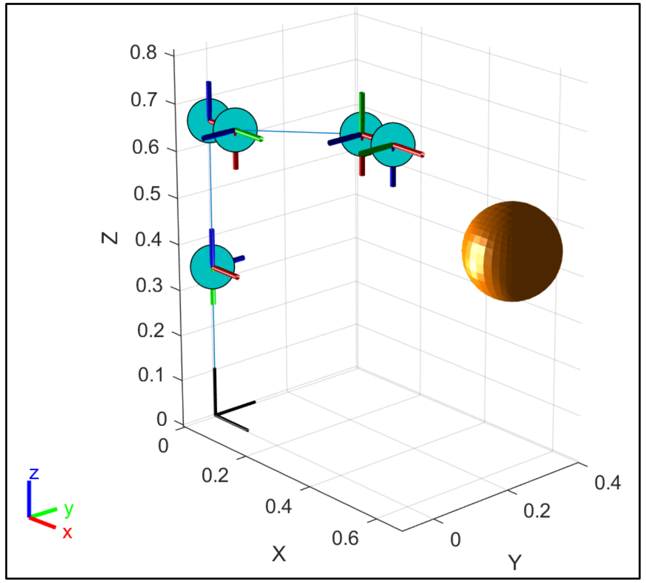


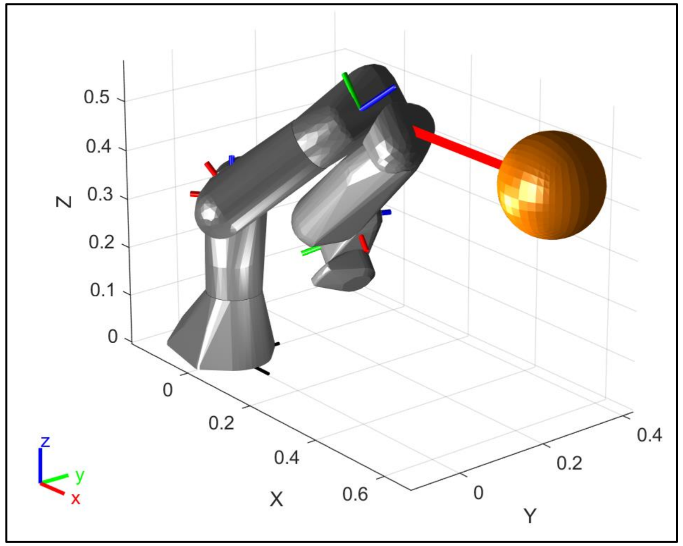
Link Collision Avoidance

- 7-DOF Franka Emika Panda
- Spherical obstacles



Pseudoinverse based Link Collision Avoidance



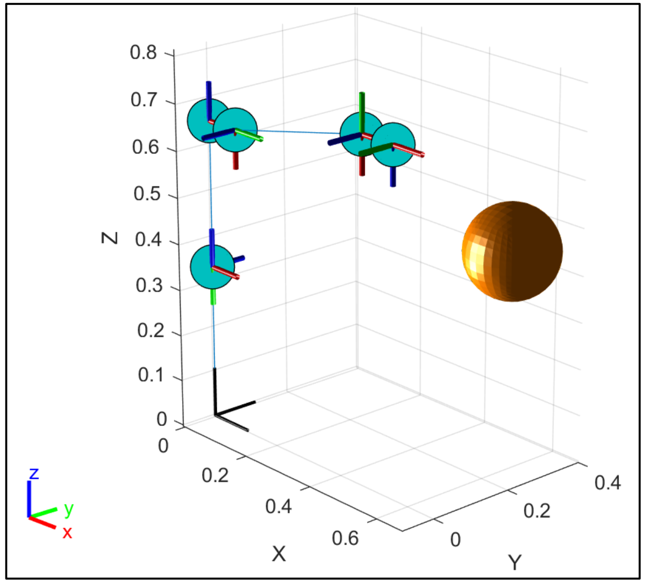


$$\dot{\boldsymbol{x}}_0 = -\gamma_L \nabla U(\boldsymbol{x}_0),$$

$$\nabla_{\boldsymbol{x}} U(\boldsymbol{x}) = \eta \left(\frac{1}{p(\boldsymbol{x})} - \frac{1}{p_0} \right) \left(\frac{-1}{p(\boldsymbol{x})^2} \right) \nabla_{\boldsymbol{x}} p(\boldsymbol{x})$$

[7] Anthony A. Maciejewski and Charles A. Klein. “Obstacle Avoidance for Kinematically Redundant Manipulators in Dynamically Varying Environments”.
[8] Dae-Hyung Park et al. “Movement reproduction and obstacle avoidance with dynamic movement primitives and potential fields”.
[9] Samuel R Buss. “Introduction to Inverse Kinematics with Jacobian Transpose, Pseudoinverse and Damped Least Squares methods”

Pseudoinverse based Link Collision Avoidance



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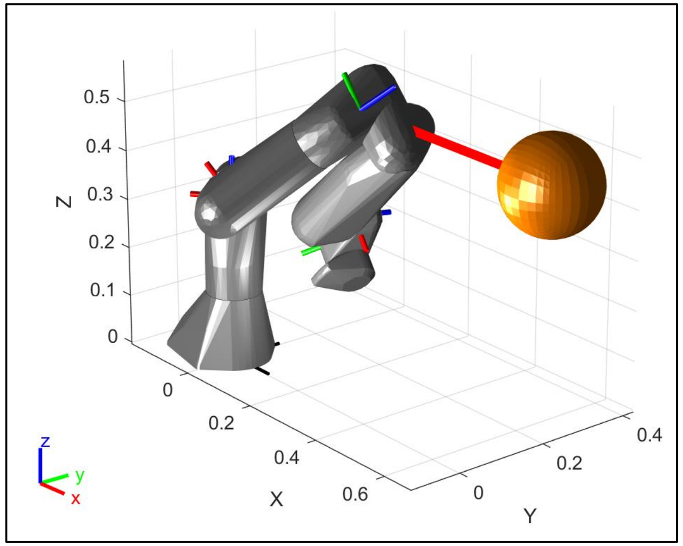
$$\boxed{\dot{q} = \boldsymbol{J}_e^{+} \dot{\boldsymbol{x}}_e + \left(\boldsymbol{I} - \boldsymbol{J}_e^{+} \boldsymbol{J}_e \right) \boldsymbol{\mathcal{E}}}$$



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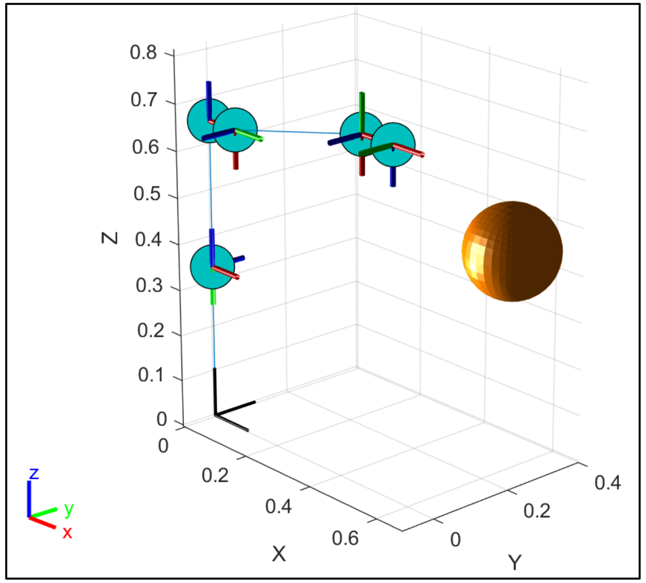
Pseudoinverse based Link Collision Avoidance



