PROJECT PRESENTATION

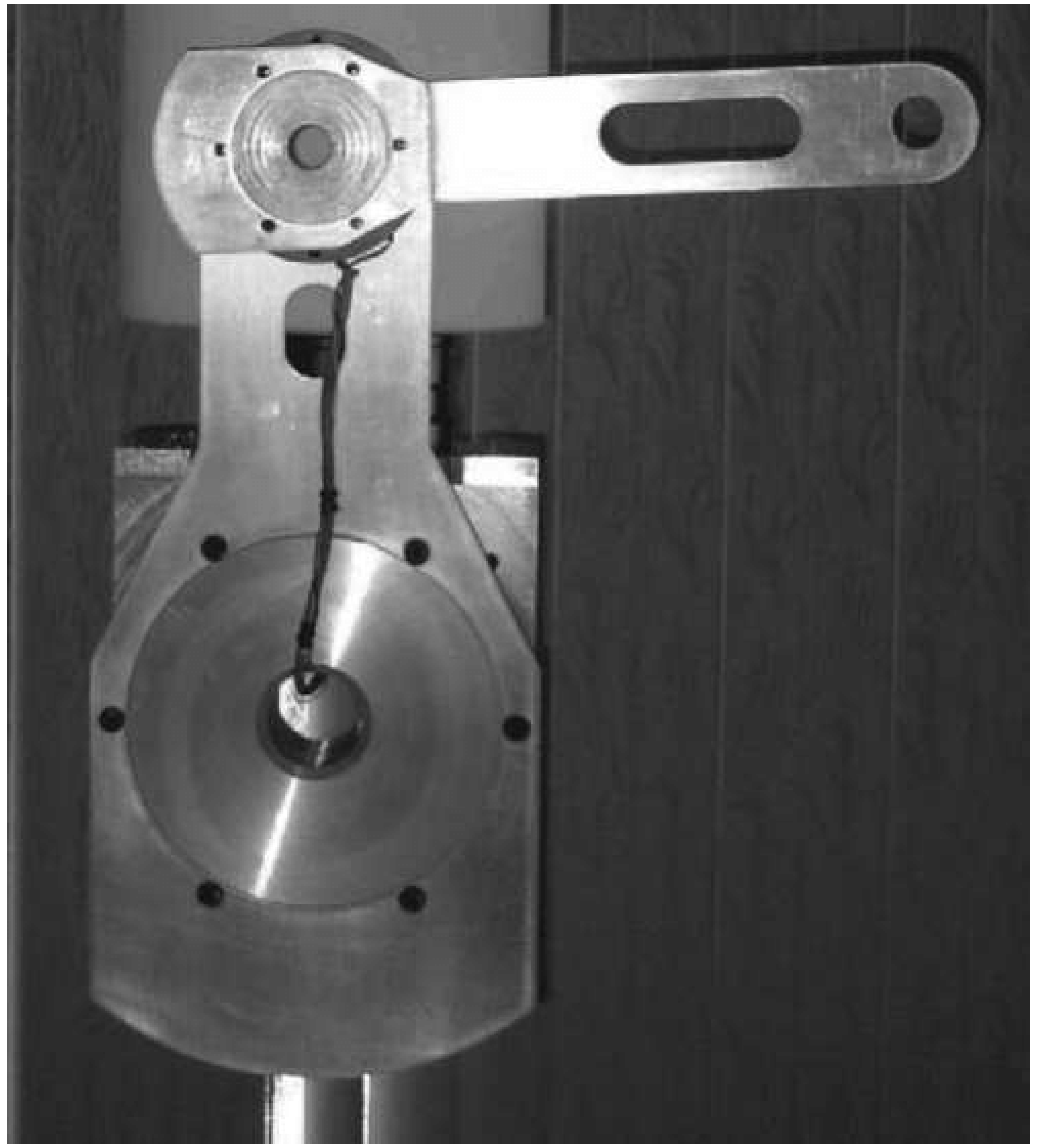
ENPM667-0101: CONTROL OF ROBOTIC SYSTEMS FALL 2021

