2022 IEEE International Conference on Mechatronics and Automation

Paper ID: 233831

Implementation and Testing of Force Control on a Spherical Articulated Manipulator

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Session : MP2-3   Title :Mobile Robot System(II)

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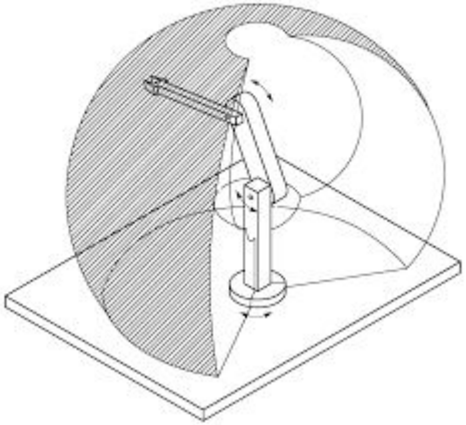
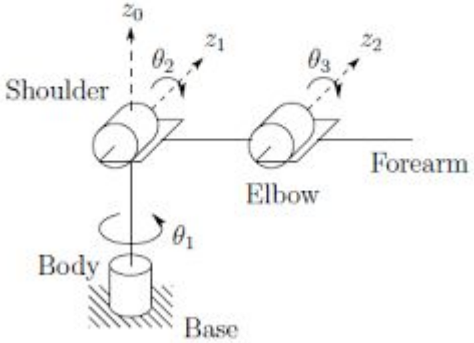
Introduction

- Robotic manipulators are gaining popularity in industrial applications due to their high-quality performance and productivity
- common applications of robotic manipulators in the industry include picking and placing objects, painting, sketching, welding, and packaging.
- Standard position control does provide a satisfactory response; however, control of position, velocity, and acceleration together would naturally improve the stability and controllability of the robot.

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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Major Takeaways from present literature

- The coupling equations and the necessary considerations that need to be considered to achieve complete stability for coupled manipulators.
- The hybrid impedance control combines both position and force control and allows the selection of appropriate impedance parameters for different manipulator designs.
- Impedance control has been shown to improve the dynamic performance of the system in all aspects of control.
- However, the main drawback of this control method is the increased computation time since many more parameters have to be considered in the classical approach.

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Contributions of our work

- We present the simplified dynamics for a spherical 3- DoF articulated manipulator. To the best of our knowledge, the control of spherical manipulators with 3- DoF has not been explored.
- A detailed analysis and performance comparison between the optimal position control and force-based impedance control for the 3-DoF manipulator.
- The performance is evaluated for several industrial scenarios with high perturbations. This opens avenues for further research on spherical manipulators.

Methodology

- Workflow:
  - Formulating the manipulators' kinematic and dynamic equations governing its motion, using Lagrange Euler method.
  - Designing the PID, LQR and Impedance control
  - 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. Moreover, our results are compared with and without disturbances on multiple use cases.

Mathematical Modelling

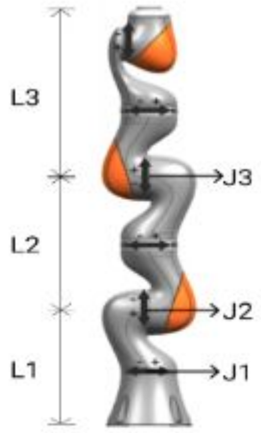
- Here, θ1, θ2, and θ3 are the positions of the base, shoulder, and the elbow joint in radians. a1 a2, and a3 are the respective link lengths from base to end-effector. X3, Y3, Y3 are the end-effector coordinates in space. All the dimensions are in meters.

