a)

We know that,

$$Y = \begin{bmatrix} \theta 1'' & \cos(2*\theta 1'' + \theta 2'')-2 & \theta 2'' & -g*\sin(\theta 1) & -g*\sin(\theta 1+\theta 2) \\ 0 & \sin(\theta 2)(\theta 2''^2) + \cos(\theta 2)*\theta 1'' & \theta 1''+\theta 2' & 0 & -g*\sin(\theta 1+\theta 2) \end{bmatrix}$$

alpha = m2*l1ˆ2 + m1*r1ˆ2 + m2*r2ˆ2 + I1 + I2
m2*l1*r2
m2*r2ˆ2 + I2
m1*r1 + m2*l1
m2*r2

Y*alpha = [θ1''(m2 l1^2 + m1 r1^2 + m2 r2^2 + I1 + I2 + 2cos(θ1)m2l2r2) +
θ2''(m2l2+2sin(θ2)(2θ1'θ2 + θ2'^2) - g sin(θ1)(m1r1 + m2 l2) - g sin(θ1 + θ2) m2 r2

θ1''(I2+m2r2^2 + m2l1r2cos(θ2) + θ2'' (m2r2^2 + I2) + m2l1r2(sin(θ2))θ1'^2 - m2r2gsin(θ1+θ2)]

Manipulator form

M(q)*q'' + C(q,q') q' + g(q) = tau

By comparing tau = [tau1;tau2] using MATLAB we can safely say that,

Y*alpha = tau

b)

```
A = [0 0 1 0; 0 0 0 1; 0 0 0 0; 0 0 0 0];
B = [0 0; 0 0; 1 0; 0 1];

lambda = [-3 -3 -4 -4];

K = place(A, B, lambda);

Acl = A - B*K;

Q = eye(4).*10;

P = lyap(Acl',Q);
```

Adaptive controller design

Theta_ddot_1d, theta_ddot_2d → desired acceleration
Theta_1d, theta_2d → desired angles
Theta_dot_1d, theta_dot_2d → desired velocity

error = [theta_1; theta_2] - [theta_1d; theta_2d];

error_dot = [theta_dot_1; theta_dot_2] - [theta_dot_1d; theta_dot_2d];

v = [theta_ddot_1d;theta_ddot_2d]- K[error; error_dot];*

Designing control input 'U'

*U = M_hat * v + C_hat * [theta_dot_1; theta_dot_2] + G_hat;*

theta_ddots = M\(U - C[theta_dot_1; theta_dot_2] - G);*

Where M,C, and G are original matrices of the manipulator form

phi = M_hat\Y;

*gamma = eye(5)*0.3;*

*est_alpha_dot = -gamma\(phi'*B'*P*[error; error_dot]);*

d)

