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Industrobot4.0

Pick and Place robot for Material Handling

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Agenda

1. Motivation and Task Definition
2. Literature Review
3. Object Detection and Sorting
4. Computed Feedforward Controller
5. PD controller with Gravity Compensation
6. Inverse Dynamics Control
7. Discussion and Conclusions
8. Q&A

Motivation and Task Definition

Motivation

- Material handling/manipulation is a routine task in every industry, esp. e-commerce and manufacturing due to staffing issues.
- The global pick-n-place robot market was valued at USD 148.1 million in 2020 and it is expected to reach USD 2870.13 million by 2026 [7].

Objectives of controller design (KPI)

- Cycle Time < 10 sec (sort frequency)
- Torque i/p - 75% of Max Torques
- Error (Joint position) < 5°
- Velocity of Conveyor = 0.3 m/s

Task Definition

Phase 1 - Object Interception Trajectory

↓

Phase 2 - Trajectory Tracking

↓

Phase 3 - Object Placement Trajectory

Joint N°	1	2	3	4	5	6
τ_{max} (N m)	97.6	186.4	89.4	24.2	20.1	21.3

Figure 1: Max Joint Torques

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https://www.mordorintelligence.com/industry-reports/piece-picking-robots-market

Literature Review

Dynamics and Modelling Assumptions

Robot - Unimation Puma 560 [2]

Dynamics Equations - Inertia, Coriolis, Centrifugal, Gravity [3]

The first 3 axis provide position whereas the next 3 provide orientation. Moment of Inertia (M.o.I) is comparatively higher and hence control effort focuses on first 3. [3]

Uses Explicit Dynamics for simulation.

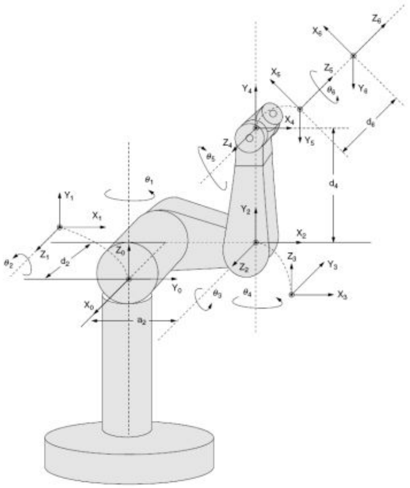

Figure 2: Puma 560

Modified D-H frame notation for a six degrees of freedom PUMA 560 robot manipulator[3]

	Joint 1	Joint 2	Joint 3	Joint 4	Joint 5	Joint 6
Gear Ratio	62.61	107.36	53.69	76.01	71.91	76.73
Maximum Torque (N-m)	97.6	186.4	89.4	24.2	20.1	21.3
Break Away Torque (N-m)	6.3	5.5	2.6	1.3	1.0	1.2

Figure 3: Motor and Drive Parameters [3]

Object Detection and Sorting

Actual Conveyor

Simulated Conveyor

Parameters

Random Parameters:
Shape, Size, Colour

Set Parameters
Speed, Width, Time Step

Single frame

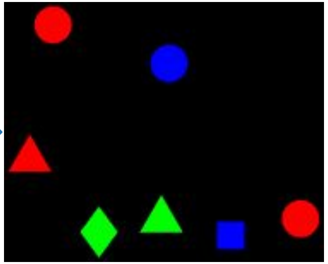

Figure 4: Flowchart

RGB Channel Separation

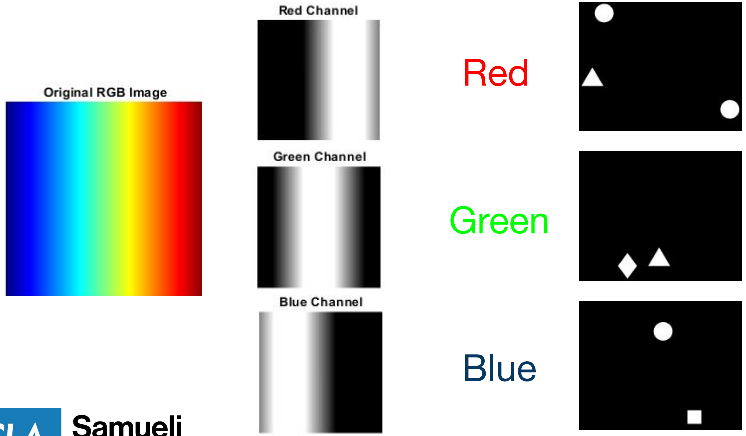

Figure 5: RGB Layers

MATLAB Image Processing Toolbox

1. ***imfindcircles***
   - Circular Hough Transform
   - Centre, Radii, No. of Circles

2. ***bwlabel***
   - Circularity R= 4*pi*A/P^2
   - Blob Perimeter, Area, Location, Circularity

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https://www.videvo.net/video/electric-waste-on-conveyor-belt-1/2200/
https://www.mathworks.com/help/images/display-separated-color-channels-of-rgb-image.html