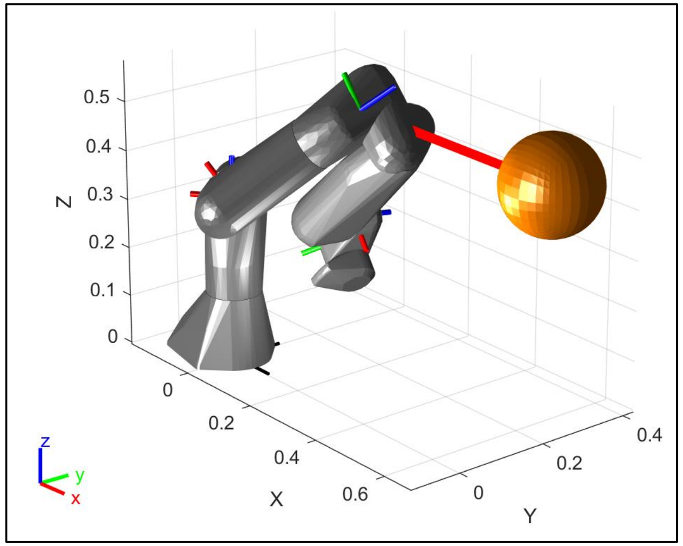
$$\dot{\boldsymbol{x}}_0 = -\gamma_L \nabla U(\boldsymbol{x}_0),$$

$$\nabla_{\boldsymbol{x}} U(\boldsymbol{x}) = \eta \left(\frac{1}{p(\boldsymbol{x})} - \frac{1}{p_0} \right) \left(\frac{-1}{p(\boldsymbol{x})^2} \right) \nabla_{\boldsymbol{x}} p(\boldsymbol{x})$$

$$\dot{q} = J_e^+ \dot{x}_e + \left(I - J_e^+ J_e \right) \mathcal{E}$$

$$\boldsymbol{\mathcal{E}} = \left(J_0 (I - J_e^+ J_e) \right)^+ \left(\dot{x}_0 - J_0 J_e^+ \dot{x}_e \right)$$

$$\dot{q} = J_e^+ \dot{x}_e + \left(J_0 (I - J_e^+ J_e) \right)^+ \left(\dot{x}_0 - J_0 J_e^+ \dot{x}_e \right)$$



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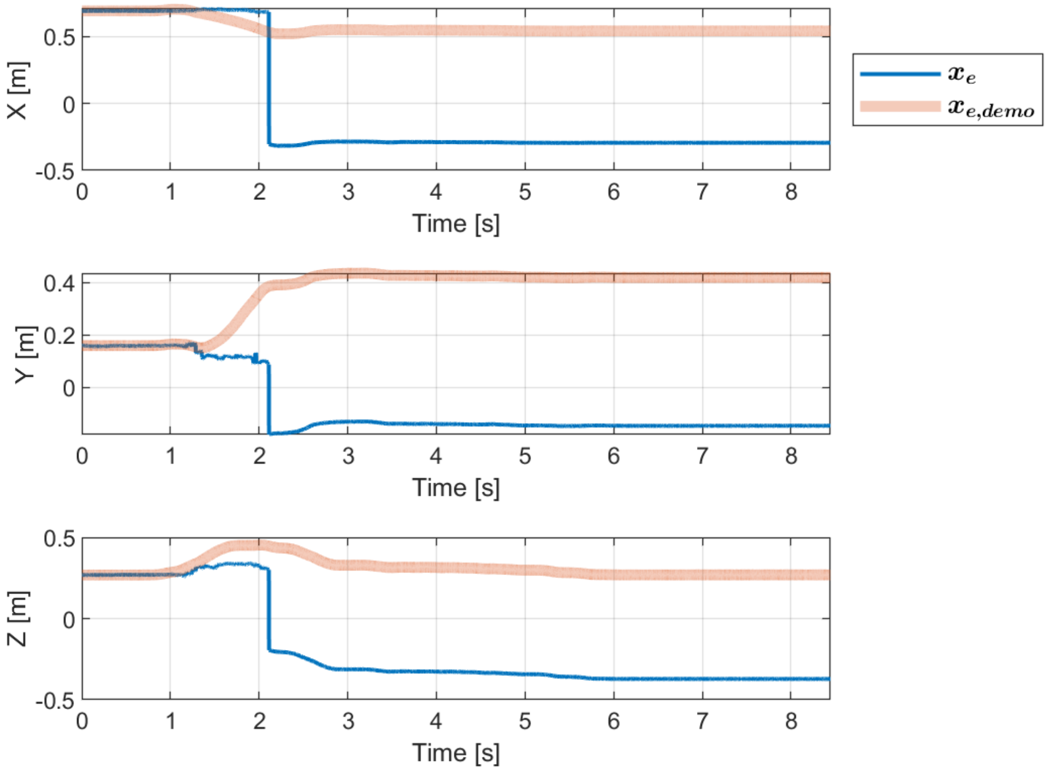
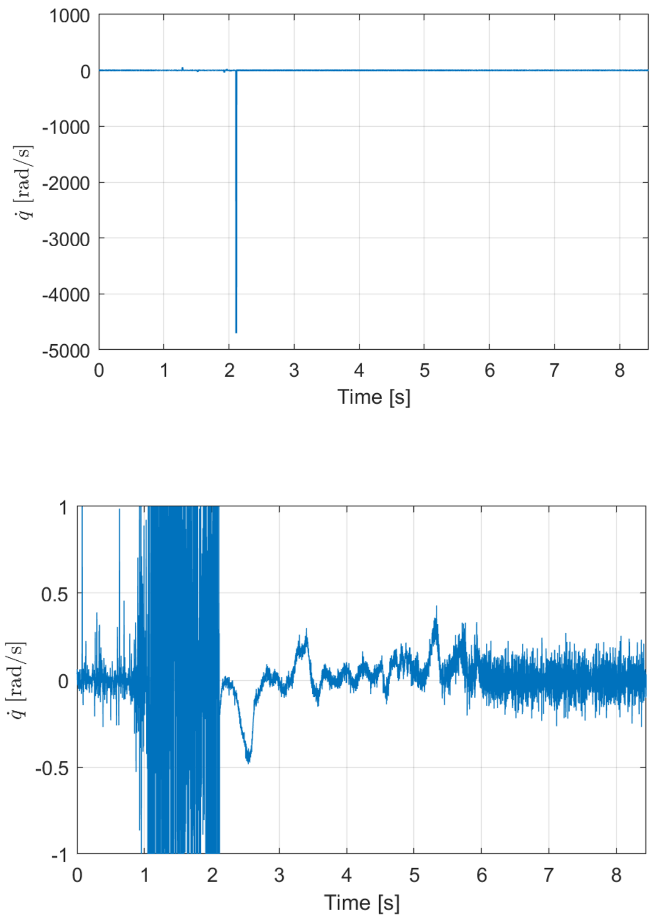
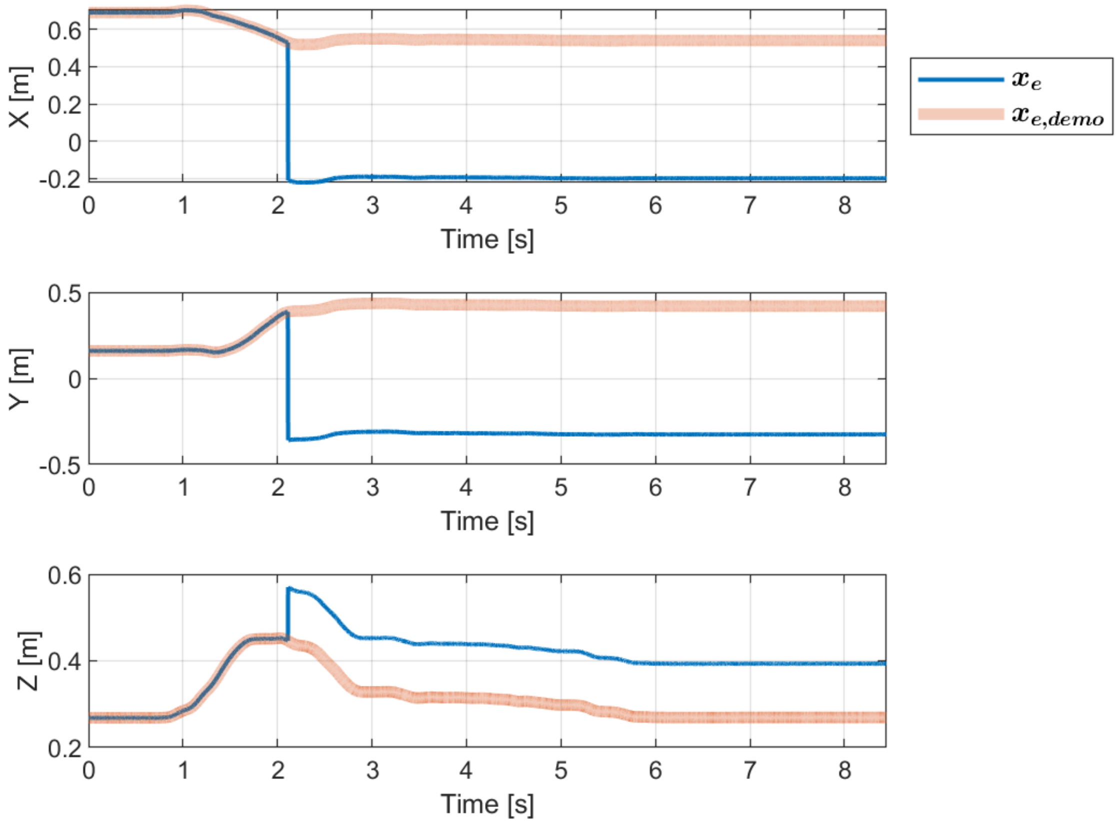
Pseudoinverse based Link Collision Avoidance