$$r = \sqrt{X_3^2 + Y_3^2 + Z_3^2 + a_1^2 - 2a_1 Z_3}$$

$$\theta_1 = \tan^{-1}\left(\frac{Y_3}{X_3}\right)$$

$$\theta_2 = \tan^{-1}\left(\frac{Z_3 - a_1}{\sqrt{X_3^2 + Y_3^2}}\right) - \cos^{-1}\left(\frac{a_3^2 - a_2^2 - r^2}{-2a_2 r}\right)$$

$$\theta_3 = \pi - \cos^{-1}\left(\frac{r^2 - a_2^2 - a_3^2}{-2a_2 a_3}\right)$$



Joint Specifications

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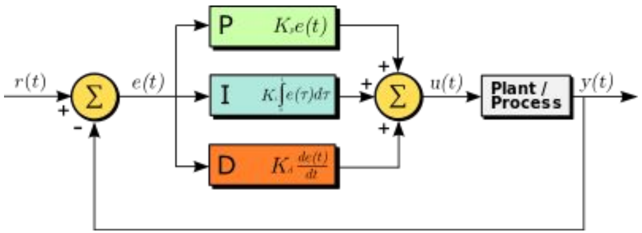
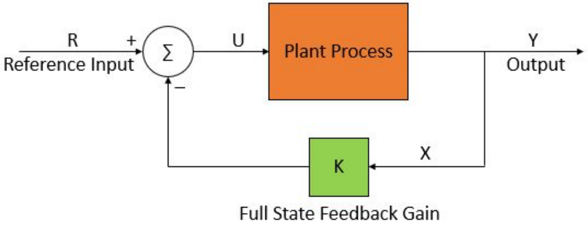
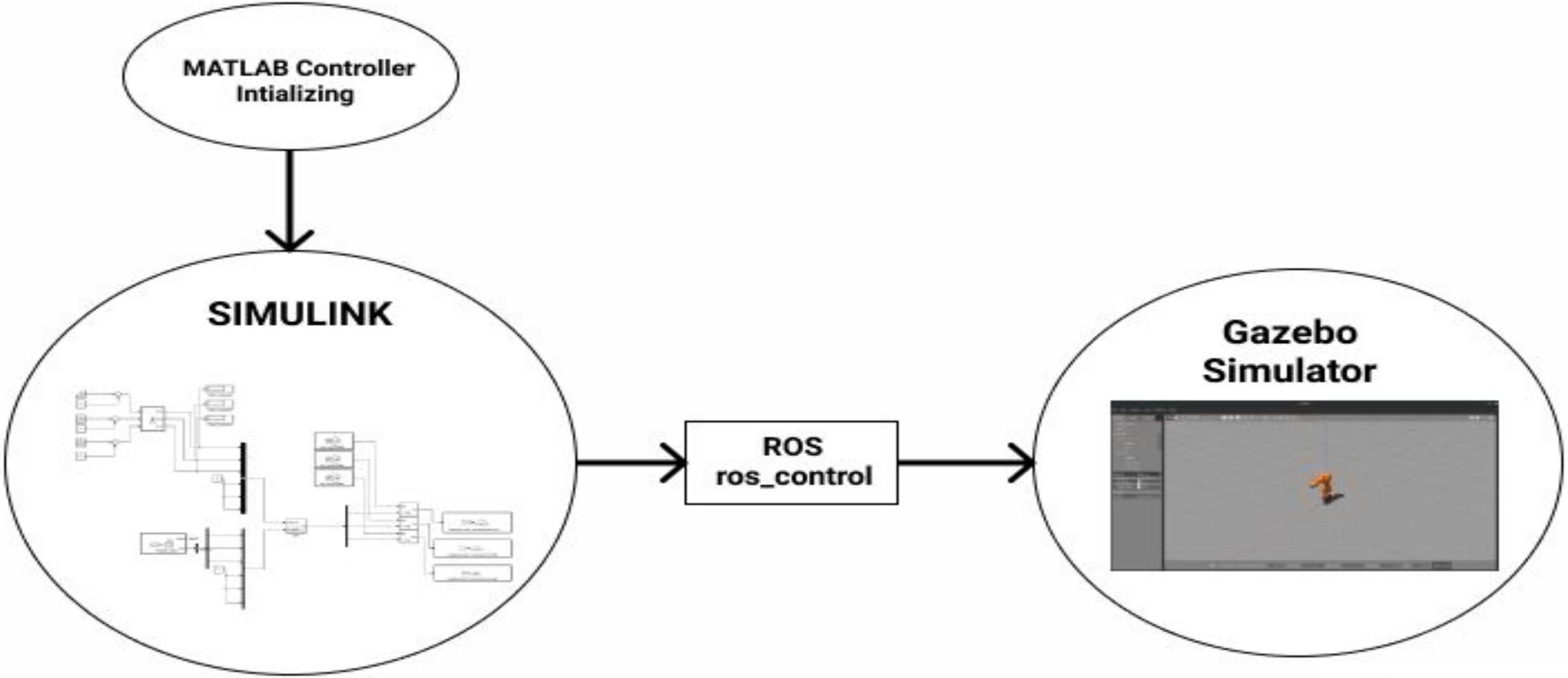
Control Theory

