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Modeling and Simulation of a Point to Point Spherical Articulated Manipulator using Optimal Control

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Session 2: Mechanical Design and Control Engineering

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Introduction

- Increase in number of robotic manipulator applications in Industry as well as Medical field
- Flexibility/ dextrosity of robotic manipulators varies as per application
- Manipulators deploy stability controllers like the Proportional-Integral-Derivative Controller (classical control)

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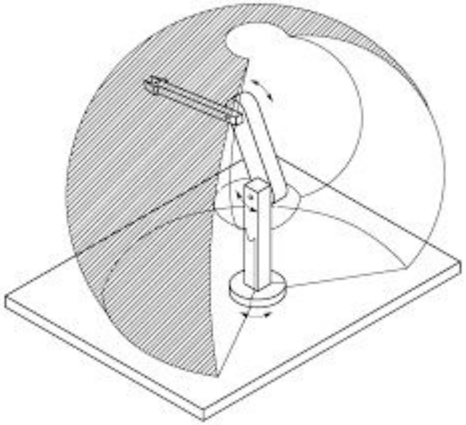
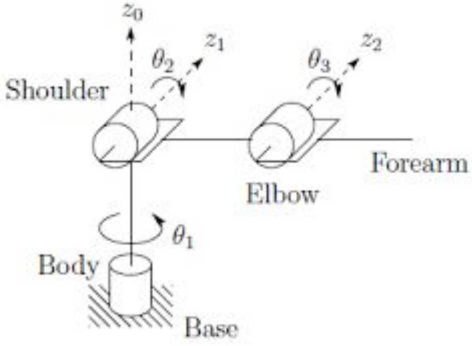
What are Spherical Articulated Manipulators?

- 3 DoF Nonlinear systems
- Consist of 3 rotary joints (Twist-Rotate-Rotate)
- Spherical workspace: Can reach any point in 3D space within their physical limit





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Need for a Controller

- Literature shows that increase in flexibility leads to more vibrations and instability
- Suhaimin et al. in their paper, ‘Analysis of Robotic Arm Control using PID controller’ show:

Without controller	With Controller
11.74% error	0.65% error

- Rojas et al. in their paper, ‘LQR hybrid approach control of a robotic arm two degrees of freedom’, claimed that LQR shows good stability while implemented for a 2DoF arm.

Drawbacks of PID Control

- Classical control theory encompasses linear time-invariant single-input single-output systems
- Applying PID control to Articulated Manipulators require system linearization
- Disturbances to flight or during start up from no load requires the PID controller gains to be tuned continuously
- With increase in number of control variables, the number of PID controllers increase, making the tuning a tedious task

Introducing Optimal Control

- Optimal control like Linear Quadratic Regulator (LQR) works with optimizing objective cost function of dynamic MIMO systems
- Finds the best solution to reach the goal position
- Expected to be more robust for manipulators in all environments
- LQR focuses on non-linear models, in contrast to PID control
- Non-linear system equations of the manipulator can be directly fed to controller to acquire desired response