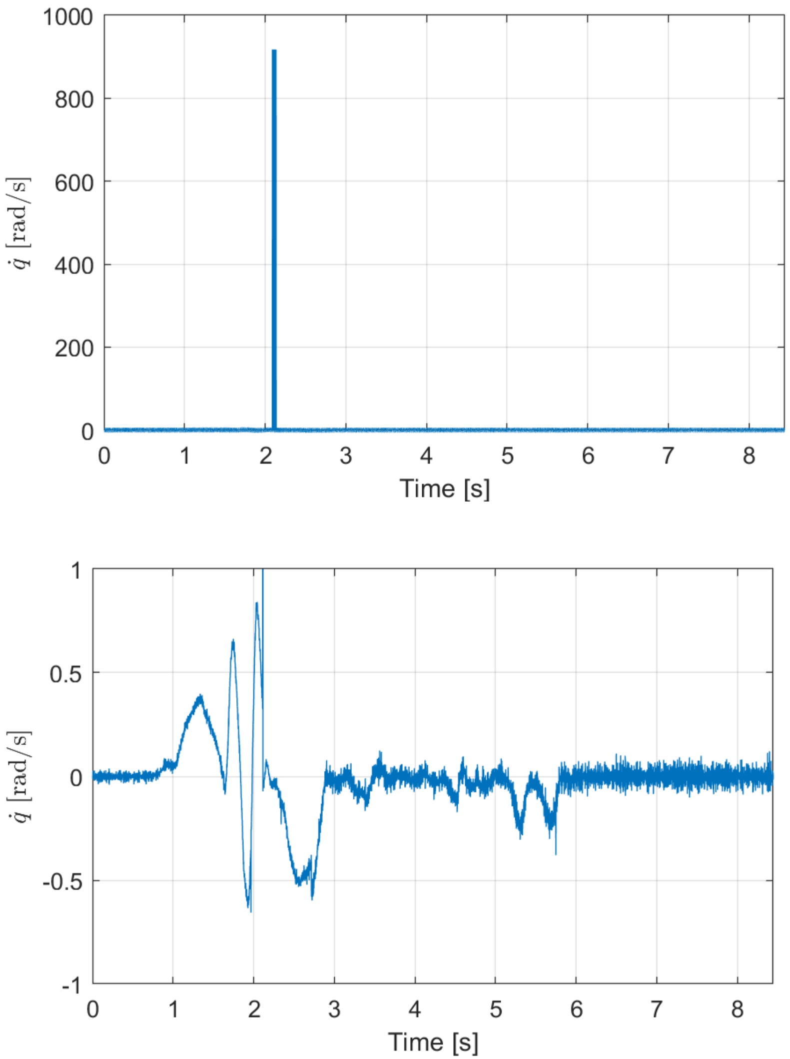




Pseudoinverse based Link Collision Avoidance

Threshold on pseudoinverse





Damped Least Squares based Link Collision Avoidance

$$\min \ f(\dot{\boldsymbol{q}}) = ||\boldsymbol{J}\dot{\boldsymbol{q}} - \dot{\boldsymbol{x}}_e||^2 + \lambda^2||\dot{\boldsymbol{q}}||^2$$

$$\dot{\boldsymbol{q}} = \boldsymbol{J}_e^T \boldsymbol{f}$$

$$(\boldsymbol{J}_e \boldsymbol{J}_e^T + \lambda^2 \boldsymbol{I})\boldsymbol{f} = \dot{\boldsymbol{x}}_e$$

- Combination of the two methods

$$\dot{q} = \boldsymbol{J}_e^T \boldsymbol{f} + \left(\boldsymbol{J}_0(I - \boldsymbol{J}_e^+ \boldsymbol{J}_e)\right)^+ (\dot{x}_0 - \boldsymbol{J}_0 \boldsymbol{J}_e^+ \dot{x}_e)$$