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)
3. Impedance Control
   -



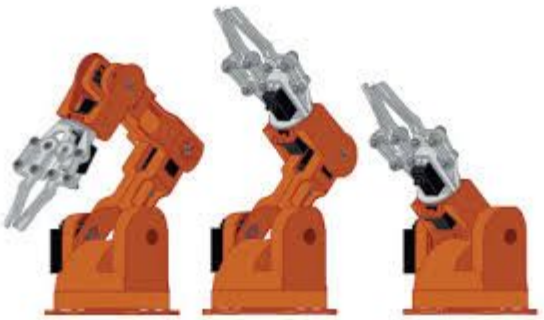


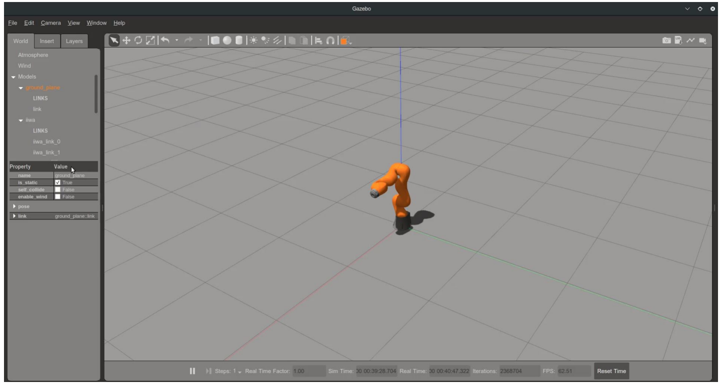
Simulation Setup



Test Conditions

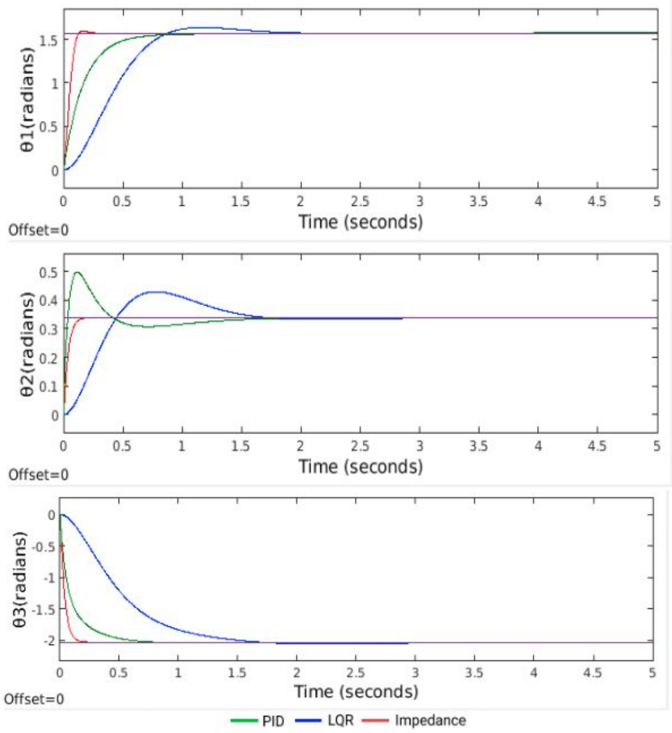
1. Motion from home position to a goal position
2. Motion from one arbitrary point to the other in 3D space
3. Back and forth motion between 2 points in 3D space