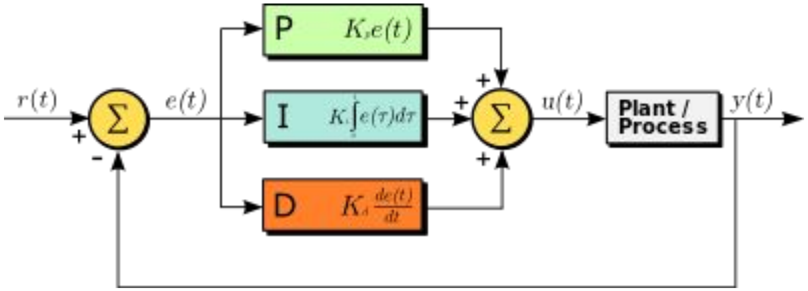
Methodology

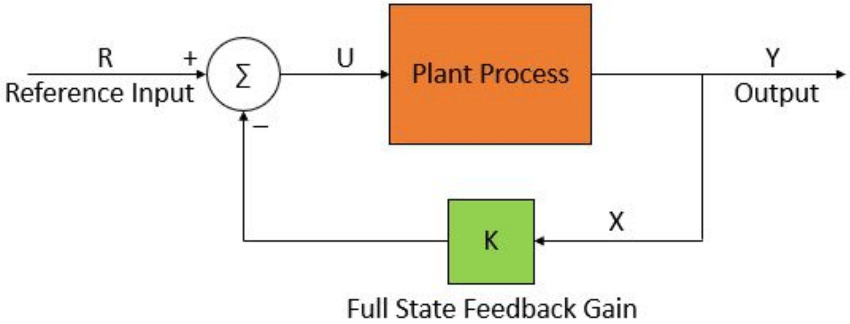
- Workflow:
  - Formulating the manipulators’ kinematic and dynamic equations governing its motion, using Lagrange Euler method.
  - Linearizing the dynamic model
  - Designing the PID and LQR control for the manipulator
  - Evaluate the manipulators performance for multiple cases
  - Compare results and present inference
- State-of-the-art: Existing literature focuses on control of a planar manipulator (2D and 3D). We have evaluated and compared the performance for control of a spherical manipulator.

Control Theory

1. Proportional Integral Derivative
   - Error correction
   - K_p, K_d, K_i constants

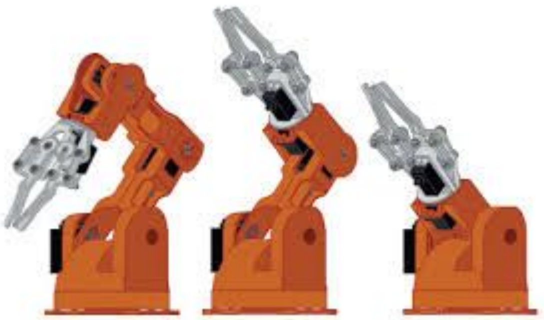
2. Linear Quadratic Regulator
   - Quadratic Cost Function
   - Quantities controlled
     - Response time (Q)
     - Power Consumption (R)

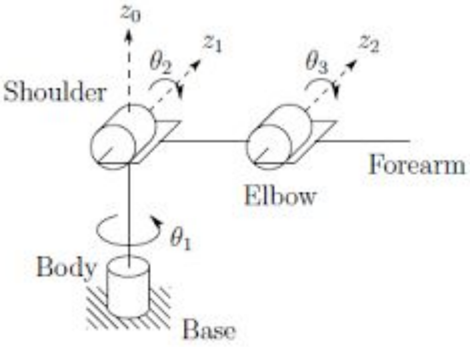




Test Conditions

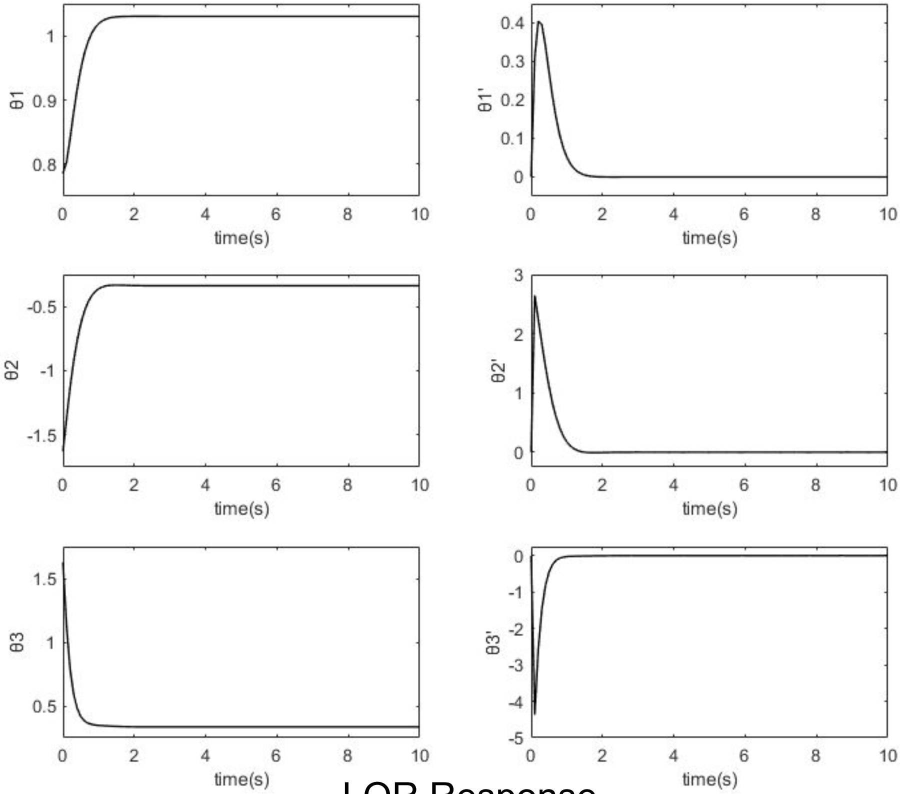
1. Motion from home position to a goal position
2. Motion from one arbitrary point to the other in 3D space
3. Back and forth motion between 2 points in 3D space