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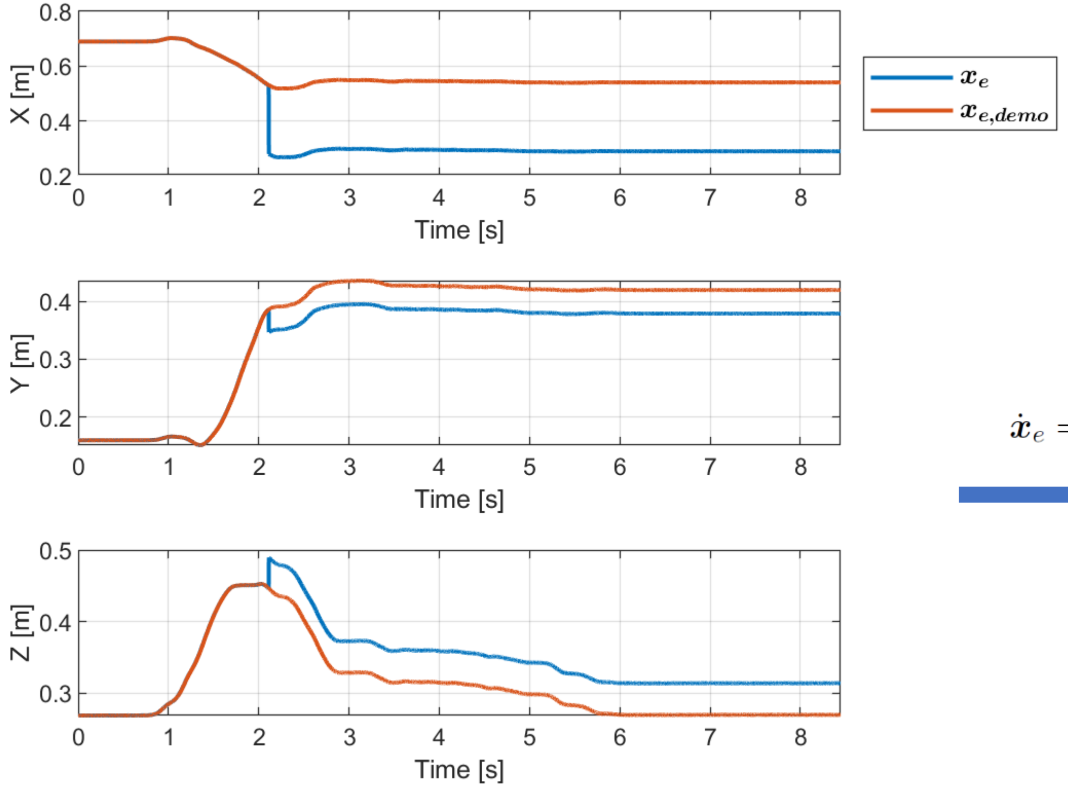
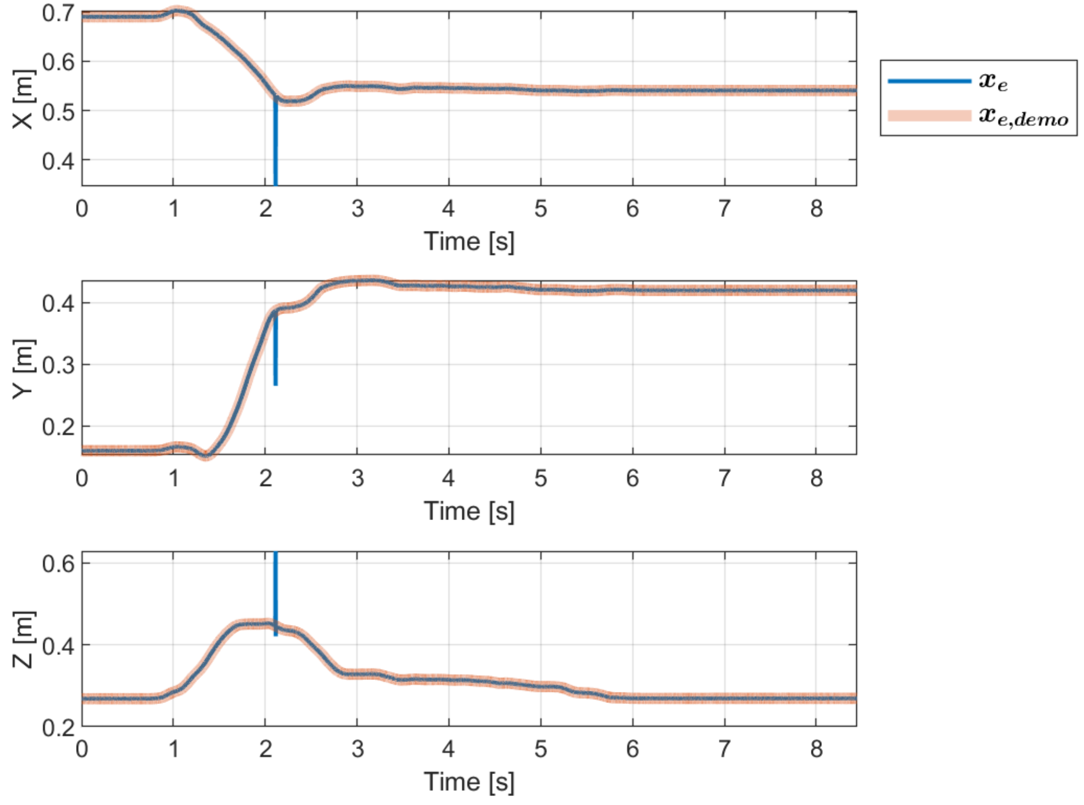
Damped Least Squares based Link Collision Avoidance



$$\dot{x}_e = \frac{x_{e,demo} - x_e}{dt}$$



Damped Least Squares based Link Collision Avoidance

Algorithm 2: Link collision avoidance using IK solved with damped least squares

Requires initialization of: $\boldsymbol{T}$ (trajectory), Δt (time step), $\boldsymbol{q}$ (initial configuration).

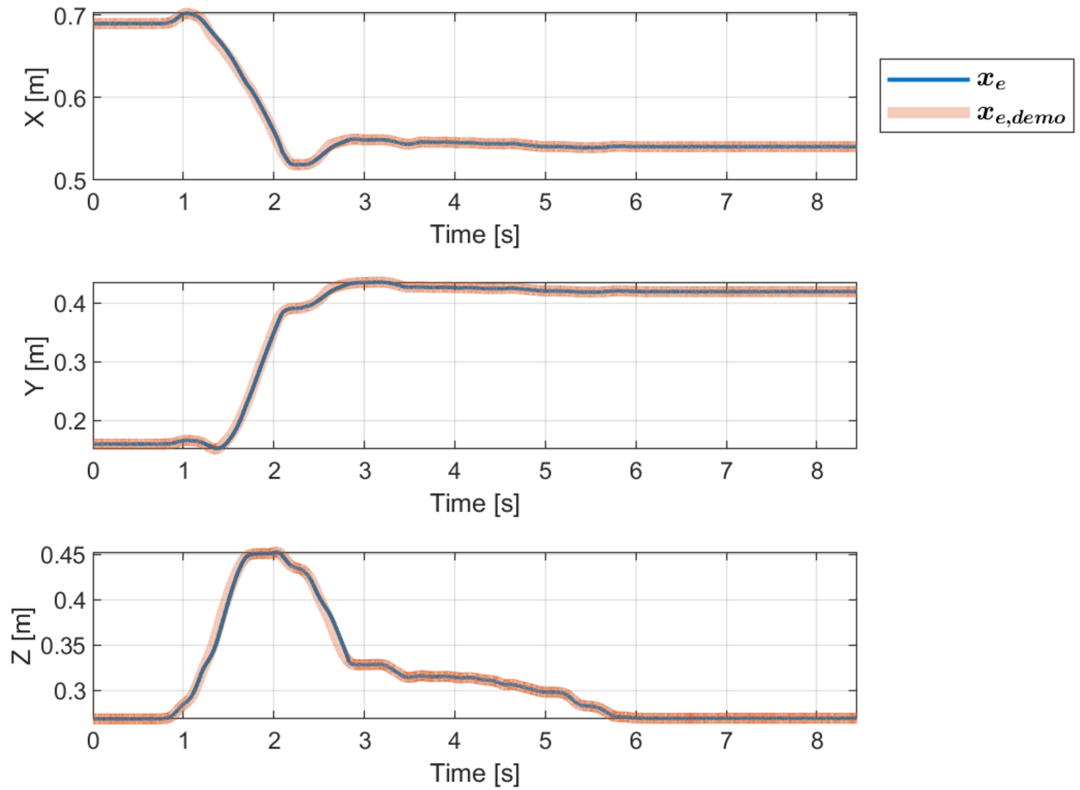
while *points left in* $\boldsymbol{T}$ **do**