Computed Torque Controller

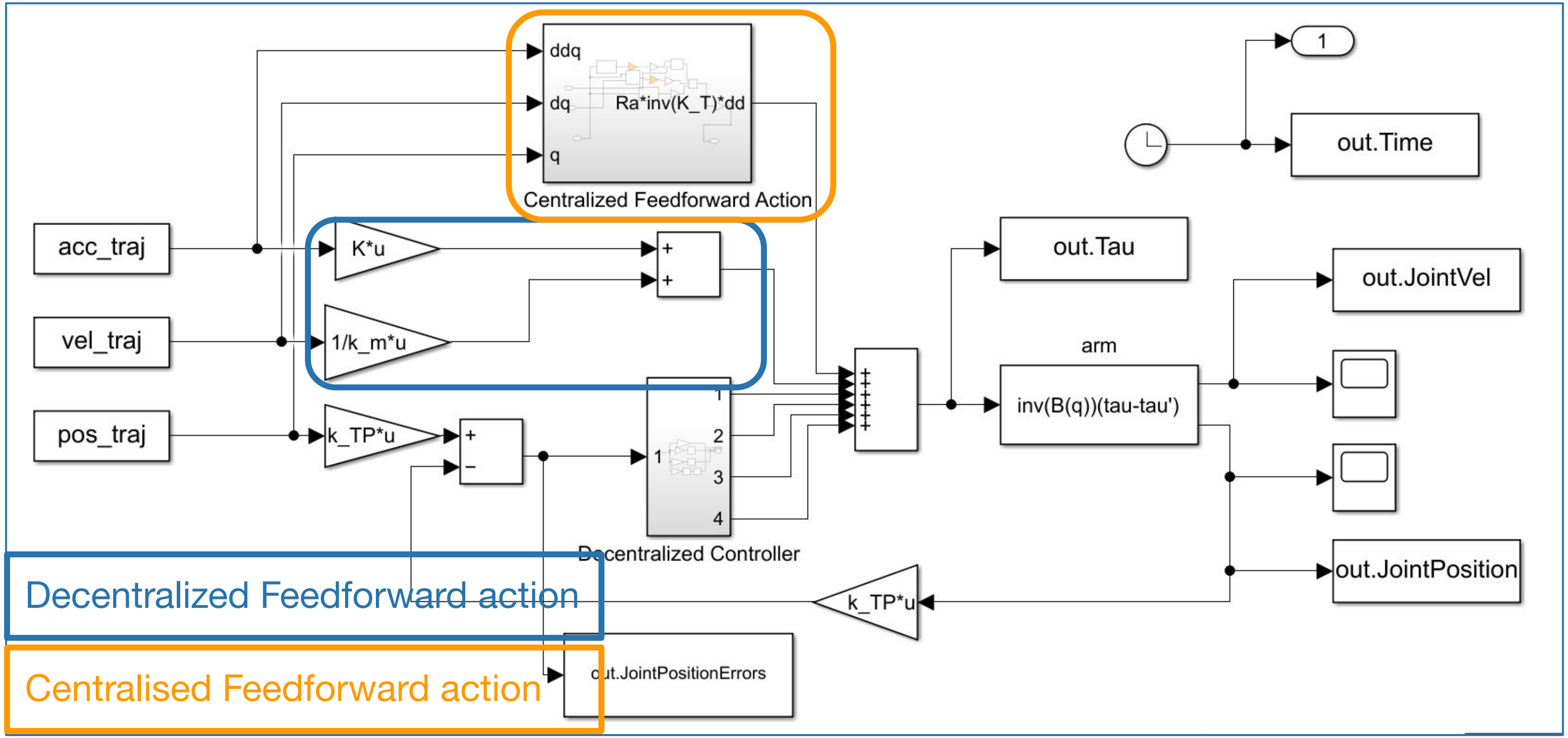

Figure 6: Computed Torque Control

Bruno Siciliano, et al. 2010. Robotics: Modelling, Planning and Control. Springer Publishing