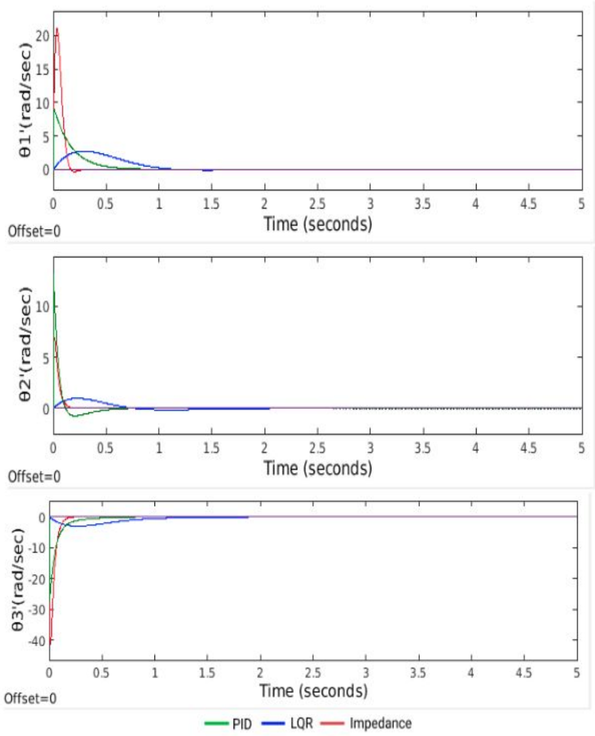




Home position

Controller Performance: Single Point No Force

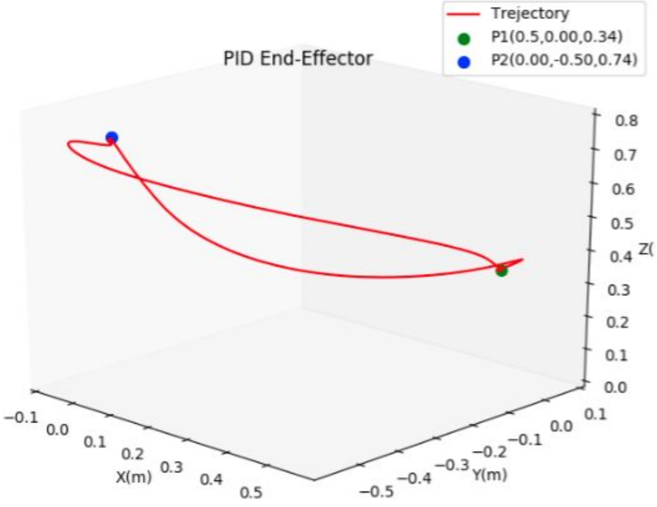


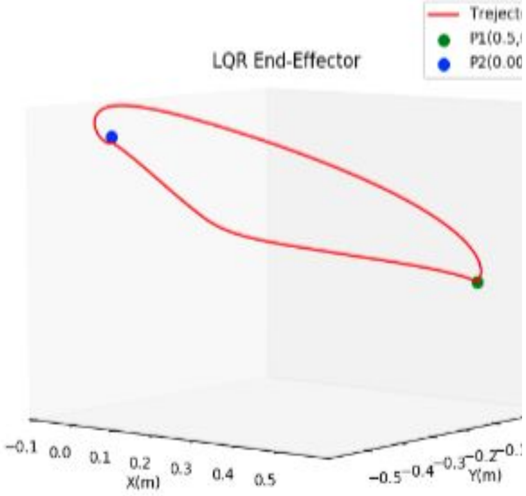


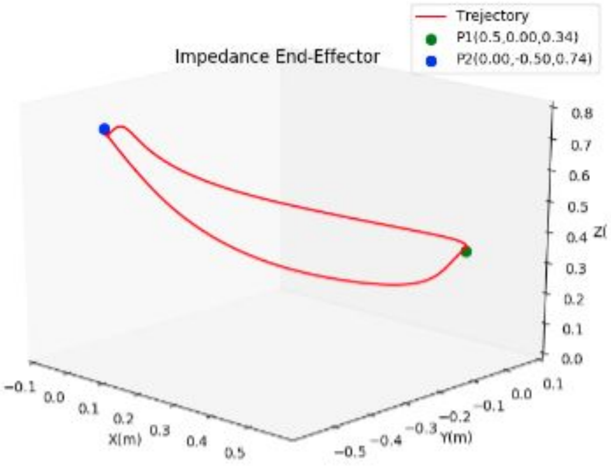
Joint Angle(Rad)-
Single point No Force

Joint Angle
Velocity(Rad/sec)- Single
point No Force

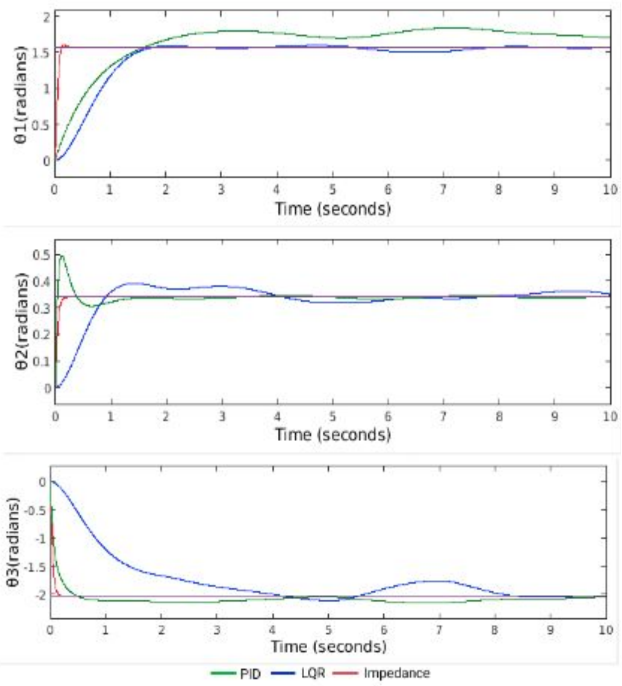
Trajectory Comparison No force Point to Point