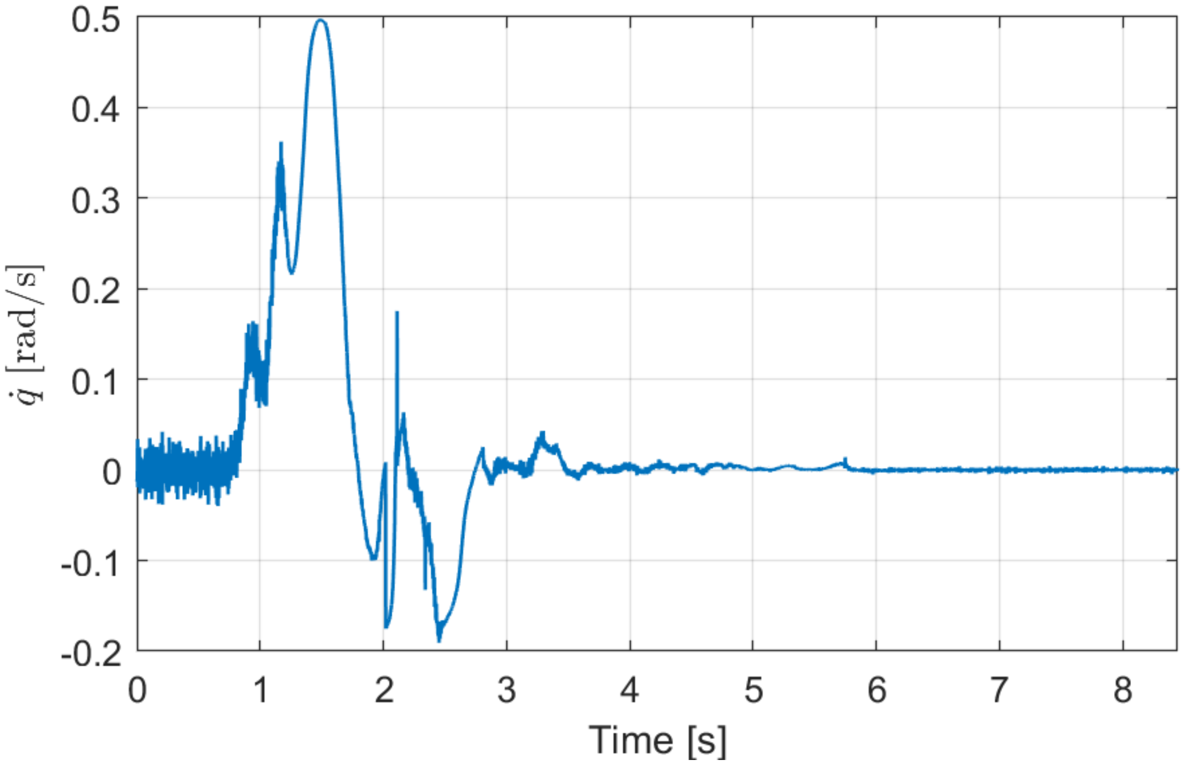
- $\dot{\boldsymbol{x}}_e = \frac{\boldsymbol{T}_{i+1} - \boldsymbol{x}_e}{\Delta t}$
- $\boldsymbol{x}_0 = \arg\min_{\boldsymbol{x}} ||(\boldsymbol{o} - \boldsymbol{x}_i)||^2$ ▷ find point on robot closest to obstacle
- $\dot{\boldsymbol{x}}_0 = -\gamma_L \nabla U(\boldsymbol{x}_0)$
- $\boldsymbol{J}_0 = \text{ComputeJacobian}(\boldsymbol{x}_0)$
- $\boldsymbol{J}_e = \text{ComputeJacobian}(\boldsymbol{x}_e)$
- $\boldsymbol{f} = \text{LinearSolve}\big((\boldsymbol{J}_e \boldsymbol{J}_e^T + \lambda^2 \boldsymbol{I})\boldsymbol{f} = \dot{\boldsymbol{x}}_e\big)$
- $\dot{\boldsymbol{q}} = \boldsymbol{J}_e^T \boldsymbol{f} + \big(\boldsymbol{J}_0(I - \boldsymbol{J}_e^+ \boldsymbol{J}_e)\big)^+ (\dot{\boldsymbol{x}}_0 - \boldsymbol{J}_0 \boldsymbol{J}_e^+ \dot{\boldsymbol{x}}_e)$
- $\dot{\boldsymbol{q}} = \text{ClampAbsMax}(\dot{\boldsymbol{q}},\ 1)$
- $\boldsymbol{q} = \boldsymbol{q} + \dot{\boldsymbol{q}} \Delta t$ ▷ configuration is being updated

end

$$\text{ClampAbsMax}(\dot{\boldsymbol{q}}, d) = \begin{cases} \dot{\boldsymbol{q}}, & ||\dot{\boldsymbol{q}}|| < d \\ d \frac{\dot{\boldsymbol{q}}}{||\dot{\boldsymbol{q}}||}, & \text{otherwise} \end{cases}$$

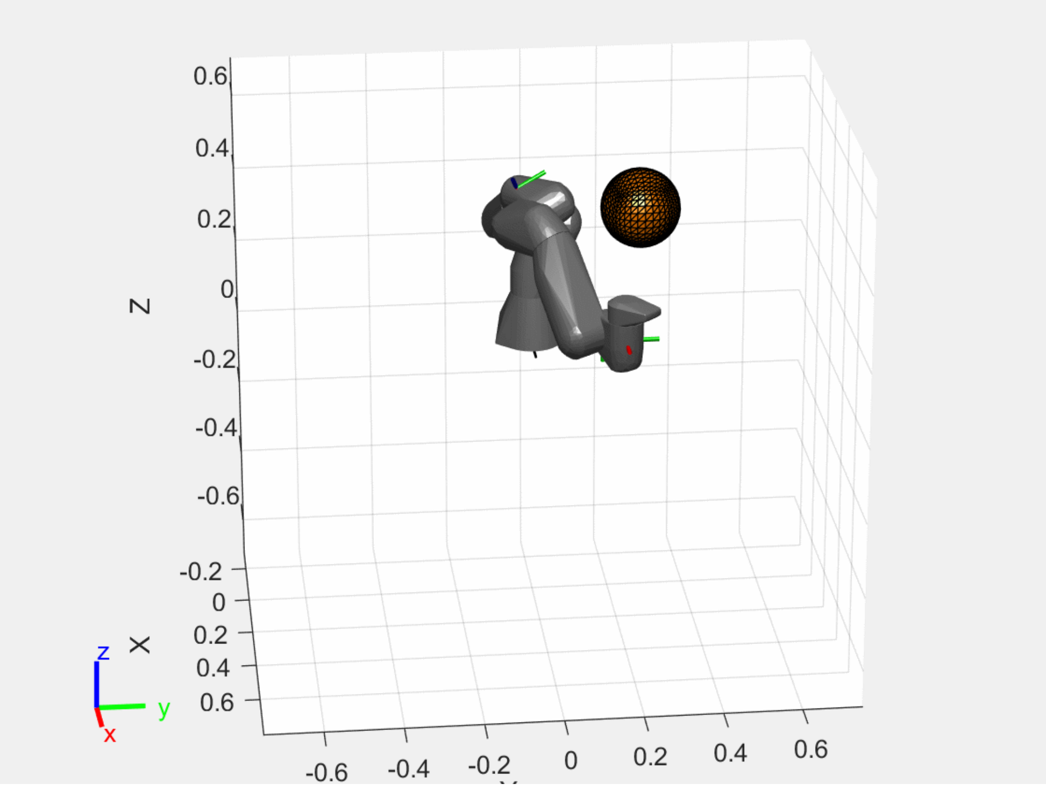
Damped Least Squares based Link Collision Avoidance