Computed Torque Controller

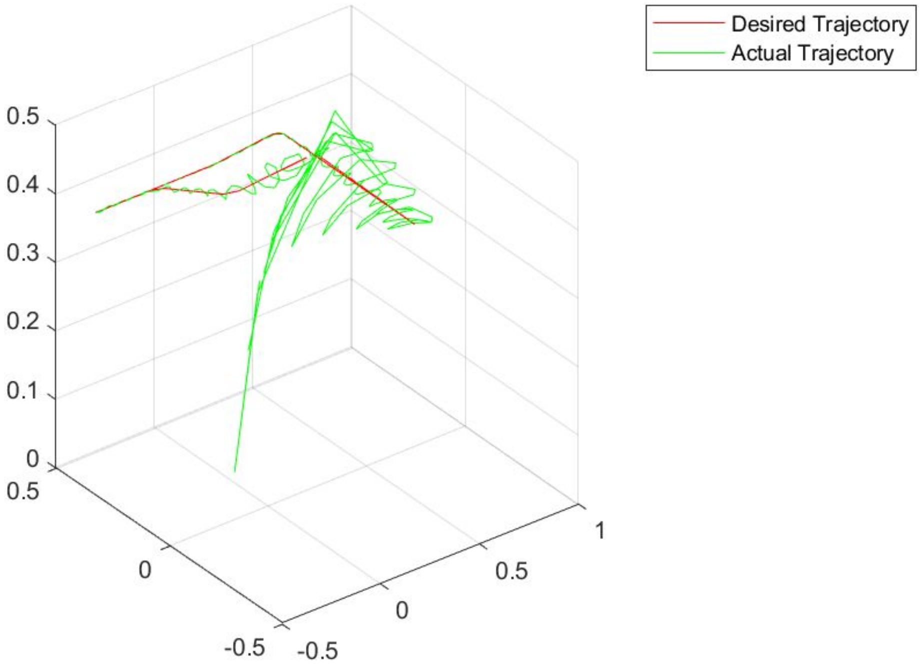

Figure 7: End Effector - Desired vs Actual Trajectory

- Decentralized controller does not consider dynamic coupling of links.
- The calculation of feedforward compensation is not able to account for couplings between the links thus accounting for very high error.
- The speeds are quite high, and hence the controller failed.

Initial - $K_p = 200*I_{6x6}$; $K_d = 50*I_{6x6}$

Final - $K_p = 280*I_{6x6}$; $K_d = 70*I_{6x6}$

PD control with Gravity Compensation

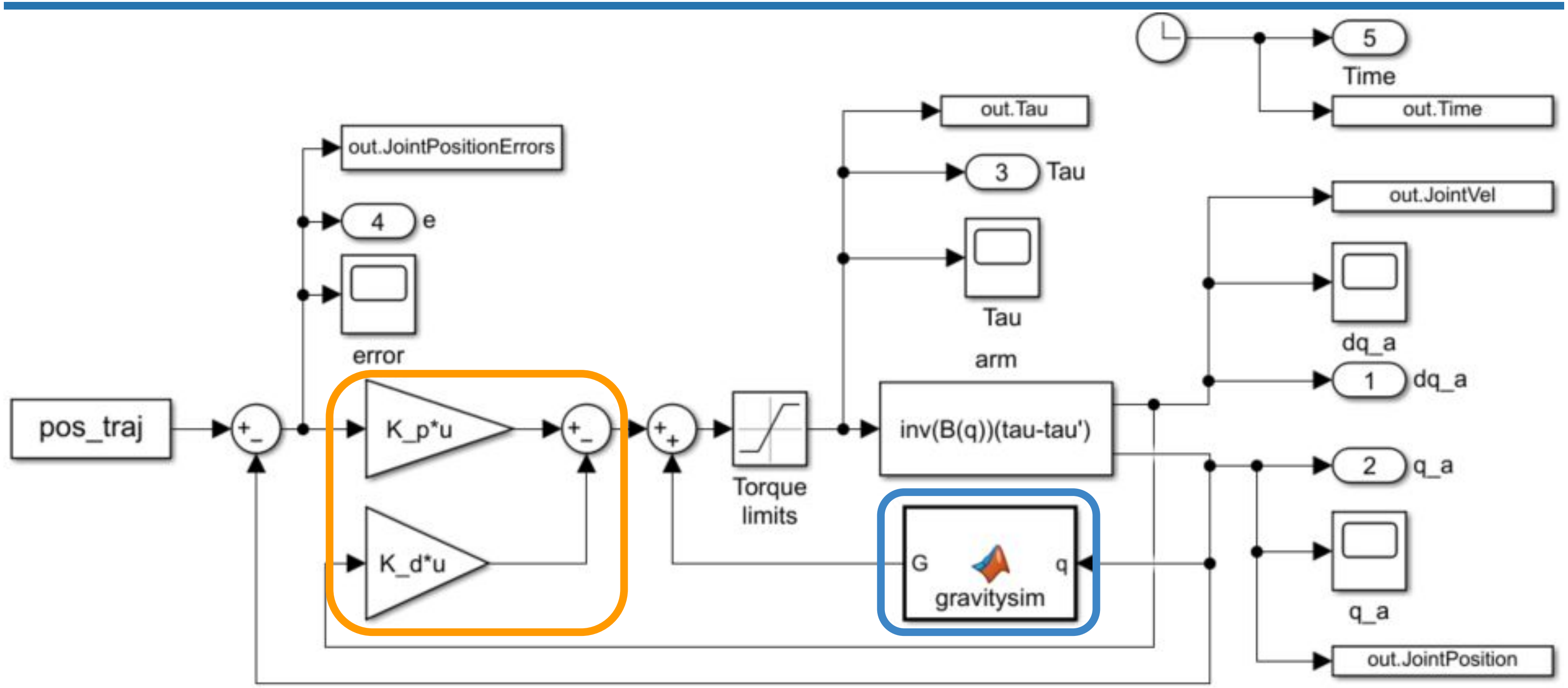

Figure 8: PD Control with Gravity Comp.

$$\underbrace{u = g(q)}_{\text{Nonlinear gravity compensation}} + \underbrace{K_P \tilde{q} - K_D \dot{q}}_{\text{Linear PD action}},$$