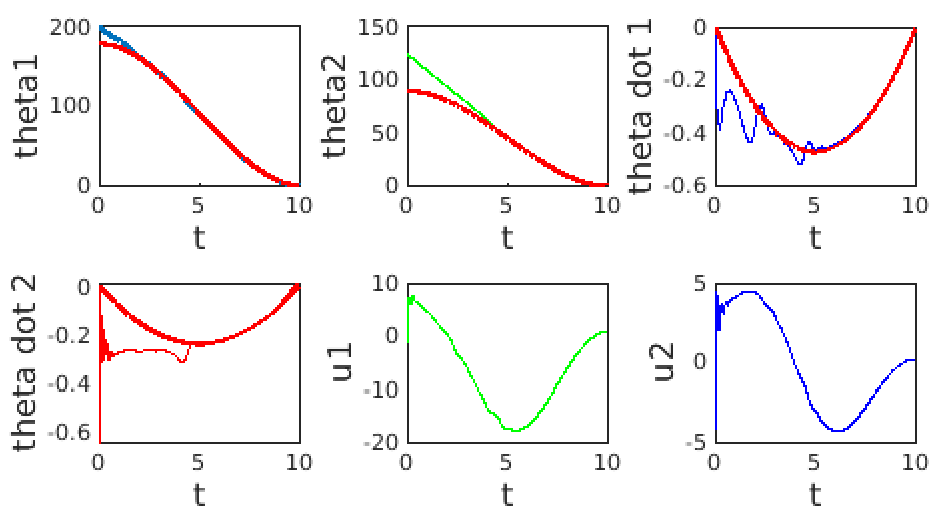

Figure 1: Adaptive control with P not equal to Zero

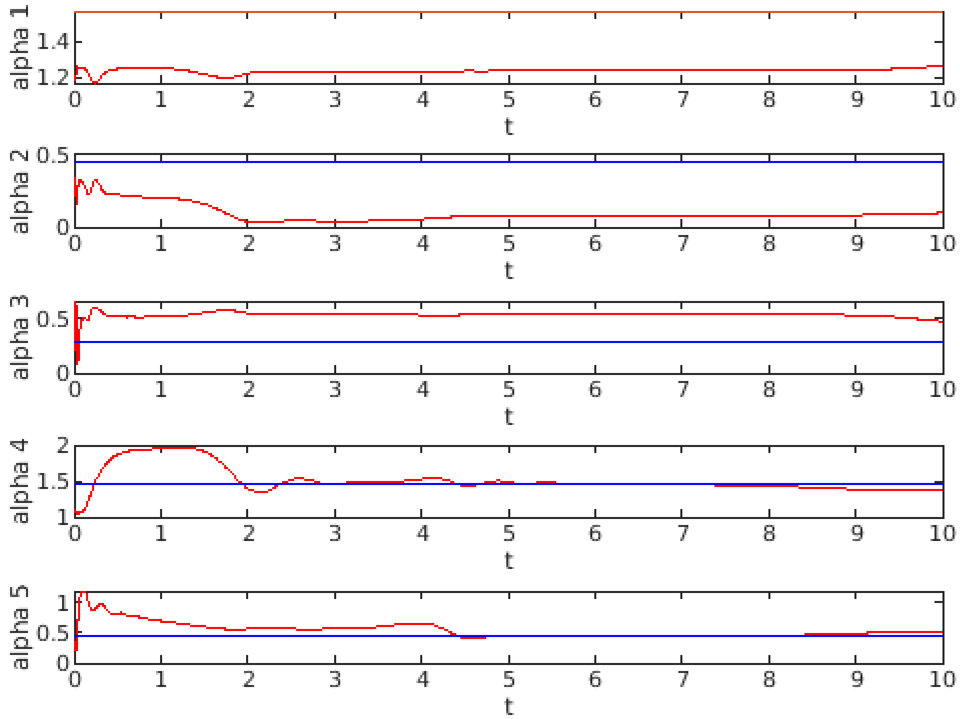

Figure 2: convergence using adaptive control (P non zero)

e)