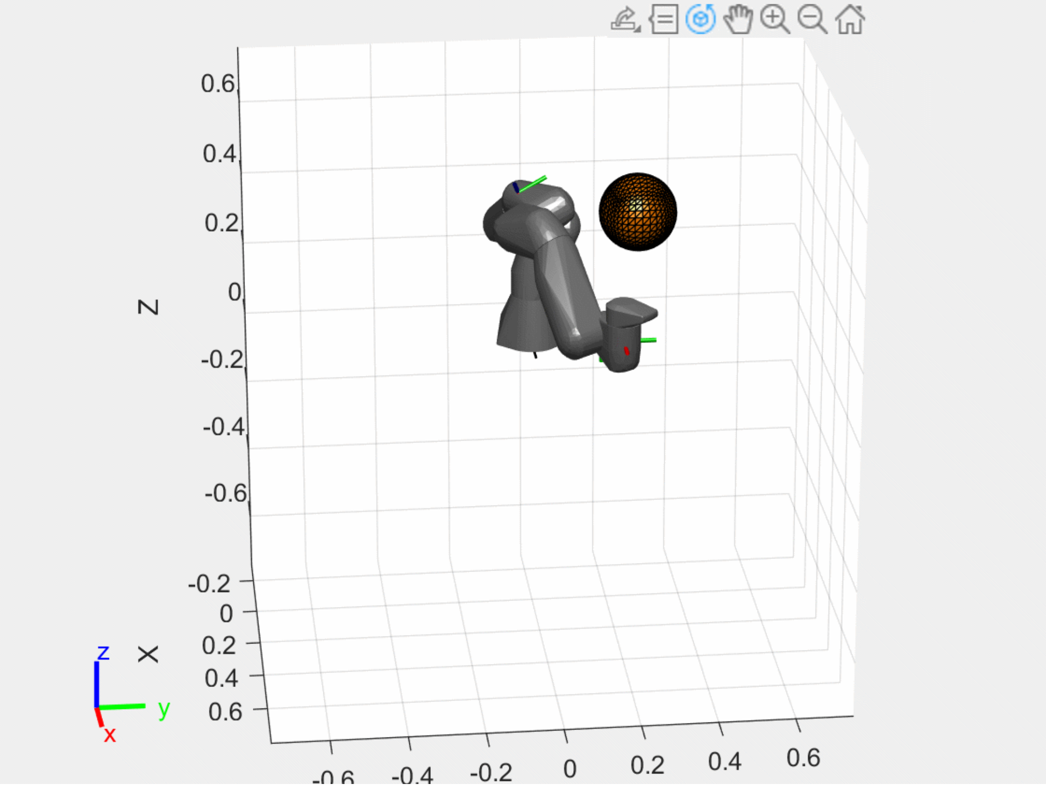


Damped Least Squares based Link Collision Avoidance

$\gamma_L = 0$

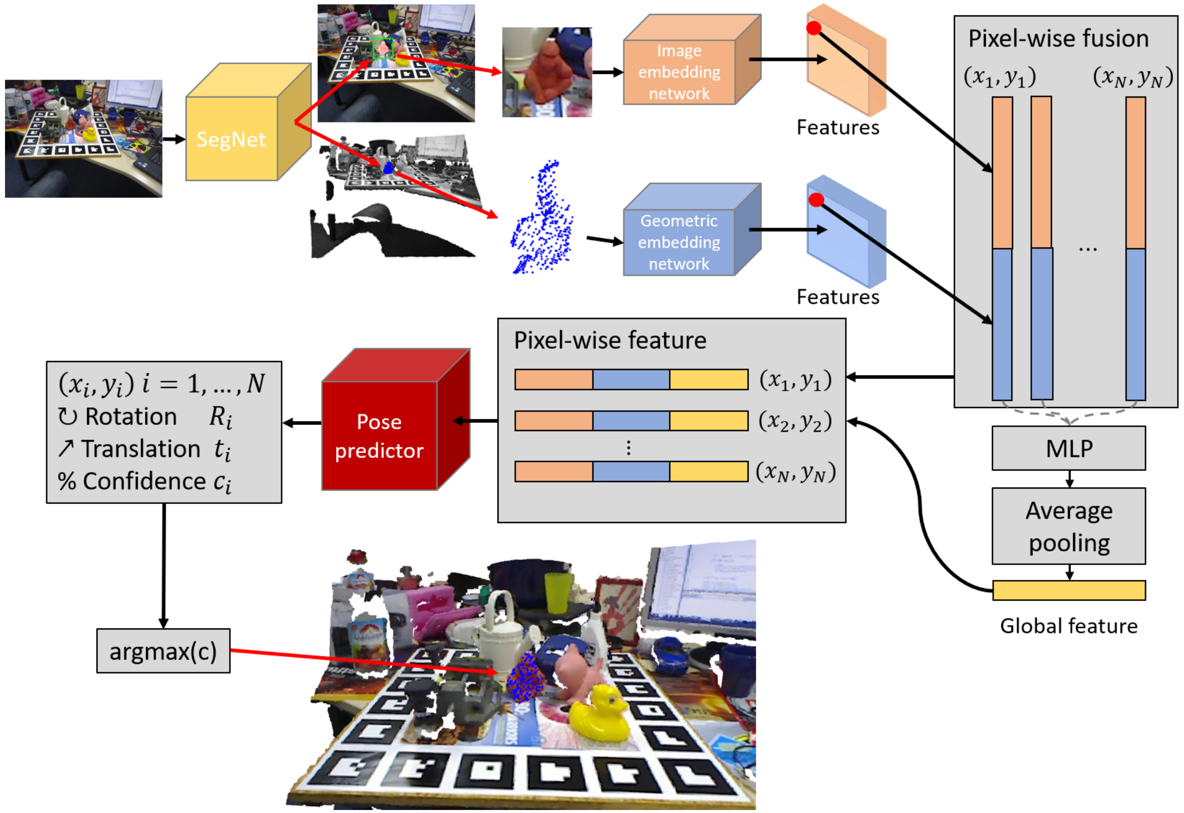


$\gamma_L = 100$



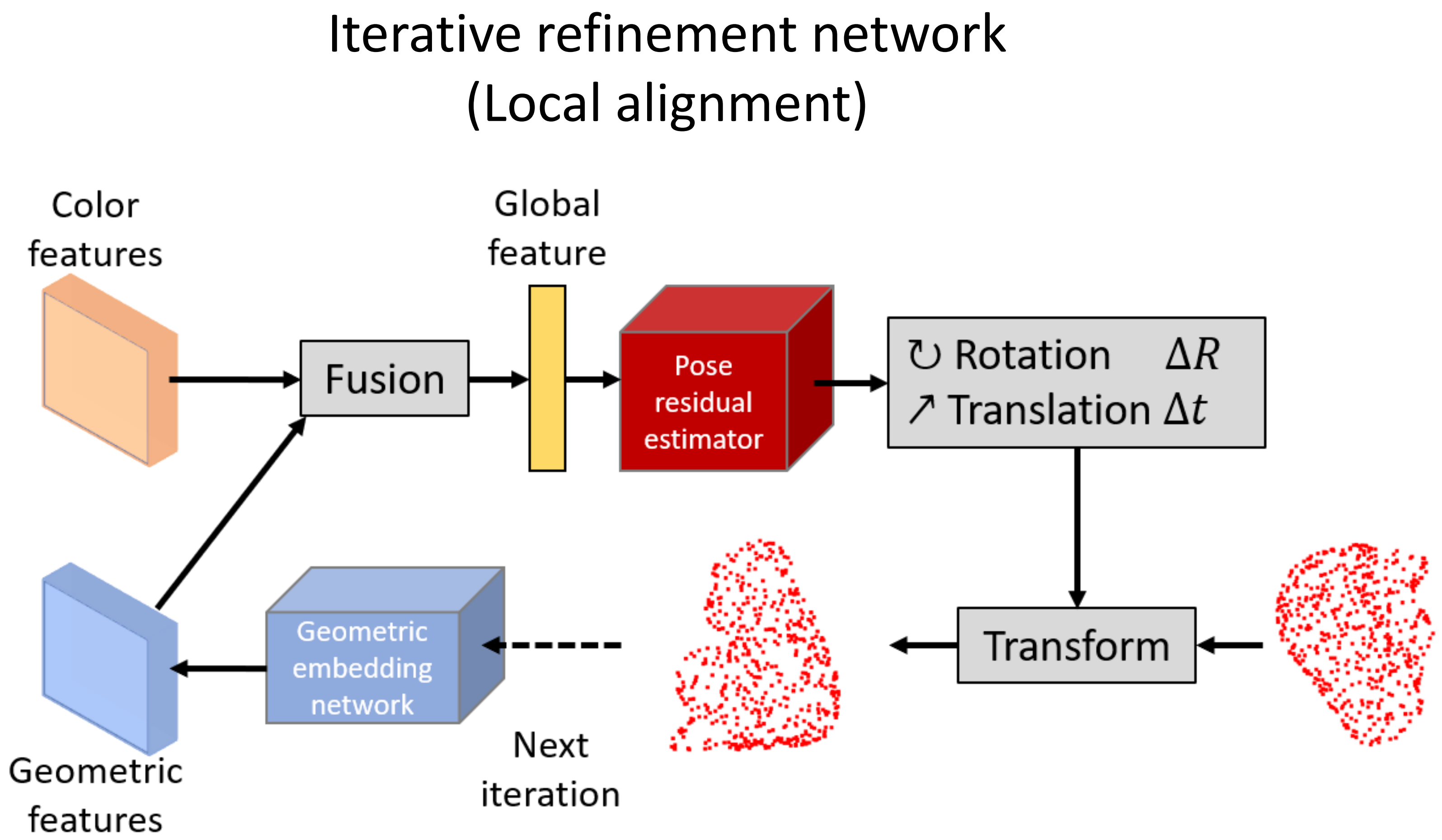
Pose Estimation - Iterative Dense Fusion