UNIVERSITY OF MARYLAND

ADAPTIVE MANIPULATOR CONTROL: A CASE STUDY BY:JEAN-JACQUES SLOTINE AND WEIPING LI

Abstract

- The paper I chose for project discusses the adaptive control technique on a high-speed two degree-of-freedom semi-direct-drive robot.
- An approach is presented to control the trajectory of initially unknown dynamics of a robot manipulator which is a nonlinear, time-varying,multi-input-multi-output.
- The experiment setup estimates the values of unknown dynamics in the first half second of the run and uses them to enhance the performance of the manipulator.



Adaptive Control

Requirements:

The accuracy of computed-torque method in direct-drive robots where gear-reduction is not available; suffer because of these uncertainties.

The basic problem in designing a robot manipulator is the variability of the loads to be manipulated.

More-so the uncertainties associated with the dynamic properties such as the moment of inertia of links and the manipulation system on the whole and the center of mass transition once the load is grasped are also few contributing factors which limit robots ability.

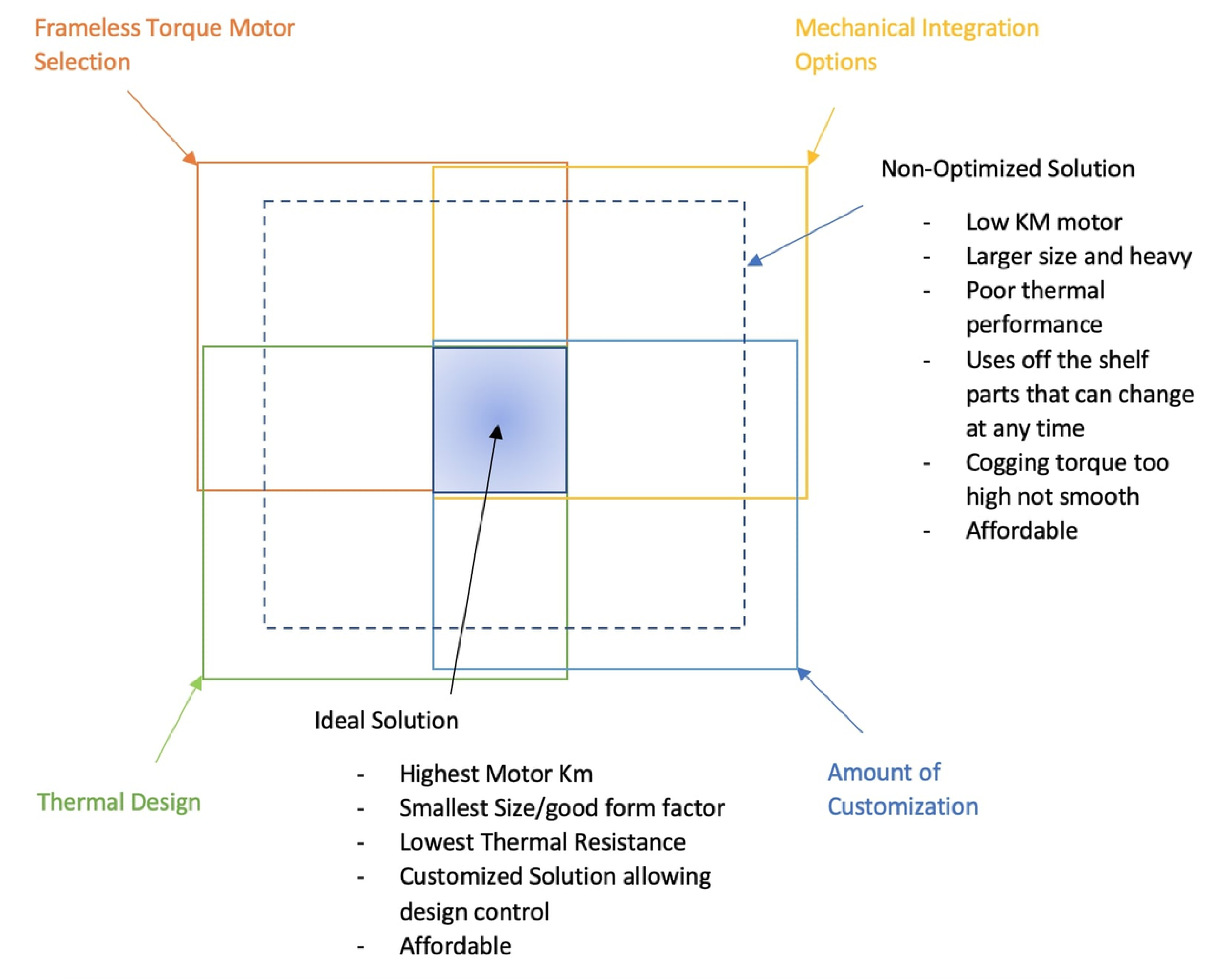
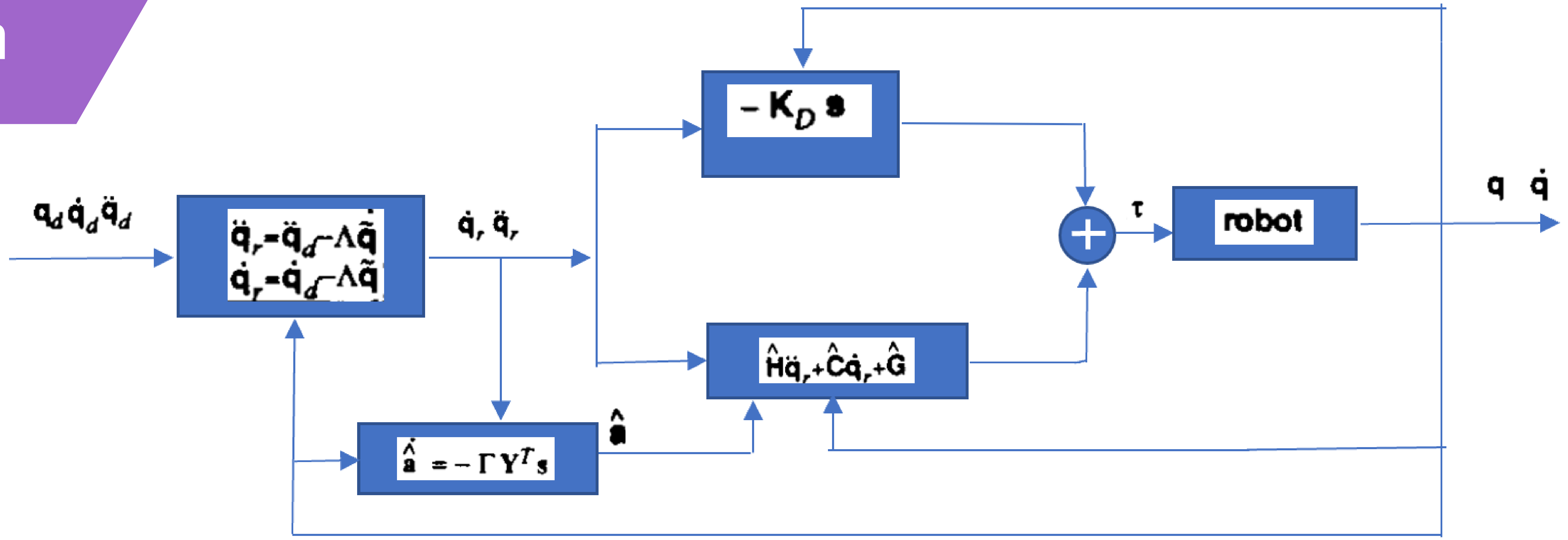


Image: https://www.sierramotion.com/blog/how-to-select-a-motor-for-a-robot-joint/

Adaptive Control Design



The basis of adaptive control is to apply a mechanism which extracts information from the tracking errors are and improves the accuracy of the system with time for varied load.