Nonlinear gravity compensation

Linear PD action

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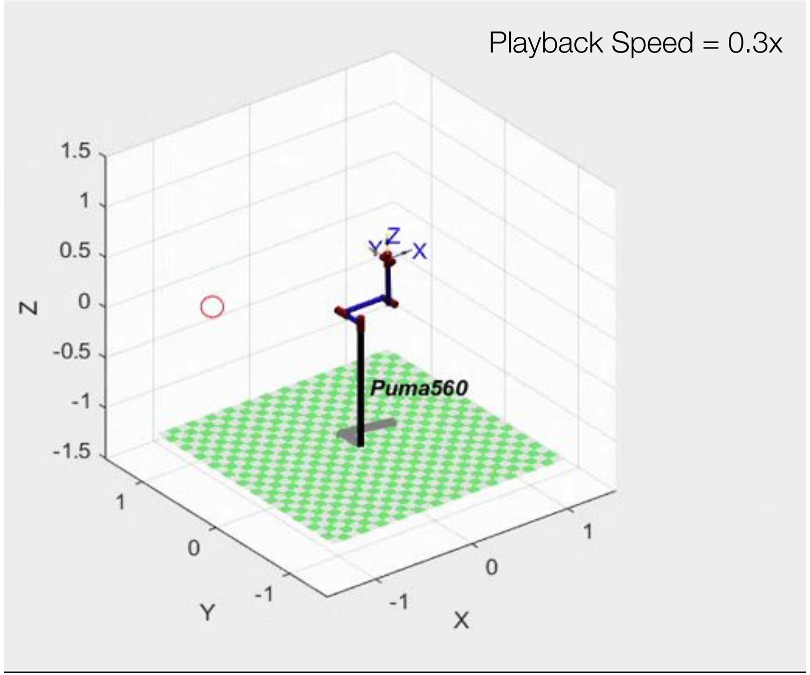
Bruno Siciliano, et al. 2010. Robotics: Modelling, Planning and Control. Springer Publishing

PD control with Gravity Compensation



Video 1: Trajectory Tracking

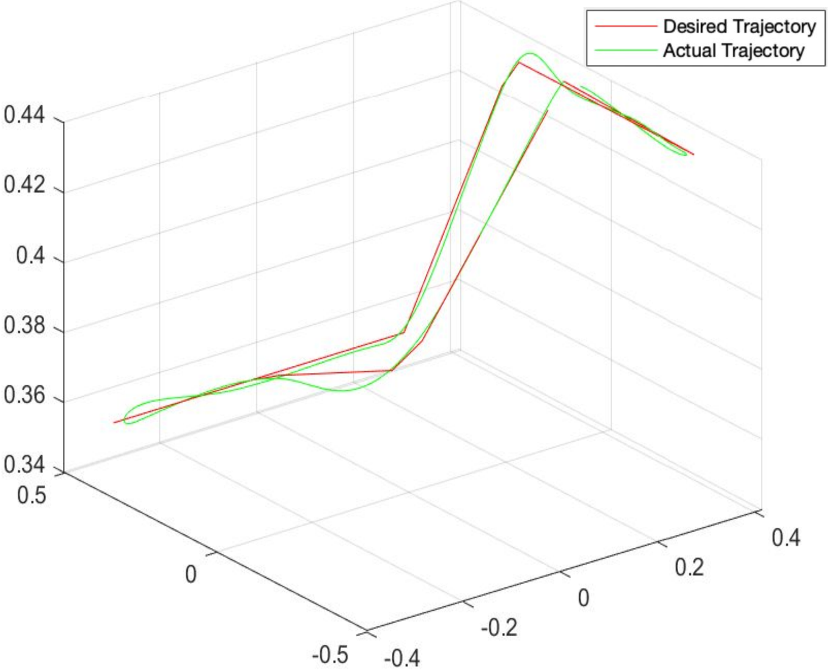


Figure 9: End Effector - Desired vs Actual Trajectory

PD control with Gravity Compensation

Controller Design

- Assumption: Speeds very low i.e. $\dot{q} \sim 0$ for global asymptotic stability for any Kp & Kd.
- Simulation: $\dot{q} \neq 0$ so errors expected
- Result: Max error ~10 degree, moderate error but not suitable for pick and place.
- Advantages:
  - Computationally inexpensive.
  - Great for low speeds.
  - Will always converge