Pose predictor network (Global alignment)



[13] Chen Wang et al. “DenseFusion: 6D Object Pose Estimation by Iterative Dense Fusion”.

Pose Estimation - Iterative Dense Fusion

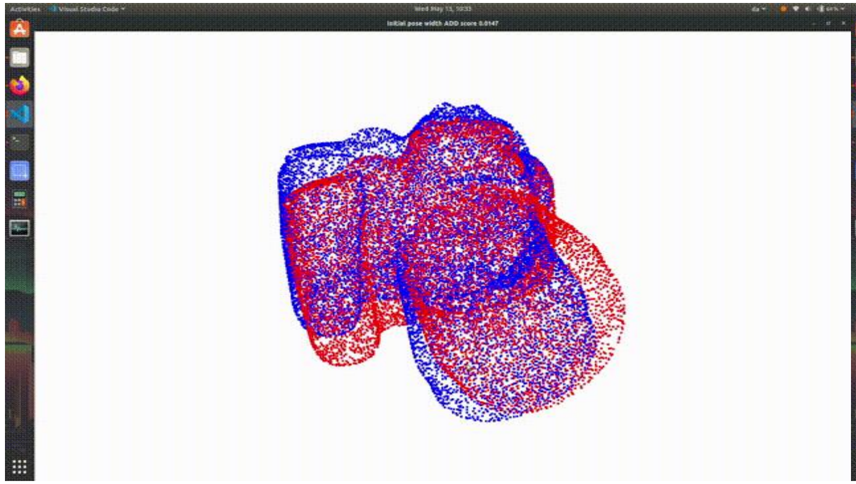


[13] Chen Wang et al. “DenseFusion: 6D Object Pose Estimation by Iterative Dense Fusion”.

