EML 6531-Adaptive Control Project 4

Submitted to: Dr.Warren Dixon, MAE Dept, University of Florida

Submitted by: Prajwal Gowdru Shanthamurthy

March 11, 2020

1)Simulation Section for RISE-based-Modular Adaptive Controller with $\dot{\hat{\theta}} = 0$

1) Control Gains used:

- K_s multiplying r in the design of $\dot{\mu}$
- β multiplying $sgn(e_2)$ in the design of $\dot{\mu}$
- α_1 multiplying e_1 in the definition of the error signal e_2
- α_2 multiplying e_2 in the definition of the error signal r

The values of which were picked as follows: $K_s = 9$, $\beta = 10$, $\alpha_1 = 1$ and $\alpha_2 = 1$

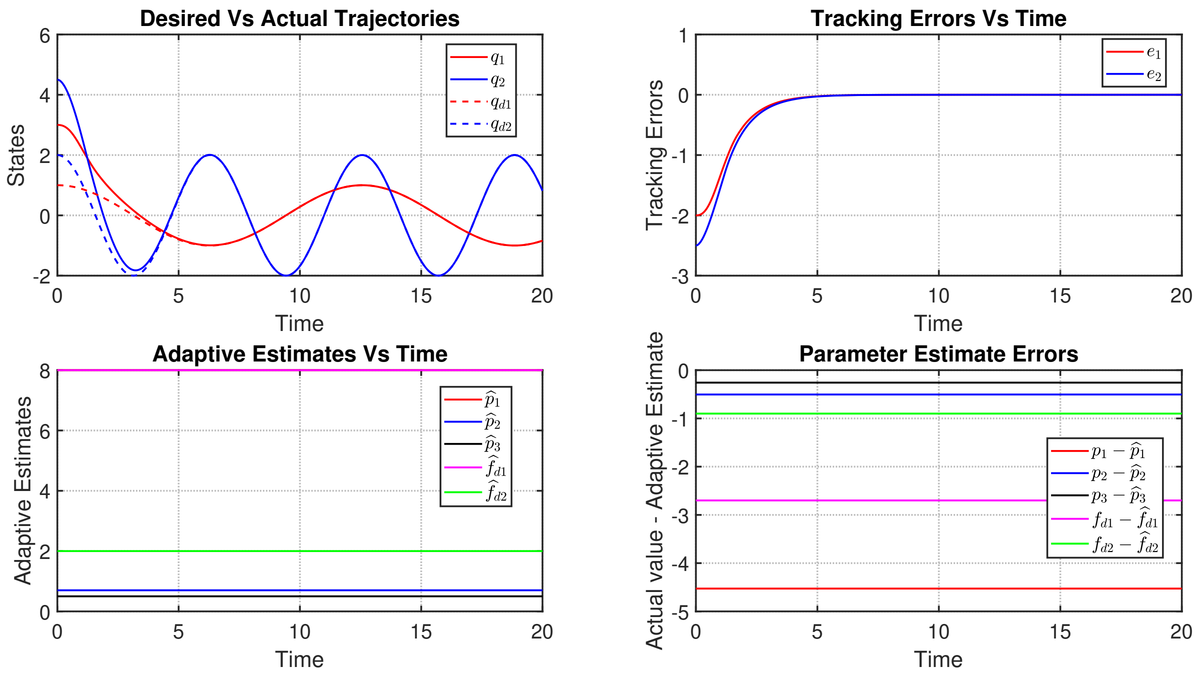

Figure 1: Modular Adaptive Control - $\dot{\hat{\theta}} = 0$

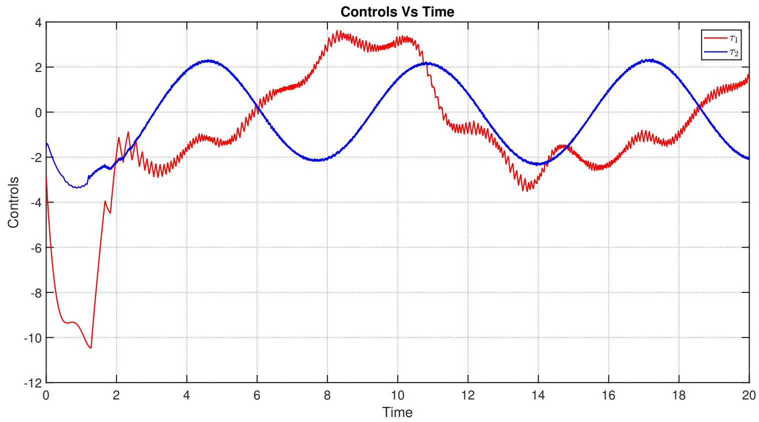

Figure 2: Control Inputs - for $\dot{\widehat{\theta}} = 0$

Maximum values of the torques are 10.4656 Nm and 3.3739 Nm respectively.