Initial - $K_p = 200*I_{6x6}$; $K_d = 40*I_{6x6}$

Final - $K_p = 150*I_{6x6}$; $K_d = 30*I_{6x6}$

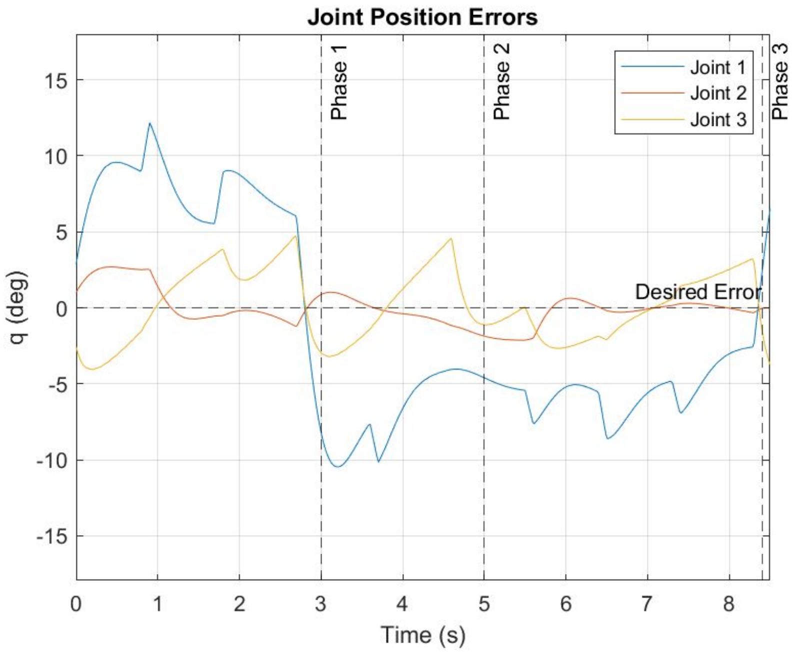


Figure 10: Joint Position Errors

PD control with Gravity Compensation

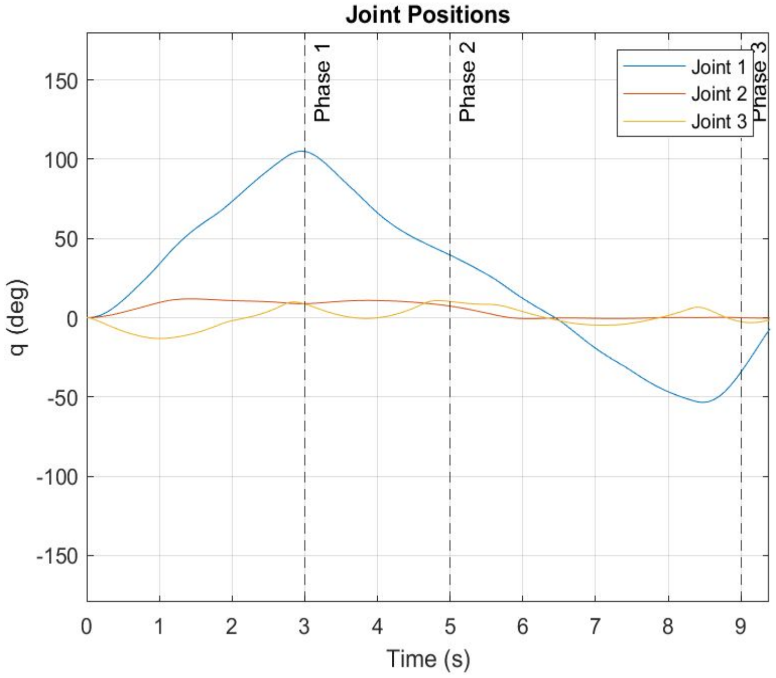


Figure 11: Joint Positions

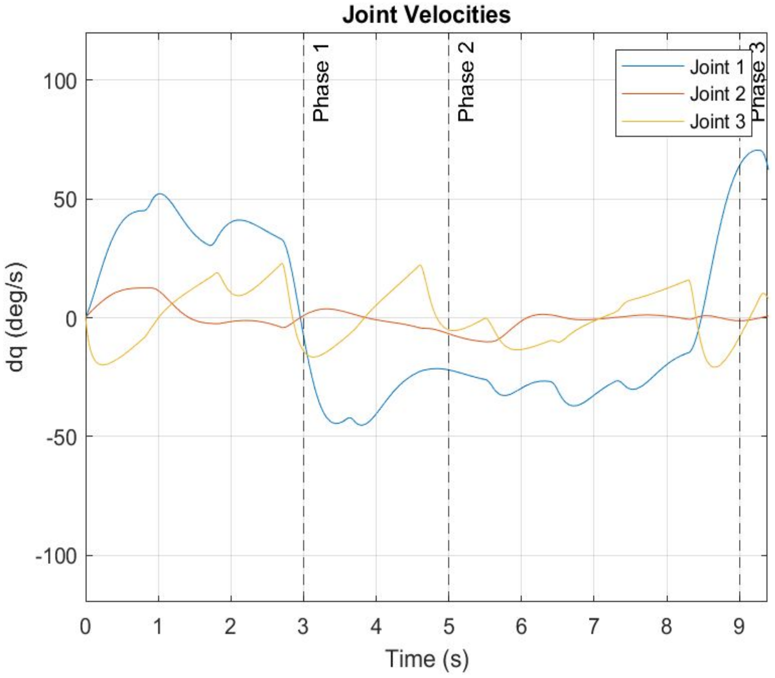
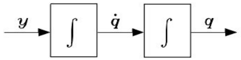