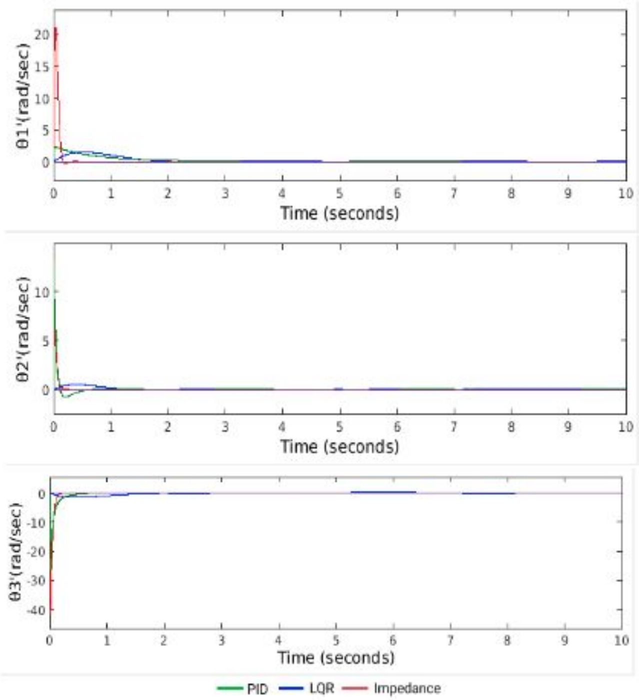






Controller Performance: Single Point 90N Force





Joint Angle(Rad)- One Point 90N

Joint Angle Velocity(Rad/sec)- One point 90N

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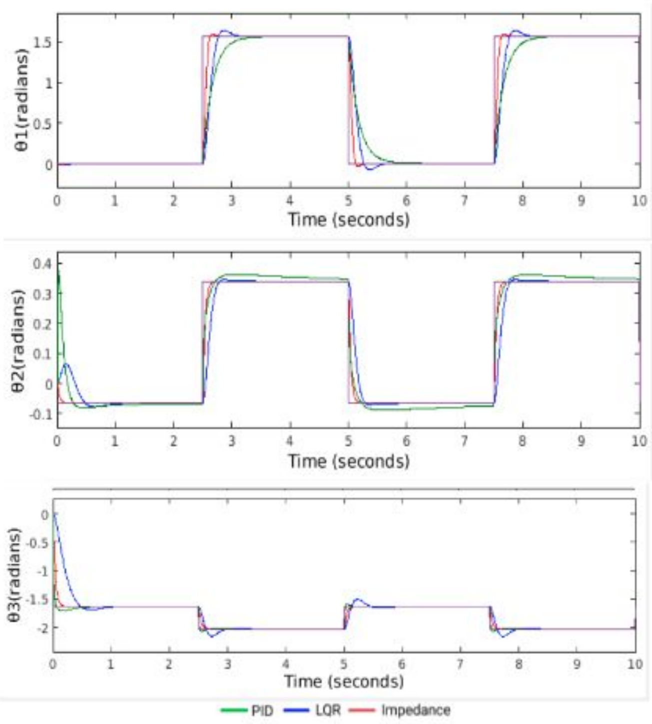
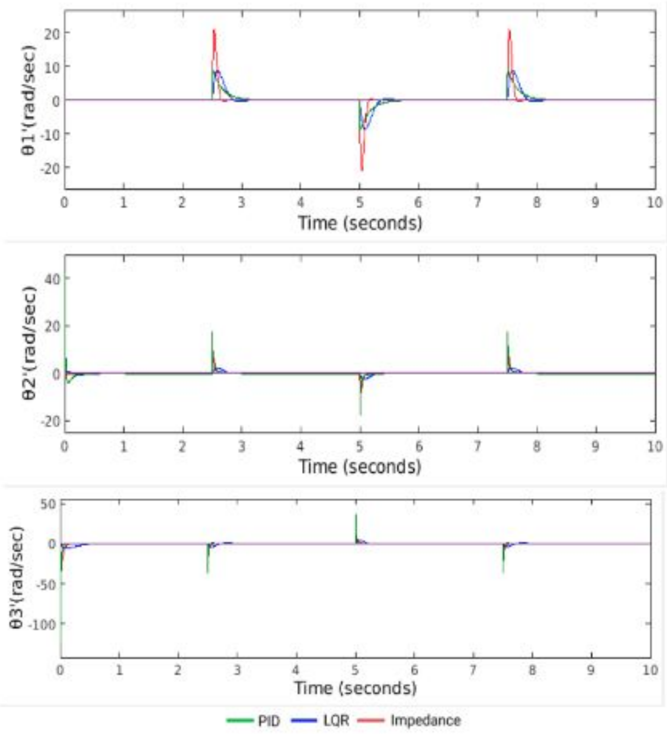
Controller Performance: Oscillatory Point No Force