2)Simulation Section for RISE-based-Modular Adaptive Controller with $\dot{\widehat{\theta}} = 0.5\sin(t)$

1) Control Gains used:

- K_s multiplying r in the design of $\dot{\mu}$
- β multiplying $sgn(e_2)$ in the design of $\dot{\mu}$
- α_1 multiplying e_1 in the definition of the error signal e_2
- α_2 multiplying e_2 in the definition of the error signal r

The values of which were picked as follows: $K_s = 9$, $\beta = 20$, $\alpha_1 = 1$ and $\alpha_2 = 1$

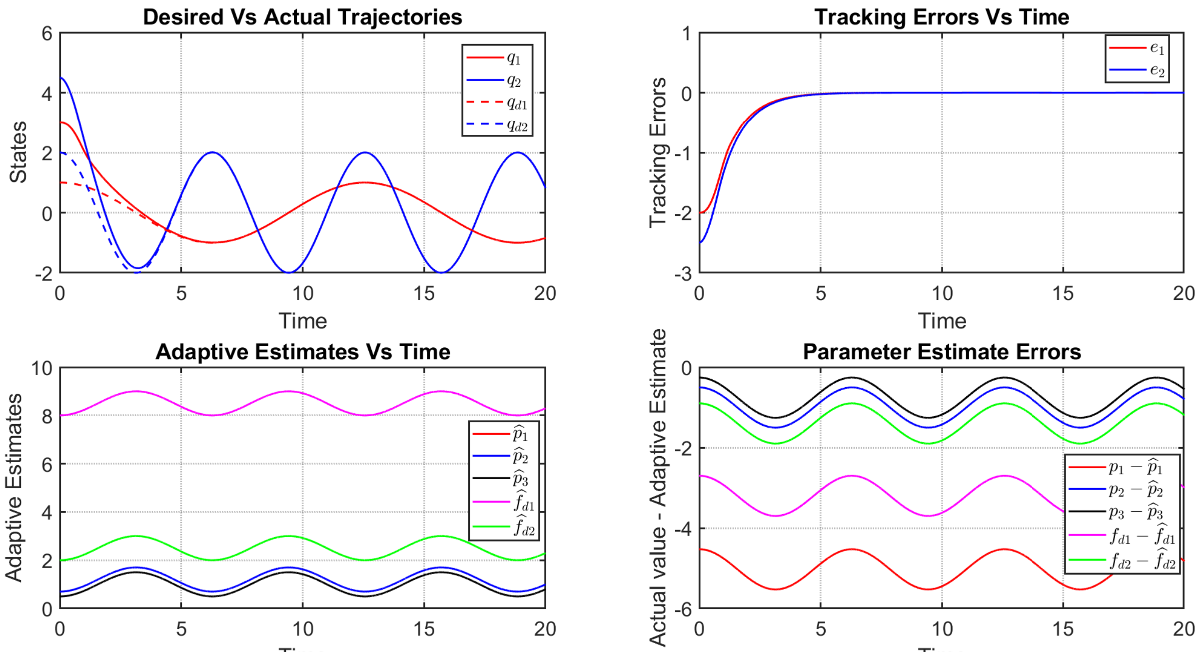

Figure 3: Modular Adaptive Control - $\dot{\hat{\theta}} = 0.5\sin(t)$

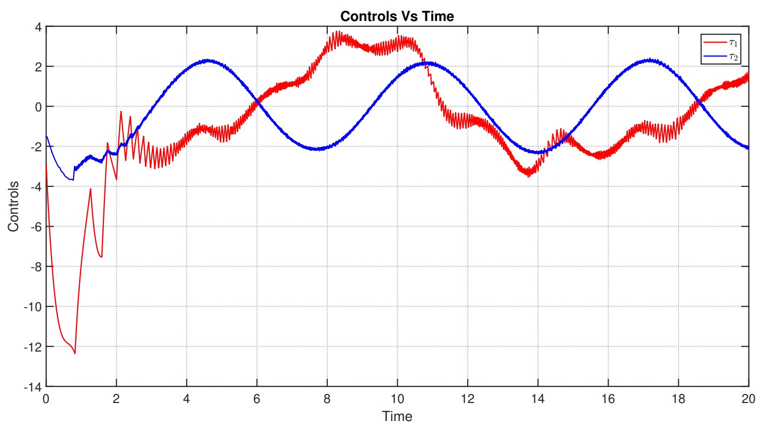

Figure 4: Control Inputs - for $\dot{\hat{\theta}} = 0.5\sin(t)$

Maximum values of the torques are 12.3589 Nm and 3.6946 Nm respectively.