Figure 12: Joint Velocities

Inverse Dynamics Control



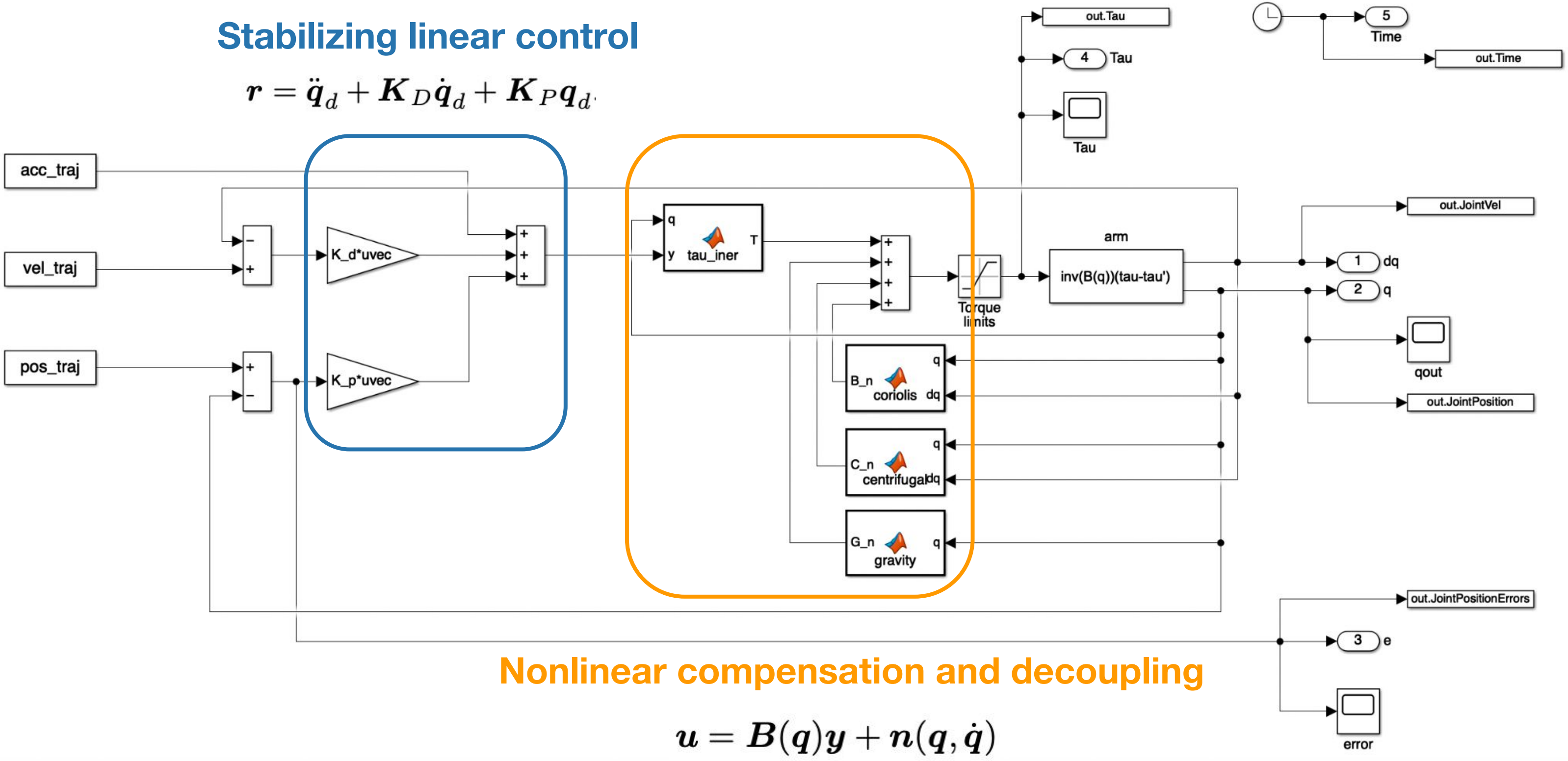
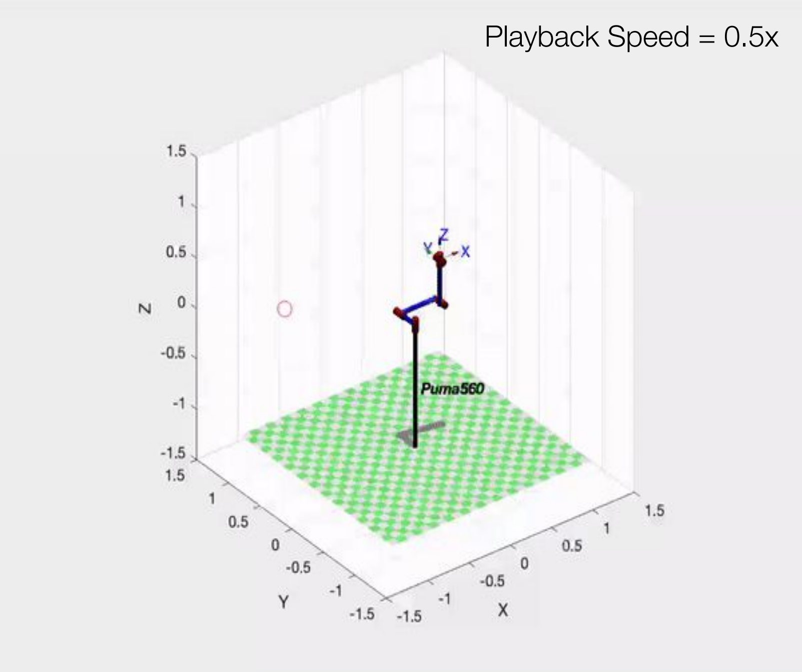