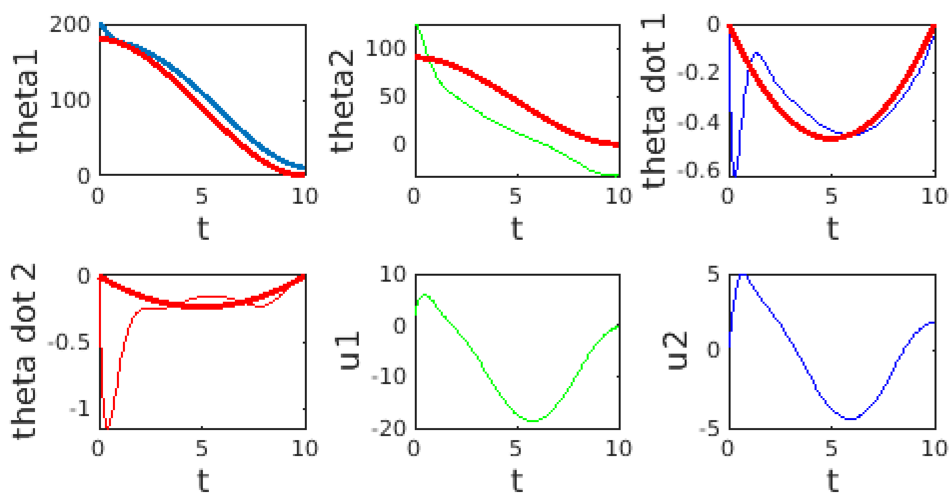

Figure 3: Adaptive control with P equal to Zero

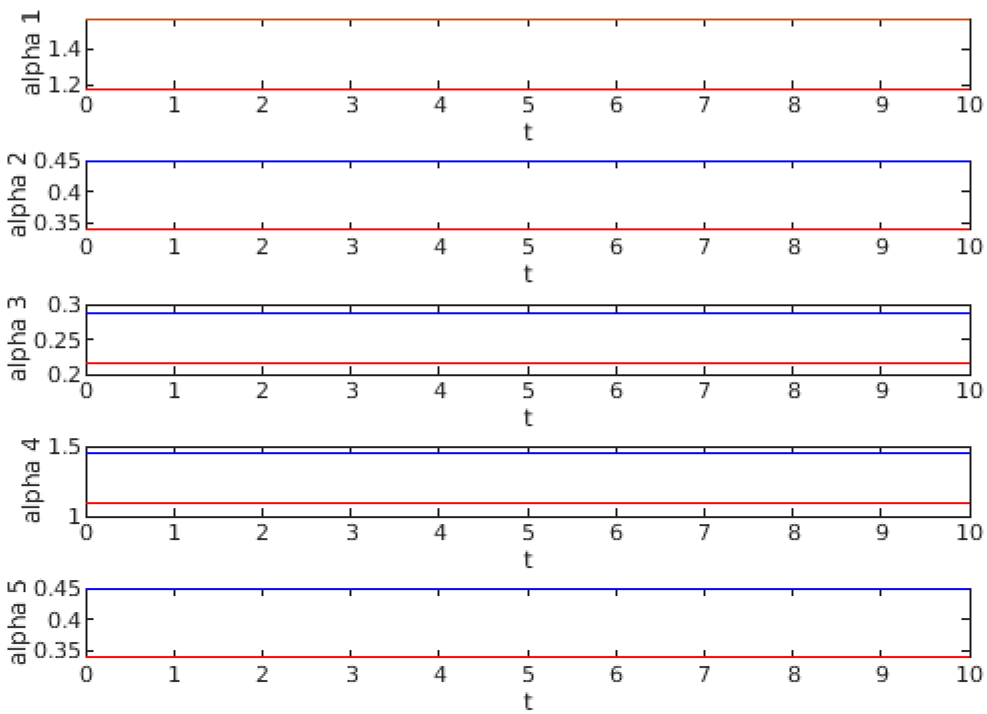

Figure 4: convergence using adaptive control (P zero)

As you can see from the Figure 4 that when P = 0, the adaptive alpha wouldn't converge to the desired value.

f)

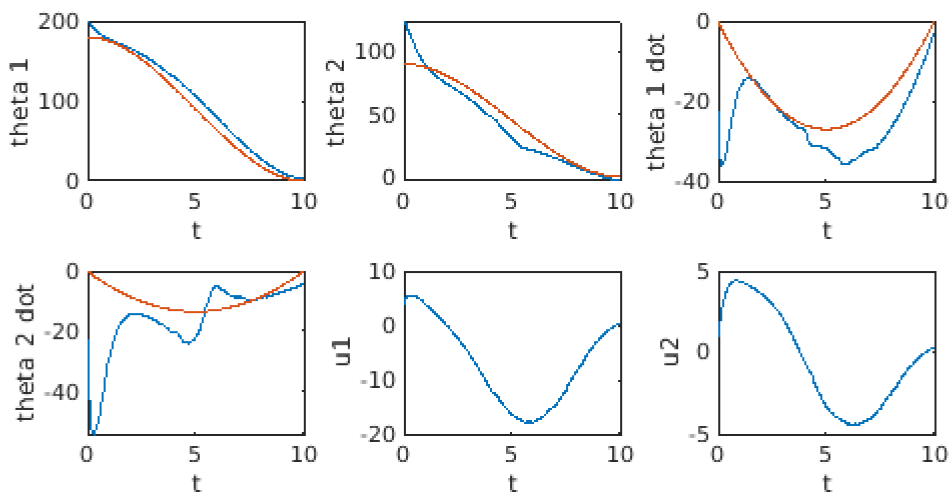

Figure 5: Plot from gazebo simulation