3)Simulation Section for RISE-based-Modular Adaptive Controller with $\dot{\hat{\theta}} = \Gamma Y_d^T \sin(e_2)$

where

$$Y_d = M(q_d)\ddot{q}_d + V_m(q_d, \dot{q}_d)\dot{q}_d + F_d\dot{q}_d$$

1) Control Gains used:

- K_s multiplying r in the design of $\dot{\mu}$
- β multiplying $sgn(e_2)$ in the design of $\dot{\mu}$
- α_1 multiplying e_1 in the definition of the error signal e_2
- α_2 multiplying e_2 in the definition of the error signal r
- Matrix Γ in the adaptive update law

The values of which were picked as follows:

$$K_s = 9,\ \beta = 20,\ \alpha_1 = 1 \text{ and } \alpha_2 = 1 \text{ and } \Gamma = \begin{bmatrix} 300 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 & 0 \\ 0 & 0 & 20 & 0 & 0 \\ 0 & 0 & 0 & 20 & 0 \\ 0 & 0 & 0 & 0 & 20 \end{bmatrix}$$

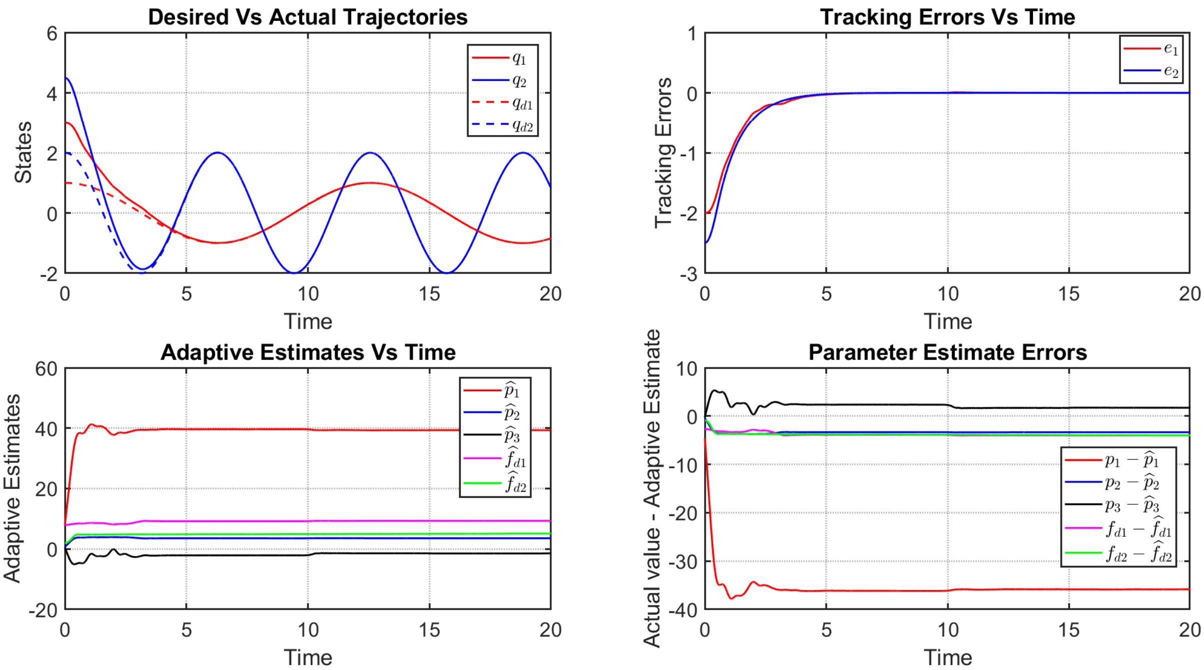

Figure 5: Modular Adaptive Control - $\dot{\hat{\theta}} = \Gamma Y_d^T \sin(e_2)$