Figure 13: Inverse Dynamics Control

Bruno Siciliano, et al. 2010. Robotics: Modelling, Planning and Control. Springer Publishing

Inverse Dynamics Controller



Video 2: Trajectory Tracking

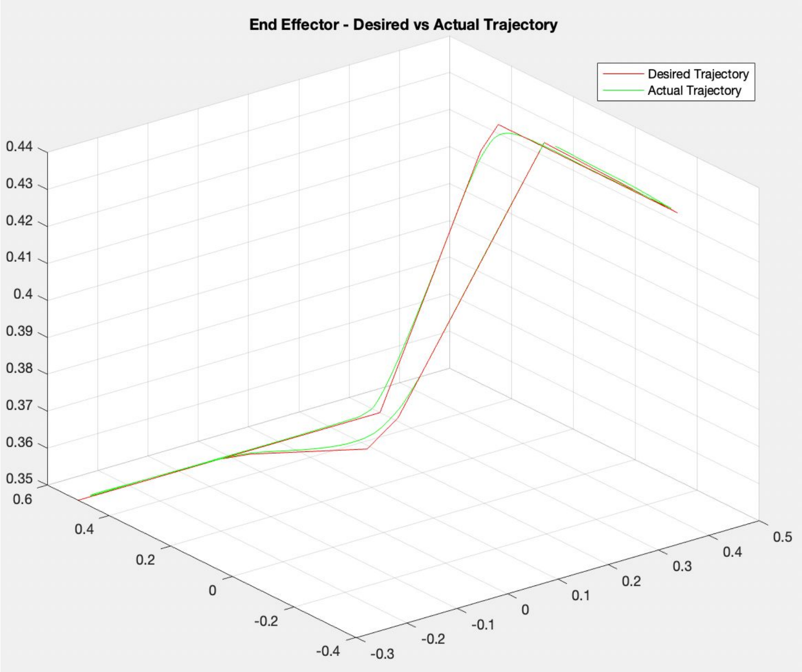


Figure 14: End Effector - Desired vs Actual Trajectory

Inverse Dynamics Controller

Controller Design

Trial 1 - $K_p = 150*I_{6x6}$; $K_d = 25*I_{6x6}$

Trial 2 - $K_p = 1200*I_{6x6}$; $K_d = 100*I_{6x6}$

Final Design - $\mathbf{K_p = 200*I_{6x6}}$ **;** $\mathbf{K_d = 40*I_{6x6}}$

Result - Max error < 3.5° (Joint 1)