Iterative Refinement Network

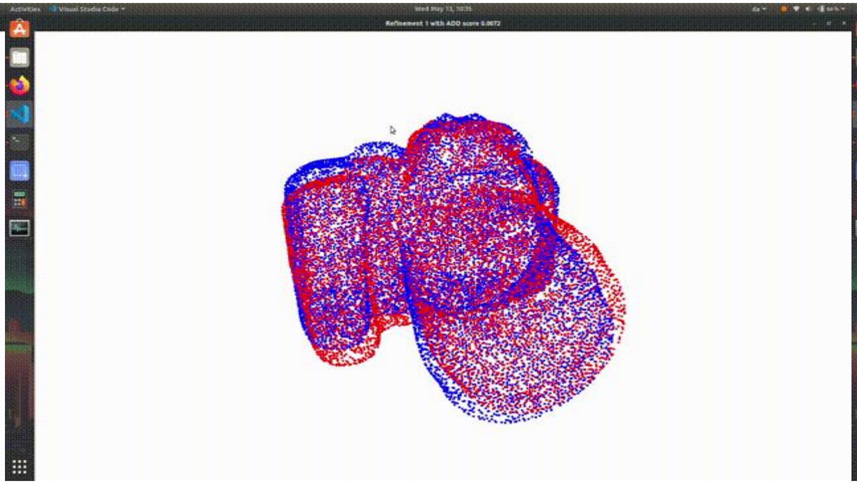
Pose predictor net

ADD score: 0.0147



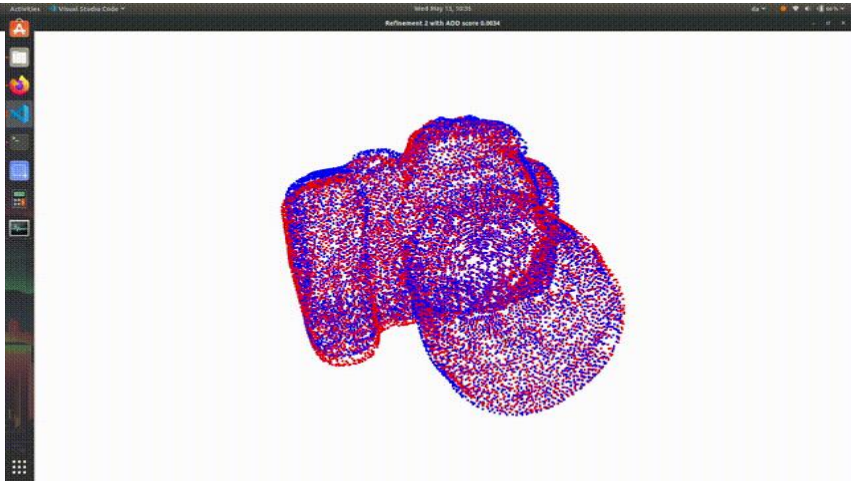
Pose refine net

ADD score: 0.0074



Pose refine net

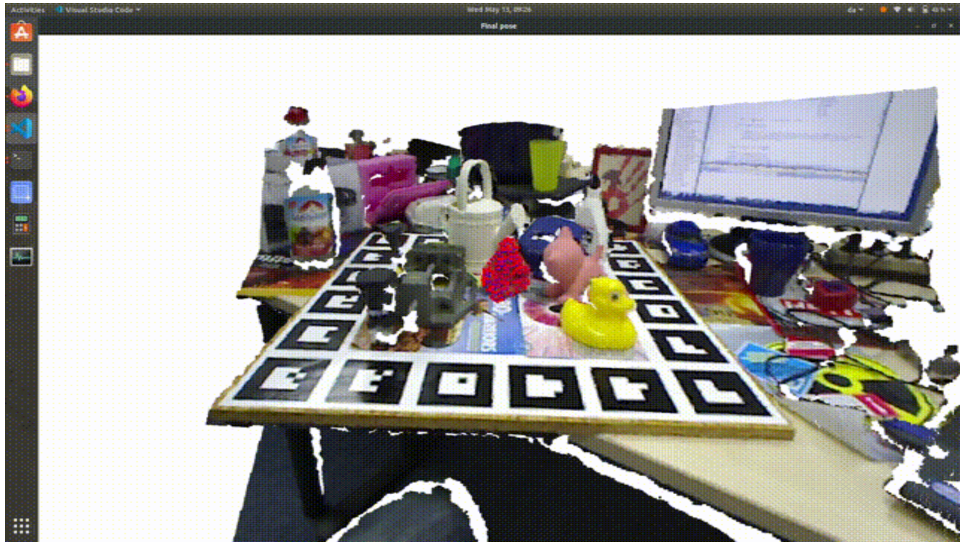
ADD score: 0.0034

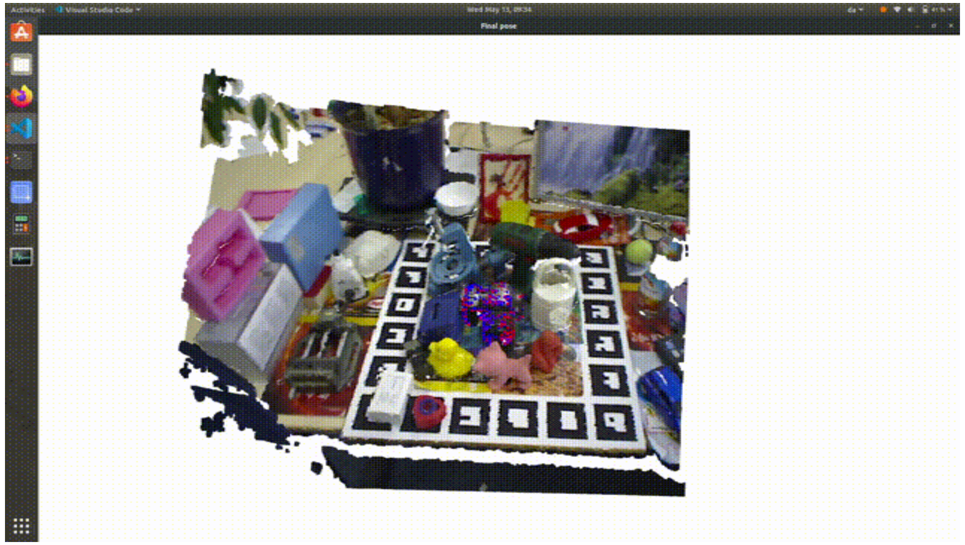


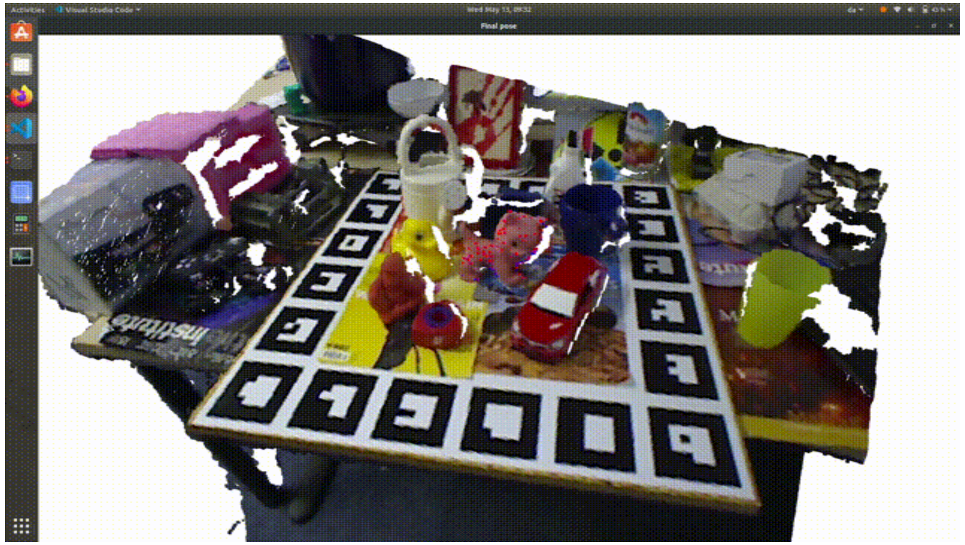
$$ADD\ score = \underset{x \in \mathcal{M}}{\text{average}} \left\| (Rx + T) - (\tilde{R}x + \tilde{T}) \right\|$$

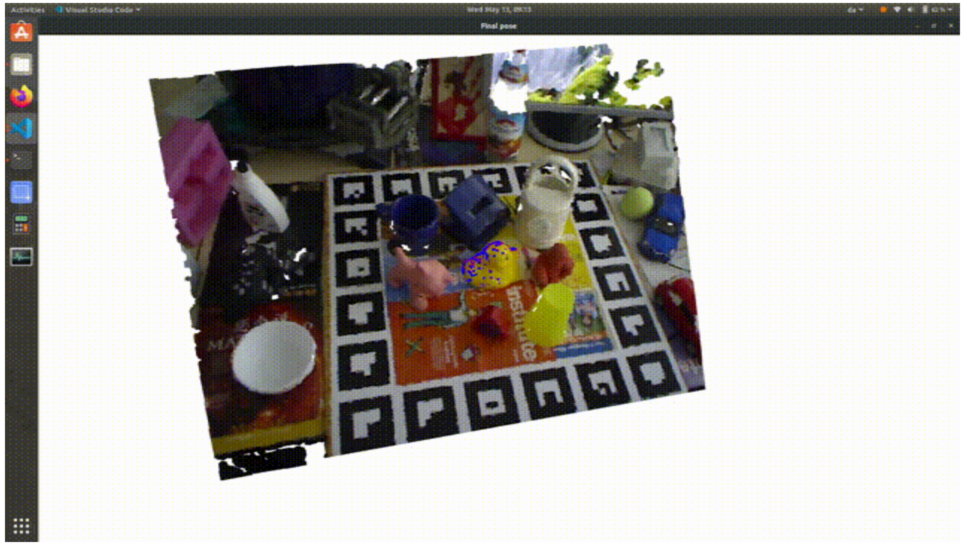
[12] Stefan Hinterstoisser et al. “Model based training, detection and pose estimation of texture-less 3d objects in heavily cluttered scenes”

Visualization of Pose Estimation









Results of DenseFusion vs. 3D-3D

	DenseFusion		3D - 3D	
	Accuracy [%]	ADD/ADD-S [cm]	Accuracy [%]	ADD/ADD-S [cm]
Ape	93.71	0.005(±0.00603)	51.38	0.02457(±0.02217)
Bench vise	94.67	0.00767(±0.0146)	59.94	0.03895(±0.04337)
Can	97.45	0.00638(±0.00928)	44.61	0.04761(±0.04139)
Camera	94.69	0.00675(±0.0143)	52.17	0.04602(±0.04364)
Cat	96.71	0.00468(±0.00852)	57.78	0.02940(±0.03124)
Drill	88.31	0.0143(±0.0263)	65.01	0.03546(±0.04351)
Duck	93.90	0.00629(±0.0191)	46.49	0.02989(±0.03083)
Eggbox	99.81	0.00763(±0.0011)	99.81	0.00744(±0.002588)
Glue	99.81	0.00481(±0.00192)	99.90	0.00611(±0.002708)
Hole pouncher	94.01	0.00683(±0.0102)	37.68	0.04104(±0.03168)
Iron	98.47	0.00651(±0.0111)	41.47	0.07298(±0.05758)
Lamp	97.02	0.00638(±0.0143)	66.41	0.03337(±0.04200)
Phone	96.35	0.00693(±0.0121)	73.97	0.02137(±0.02907)
All	95.76	0.00693(±0.0133)	61.28	0.03510(±0.03240)

References

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