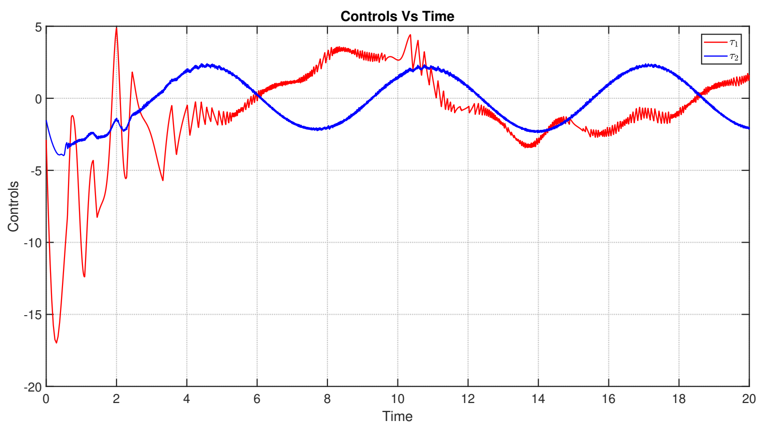

Figure 6: Control Inputs - for $\dot{\hat{\theta}} = \Gamma Y_d^T \sin(e_2)$

Maximum values of the torques are 16.9842 Nm and 3.9767 Nm respectively.

4)Simulation Section for RISE-based-Modular Adaptive Controller with $\dot{\hat{\theta}} = \Gamma Y_d^T \tanh(e_1)$

where

$$Y_d = M(q_d)\ddot{q}_d + V_m(q_d, \dot{q}_d)\dot{q}_d + F_d\dot{q}_d$$

1) Control Gains used:

- K_s multiplying r in the design of $\dot{\mu}$
- β multiplying $sgn(e_2)$ in the design of $\dot{\mu}$
- α_1 multiplying e_1 in the definition of the error signal e_2
- α_2 multiplying e_2 in the definition of the error signal r
- Matrix Γ in the adaptive update law

The values of which were picked as follows:

$K_s = 9$, $\beta = 20$, $\alpha_1 = 1$ and $\alpha_2 = 1$ and $\Gamma = \begin{bmatrix} 300 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 & 0 \\ 0 & 0 & 20 & 0 & 0 \\ 0 & 0 & 0 & 20 & 0 \\ 0 & 0 & 0 & 0 & 20 \end{bmatrix}$