Challenges

- Accuracy of parameters of the system dynamic model
- Online computation

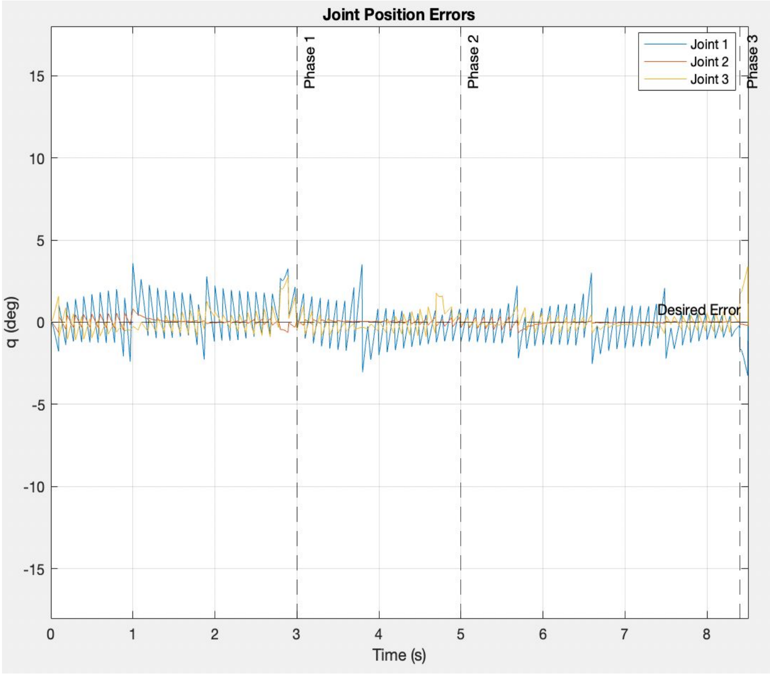


Figure 15: Joint Position Errors

Inverse Dynamics Controller

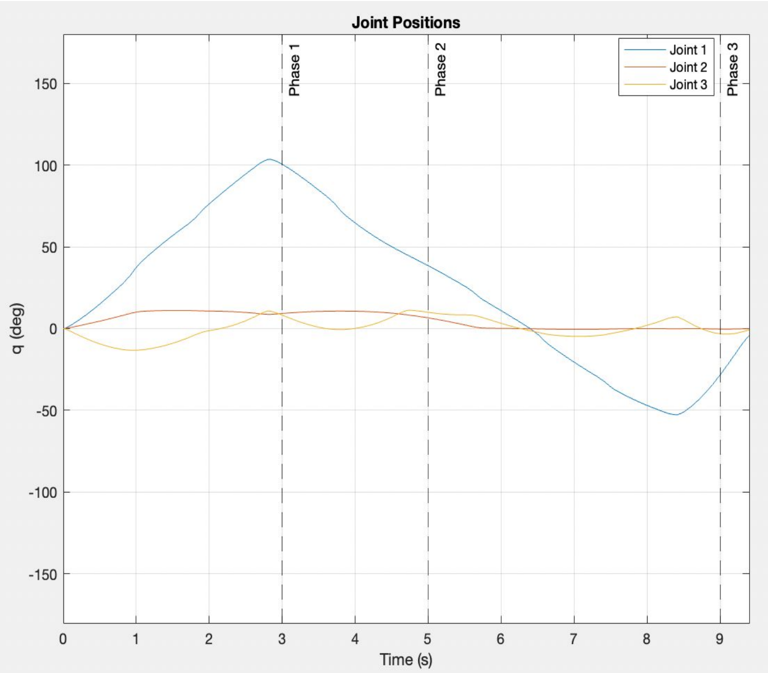


Figure 16: Joint Positions

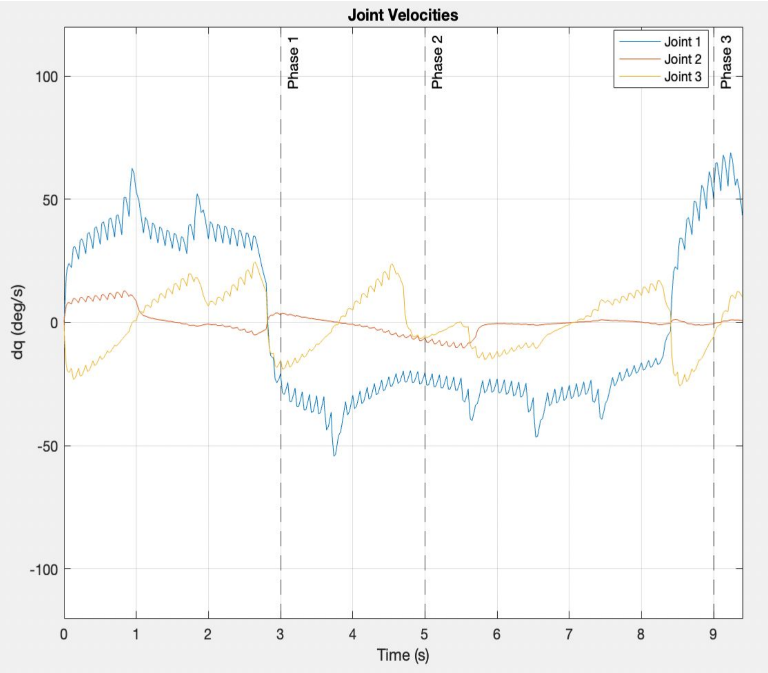


Figure 17: Joint Velocities

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Discussion and Conclusion

- **Studied 3 controllers for high speed pick and place operation**
  - Cycle time, t = 9.5 [sec]
  - CTFA = Max error
  - PDGF = Max error < 10° in Joint 1
  - IDC = Max error < 3.5° in Joint 1

- **Error analysis for task at higher speed**
  - To further demonstrate the robustness of Inverse Dynamics Control for these applications, we ran the task with higher speeds
  - Cycle time, t = 7.1 [sec]
  - Max error ~5° in Joint 1

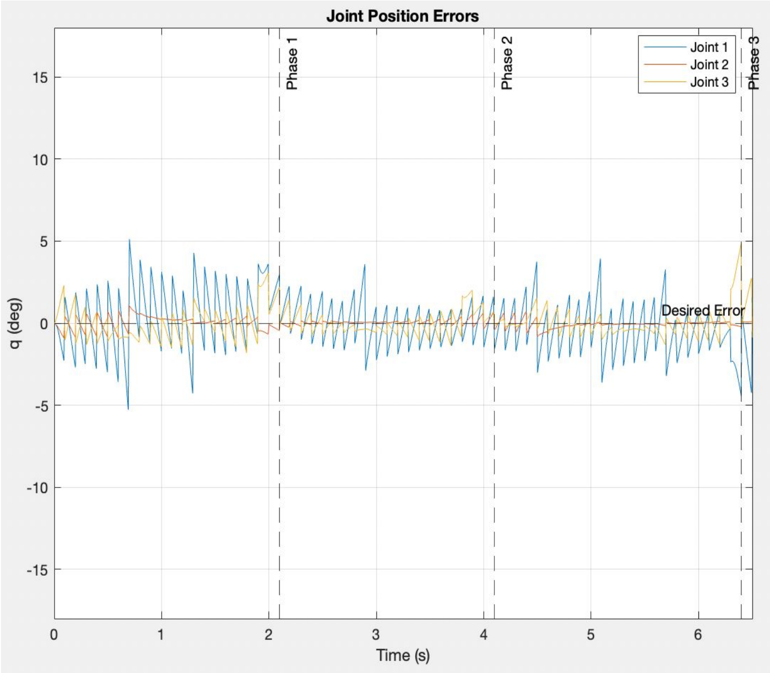

Figure 18: Joint Position Errors

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Q&A