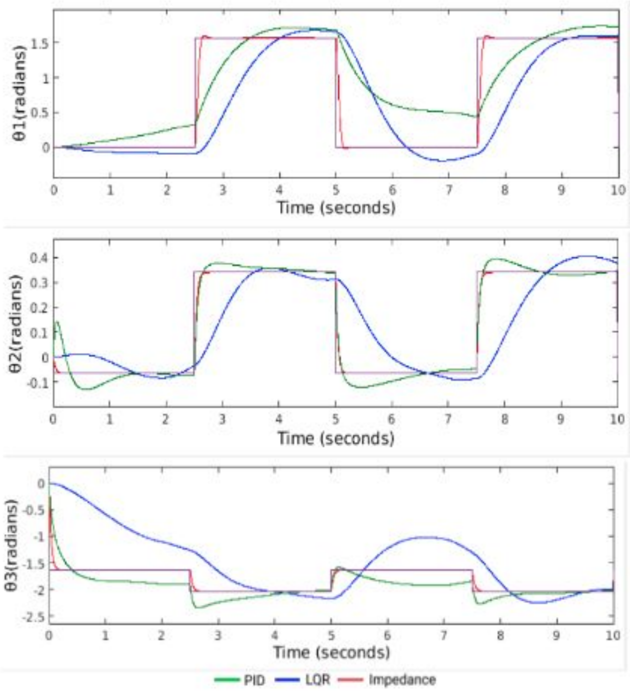


Joint Angle(Rad)- Oscillatory motion No Force

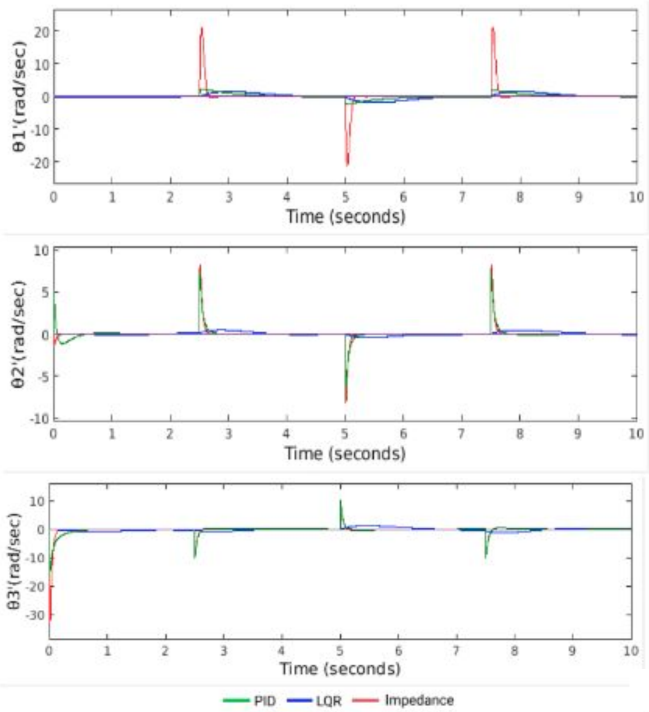


Joint Angle Velocity(Rad/sec)- Oscillatory motion No Force

Controller Performance: Oscillatory motion with 90N disturbance

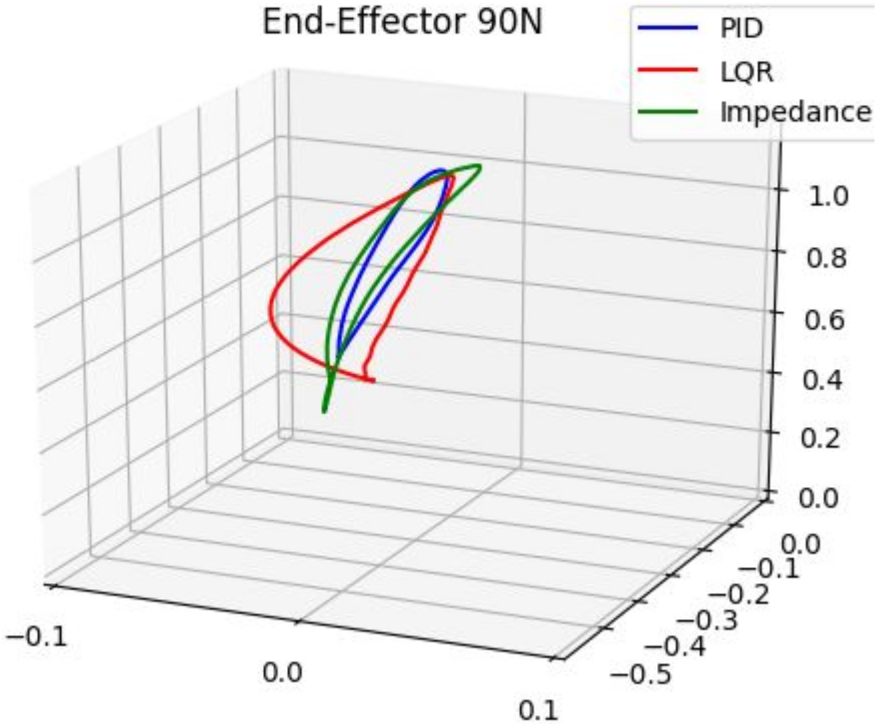


Joint Angle(Rad)- Oscillatory motion 100N



Joint Angle Velocity(Rad/sec)- Oscillatory motion 100N

Trajectory Comparison 90N force Point to Point



Conclusion

- In this paper, we compared the performance of an articulated KUKA manipulator using position and force control techniques.
- On simulating the controllers on the KUKA IIWA LBR7 R800 manipulator in the ROS -Gazebo, a 20 % faster settling time and 90 %, less overshoot is observed for the force control than the optimal controller.
- the impedance control provides higher tolerance to high perturbations as compared to the classical PID and optimal LQR controller. The deviations from the set point under constant disturbances are also significant for the optimal controller and are hardly observed for the impedance-based manipulator test.
- The results prove that a force-based control scheme is more suitable than an optimal controller for higher order linked systems in industrial applications.
- Optimal algorithms like LQR work efficiently for unconstrained systems like quadrotors and mobile wheeled robot.