In this paper an experiment is conducted using a joint-space adaptive tracking controller on a high-speed two degree-of-freedom semi-direct-drive robot.

In the given paper the control law for the actuator torques and an estimation law for the unknown parameters is designed in a way that manipulator joint position q(t) precisely tracks desired joint position q_d(t) after an initial adaptation process.

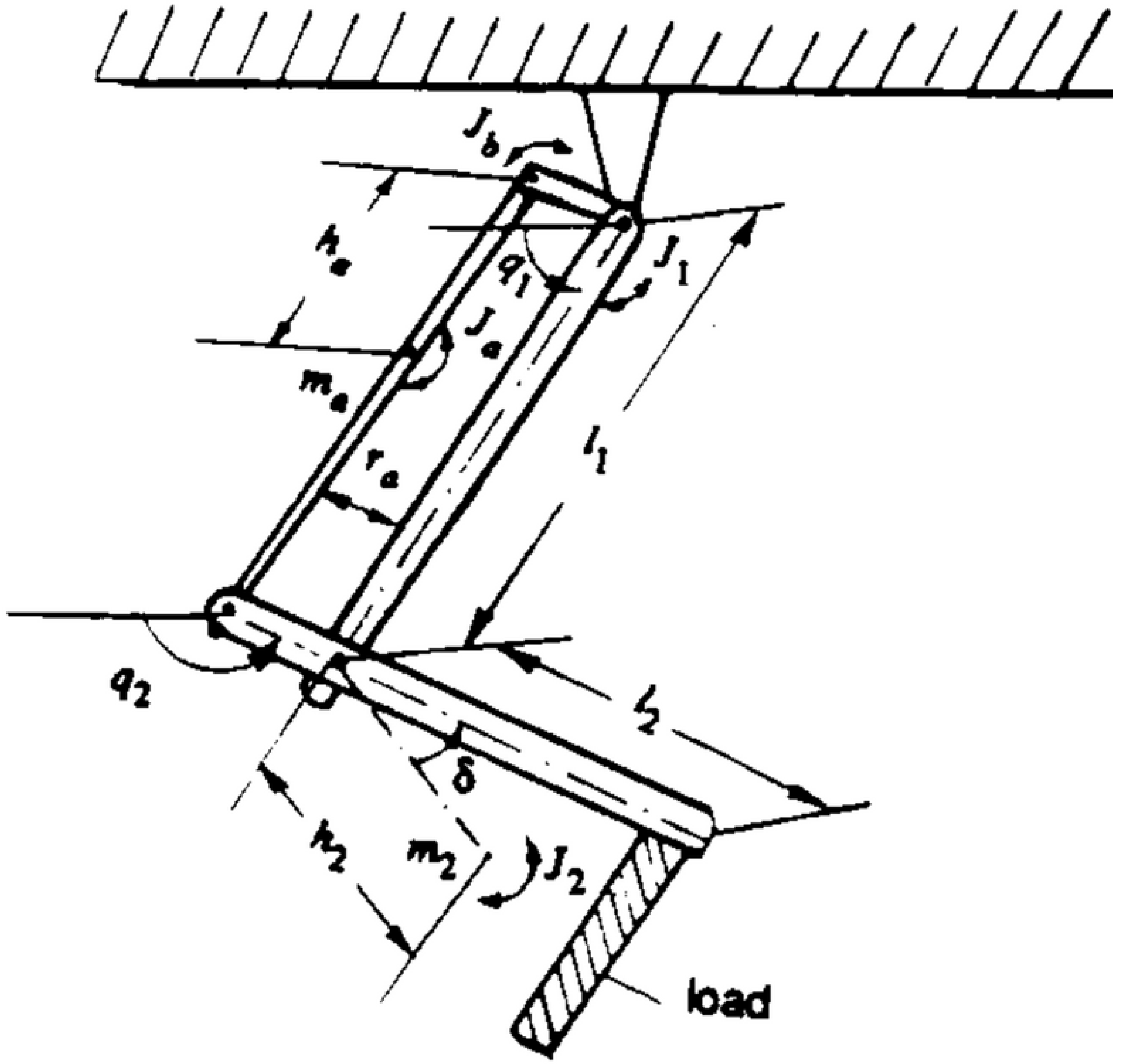
First is is based on estimated parameters with three terms of inertial, centripetal and Coriolis, and gravitational torques. This in turn provides the joint dynamic torques necessary to make the desired motions.