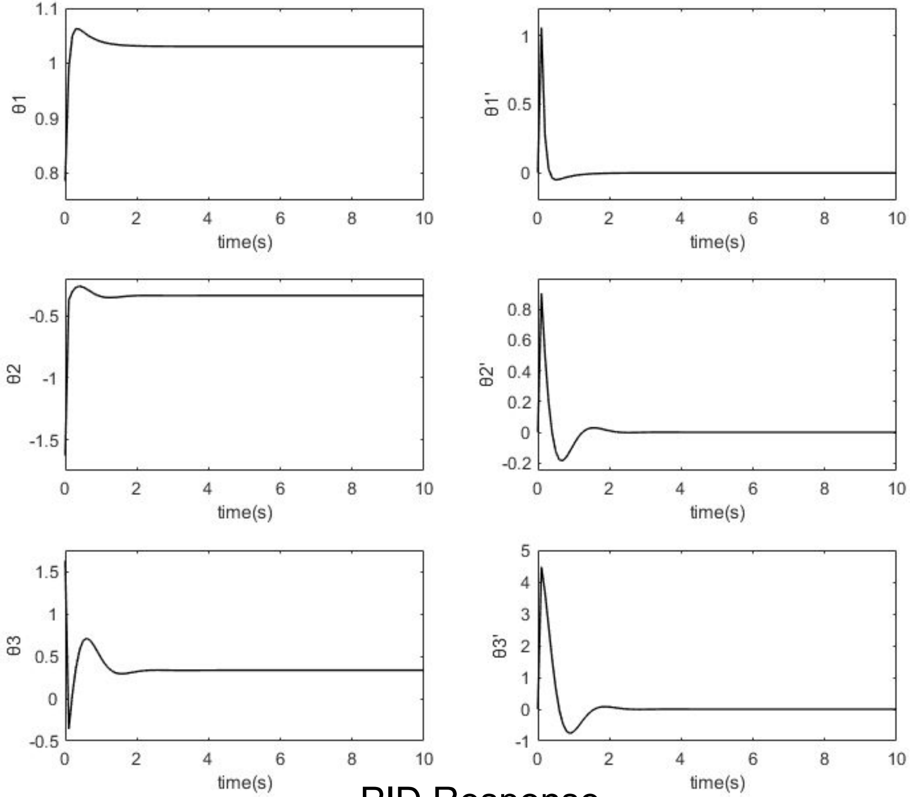


Home position

Controller Performance: point to point motion

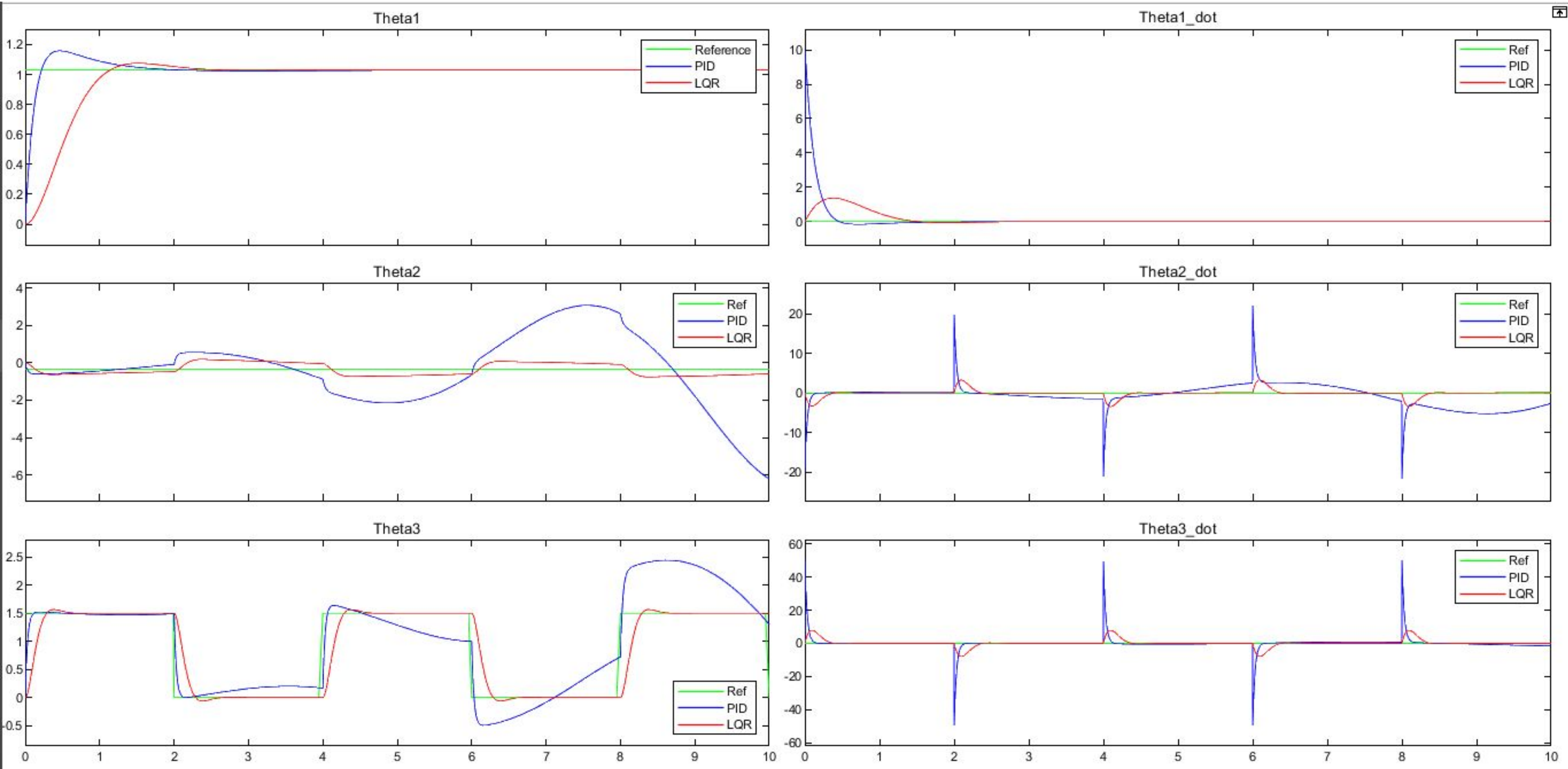


LQR Response



PID Response

Controller Performance: point to point repetitive motion



Conclusion

	PID	LQR
1.	Low computation cost	High computation cost
2.	High overshoot	No/ Low overshoot
3.	Aggressive response	Robust response
4.	Complex design	Simple design

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Future Scope

- Testing the 2 controllers for payload conditions
- Implementation of PID and LQR on hardware system and check the performance
- Exploring advanced control techniques like Impedance control which is better suited for articulated manipulators as per literature

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Thank You!