Future Scope

- Testing the 3 controllers for payload conditions
- Implementation of PID, LQR And Impedance on hardware system and check the performance
- we found that the velocity over- shoots are smaller in the case of optimal control than in the case of impedance control. We intend to use this property of optimal control in conjunction with impedance control to increase accuracy and reduce overshoot in our future work.
- We also plan to develop an adaptive control strategy such as model predictive control along with image processing to automate the entire manipulation process.

References

[1] J. N. Pires, Robot Manipulators and Control Systems. In: Industrial Robots Programming, Springer, Boston, MA.

[2] M. Ben-Ari, F. Mondada, Kinematics of a Robotic Manipulator. In: Elements of Robotics, Springer, Cham. 2018.

[3] E. Rastogi and L. B. Prasad, "Comparative performance analysis of PD/PID computed torque control filtered error approximation based control and NN for a robot manipulator", *IEEE conference on Electrical Computer and Electronics*, December, 2015, pp. 1-6.

[4] J. C. John, “Introduction to robotics: mechanics and control” Third Edition: Addison-Wesley, 1986.

[5] Qu ZH., “Global stability of trajectory tracking of robot under PD control”, Dynamics and Control, 1994; 4(1): 59-71.

[6] R. Kelly, “PD control with desired gravity compensation of robotic manipulators: a review”, The International Journal of Robotics Research, 1997; 16(1): 660-672.

[7] Q Chen, H Chen, YJ Wang, PY Woo, “Global stability analysis for some trajectory tracking control schemes of robotic manipulators”, Journal of Robotic Systems, 2001; 18(2): 69-75.

[8] Z. M. Doina, "LQG/LQR optimal control for flexible joint manipulator," International Conference and Exposition on Electrical and Power Engineering, Iasi, 2012, pp. 35-40.

IEEE

[9] A. Kumar, S. Kasera and L. B. Prasad, "Optimal control of 2-link underactuated robot manipulator," International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS), Coimbatore, 2017, pp. 1- 6.

[10] J. G. Batista, D. A. Souza, L. L. N. dos Reis, L.V.O. Filgueiras, K. M. Ramos, A. B. S. Junior, W. B. Correia, "Performance Comparison Between the PID and LQR Controllers Applied to a Robotic Manipulator Joint," 45th Annual Conference of the IEEE Industrial Electronics Society, Lisbon, Portugal, 2019, pp. 479-484.

[11] H. Asif, A. Nasir, U. T. Shami, S. T. H. Rizvi and M. M. Gulzar, "Design and comparison of linear feedback control laws for inverse Kinematics based robotic arm," 13th International Conference on Emerging Technologies (ICET), Islamabad, 2017, pp. 1-6.

[12] M. Baroudi, M. Saad and W. Ghie, "State-feedback and Linear Quadratic regulator applied to a single-link flexible manipulator," IEEE International Conference on Robotics and Biomimetics (ROBIO), Guilin, 2009, pp. 1381-1386.

[13] H Sadegh and H Zarabadipour, “Modeling, Simulation and Position Control of 3DOF Articulated Manipulator”, Indonesian Journal of Electrical Engineering and Informatics, 2014, 2(3), pp. 132- 140.

[14] S. M. Mahil and A. Al-Durra, "Modeling analysis and simulation of 2-DOF robotic manipulator," IEEE 59th International Midwest Symposium on Circuits and Systems (MWSCAS), Abu Dhabi, 2016, pp. 1-4.

[15] J. H. C. Rojas, R Rodriguez J. A. Q López and K. L. R. Perdomo, “LQR hybrid approach control of a robotic arm two degrees of freedom” 2016, 11. pp. 9221-9228.

Thank You!