The second part has two terms representing PD feedback which is used to keep the real trajectories close to desired trajectories.

The equipment used for experiment in this paper is defined as a two degree-of-freedom semi- direct-drive robot arm.

The arm lies in the horizontal plane, and therefore, the effects of gravity are absent. A four-bar linkage mechanism is used to transmit the torque from the upper motor to the outer link.

The joint velocities are directly measured by tachometers.



Control Law

The dynamic law is derived from Lagrange's equation as:

$$a_1\ddot{q}_1 + (a_3c_{21} + a_4s_{21})\ddot{q}_2 - a_3s_{21}\dot{q}_2^2 + a_4c_{21}\dot{q}_2^2 = \tau$$

$$(a_3c_{21} + a_4s_{21})\ddot{q}_1 + a_2\ddot{q}_2 + a_3s_{21}\dot{q}_1^2 + a_4c_{21}\dot{q}_1^2 = \tau$$

where

$$\begin{aligned} c_{21} &= cos(q_2 - q_1) \\ s_{21} &= sin(q_2 - q_1) \\ a_1 &= J_1 + J_a + m_2l_1^2 + m_ah_a^2 \\ a_2 &= J_2 + J_b + m_2h_2^2 + m_ar_a^2 \\ a_3 &= m_2h_2l_1cos\delta - m_ah_ar_a \\ a_4 &= m_2h_2l_1sin\delta \end{aligned}$$

The feedback gain matrix and the adaptation gain matrix in controller design are chosen as diagonal:

$$\begin{aligned} K_D &= diag(k_{d1}, k_{d2}) \\ \mathcal{T} &= diag(\gamma_1, \gamma_2, \gamma_3, \gamma_4) \end{aligned}$$

Hence we get the control law combining the above values into

$$\tau_1 = Y_{11}a_1 + Y_{13}a_3 + Y_{14}a_4 - k_{d1}s_1$$
$$\tau_2 = Y_{22}a_2 + Y_{23}a_3 + Y_{24}a_4 - k_{d2}s_2$$

where the values are

$$Y_{11} = \ddot{q_r}1$$
$$Y_{22} = \ddot{q_r}2$$
$$Y_{13} = c_{21}\ddot{q_r}2 - s_{21}\dot{q}_2\dot{q_r}2$$
$$Y_{23} = c_{21}\ddot{q_r}1 - s_{21}\dot{q}_1\dot{q_r}1$$
$$Y_{14} = s_{21}\ddot{q_r}2 - c_{21}\dot{q}_2\dot{q_r}2$$
$$Y_{24} = s_{21}\ddot{q_r}1 - c_{21}\dot{q}_1\dot{q_r}1$$

Adaptation Law

$$\dot{\hat{a}}_1 = -\gamma_1 Y_{11} s_1$$

$$\dot{\hat{a}}_2 = -\gamma_2 Y_{22} s_2$$

$$\dot{\hat{a}}_3 = -\gamma_3 (Y_{13} s_1 + Y_{23} s_2)$$

$$\dot{\hat{a}}_4 = -\gamma_4 (Y_{14} s_1 + Y_{24} s_2)$$

Conclusion

The performance of adaptive controller in high seed operations with uncertain dynamic factors and undefined errors; comes out to be better or at least similar to PD controller and computed-torque schemes.

With respect to the standard rigid body model of robot arm dynamics the adaptive algorithm enjoys better convergence of tracking error over the desired trajectories, a global asymptotic stability, easier computation plus it requires less approximations on our part and provides same level of robustness.

Hence, adaptation is the easiest, fastest, and most accurate method for obtaining parameter values for use in fixed-parameter controllers.

Thank you!