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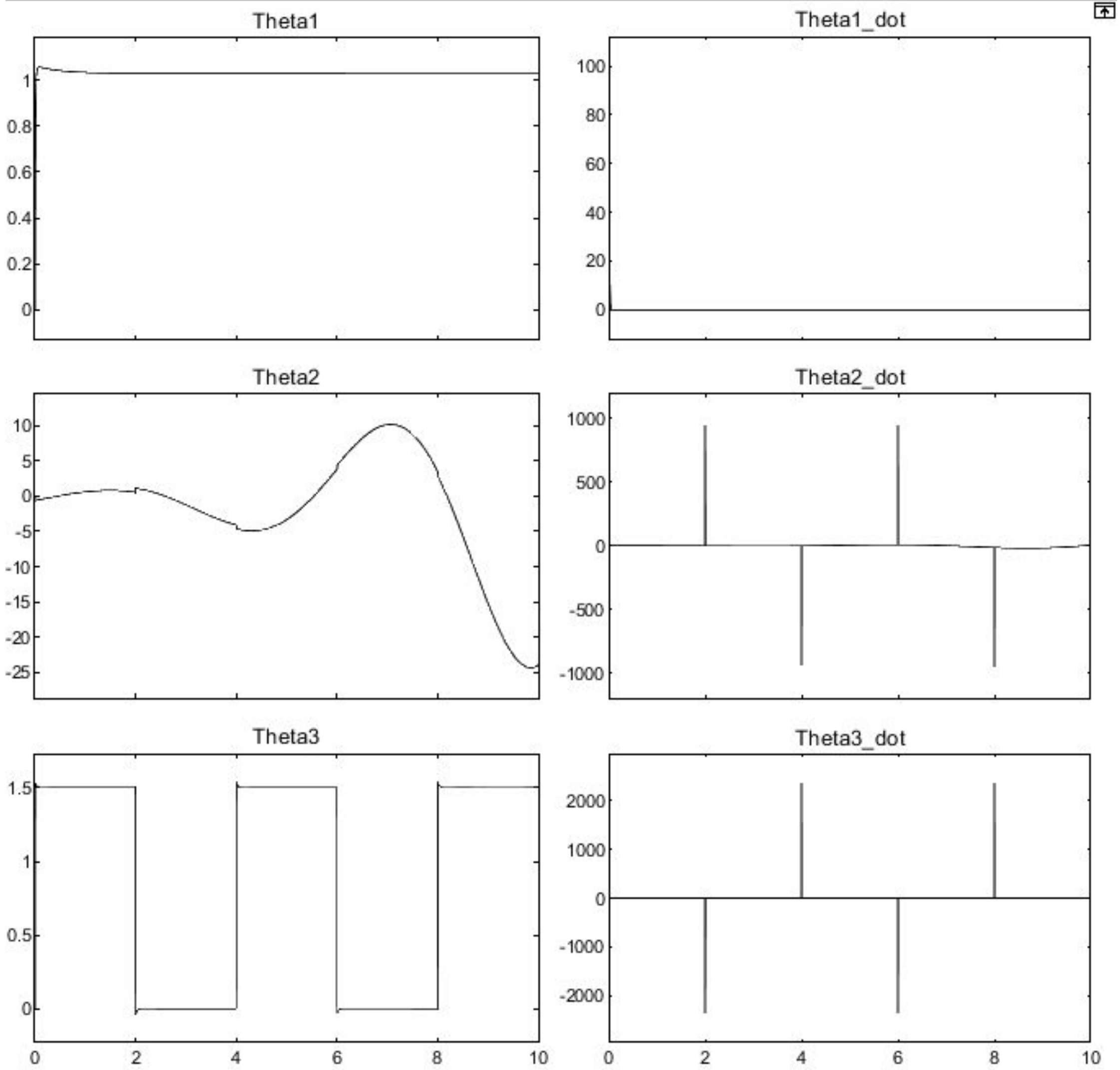
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$$K = \begin{bmatrix} 100 & 0 & 0 & 325.32 & 0 & 0 \\ 0 & 100 & 0 & 0 & 316.35 & 102.11 \\ 0 & 0 & 100 & 0 & 102.11 & 112.14 \end{bmatrix}$$