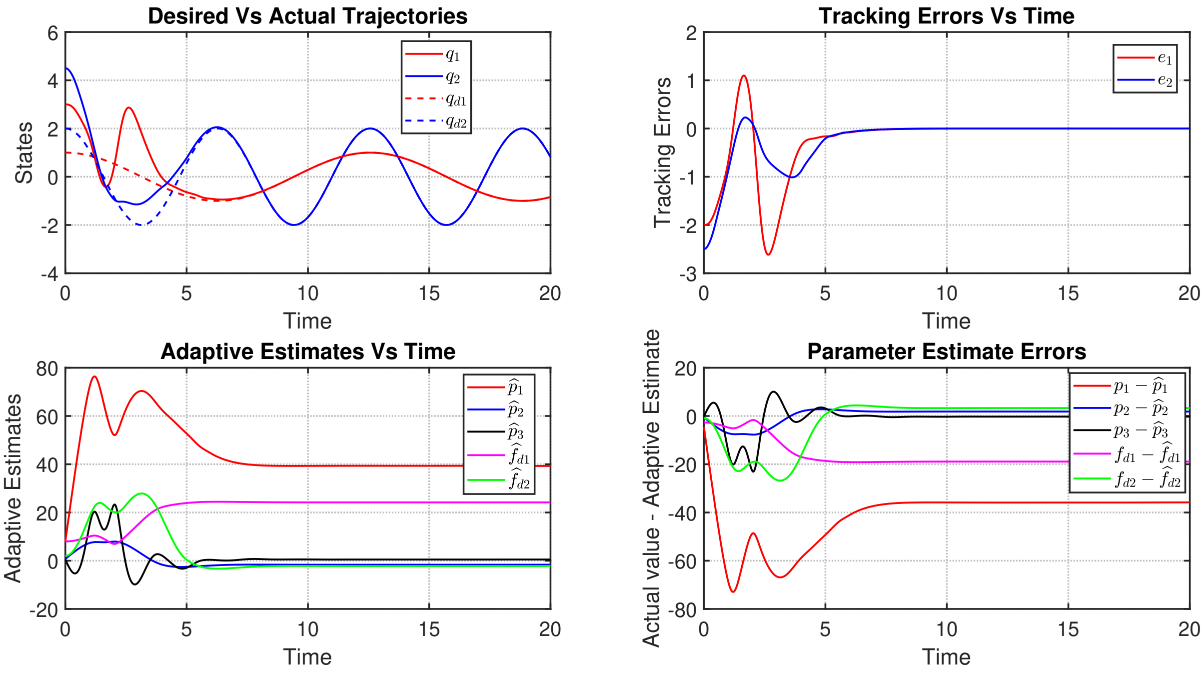

Figure 7: Modular Adaptive Control - $\dot{\hat{\theta}} = \Gamma Y_d^T \tanh(e_1)$

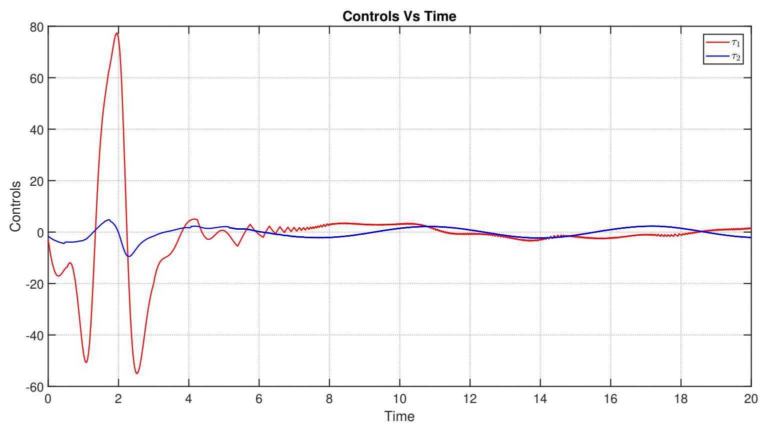

Figure 8: Control Inputs - for $\dot{\hat{\theta}} = \Gamma Y_d^T \tanh(e_1)$

Maximum values of the torques are 77.4403 Nm and 9.4933 Nm respectively.

5)Discussion Section

- Increasing the gain K_s increases the speed of convergence of the tracking error to zero. However, this comes at the cost of a bigger control effort.The gains are therefore fixed based on the maximum control torques that the motors are capable of delivering.
- In all the above controllers increasing the gain β brings the tracking error to zero faster. A large enough β crushes the $\tilde{\theta}$ disturbance term as long as it is bounded. This helps in achieving asymptotic tracking. In fact, the reason for placing the requirement that $\tilde{\theta}$ must be bounded is that otherwise the $\tilde{\theta}$ disturbance term cannot be crushed no matter how big the choice of β is.
- This also means that asymptotic tracking is achieved because of the RISE terms even if the adaptive estimates do not converge to the actual parameter values. In other words, our design of the adaptive update law is no longer dictated by the Lyapunov analysis. We have asymptotic tracking provided that our design of $\widehat{\theta}$ and $\dot{\widehat{\theta}}$ satisfy certain bound requirements. This is what we are going for in **Modular adaptive control**.
- In cases where the adaptive update law is designed so as to drive the adaptive estimate errors to zero, our choice of the Learning Gain Matrix, Γ, determines the speed of convergence of the adaptive estimates to the actual parameter values.
- The composite adaptive controller with an additional RISE term which was implemented in Project 2 is an example of an adaptive update law which in the modular adaptive control setting drives the adaptive estimate errors to zero. In fact, the implementation would be exactly the same as in project 2.
- For our 4 choices of the adaptive update laws, the adaptive estimates do not converge to the actual parameter values.
- Implementation of the Adaptive update laws $\dot{\widehat{\theta}} = 0$ and $\dot{\widehat{\theta}} = 0.5\sin(t)$ illustrate that asymptotic tracking is achieved as long as the bound requirements on $\widehat{\theta}$ and $\dot{\widehat{\theta}}$ are satisfied even if they are some random functions of time.
- Adaptive update laws $\dot{\widehat{\theta}} = \Gamma Y_d^T \sin(e_2)$ and $\dot{\widehat{\theta}} = \Gamma Y_d^T \tanh(e_1)$ although valid candidates for the update law and are functions of the error signals, do not drive the adaptive estimate errors to zero. The adaptive estimates however do settle at some constant values with time.