Question:

The components of a bilateral control system are given by

$$a_m(q_m)\ddot{q}_m + b(q_m, \dot{q}_m) + g(q_m) = \tau_m - \tau_h,$$

$$\tau = k_{tm} i_m,$$

$$a_s(q_s)\ddot{q}_s + b(q_s, \dot{q}_s) + g(q_s) = \tau_s - \tau_e,$$

$$\tau = k_{ts} i_s,$$

$$\tau_h = D_h(\dot{q}_m - \dot{q}_h) + k_h(q_m - q_h).$$

$$\tau_e = D_e(\dot{q}_s - \dot{q}_e) + k_e(q_s - q_e).$$

Further, parameters of the master and slave robots are given by

Master	**Slave**
$a_m = 0.1(1 + 0.5cos(12t))$ [kg]	$a_s = 0.1(1 + 0.5cos(12t))$ [kg]
$b_m = -16q_m - 8\dot{q}_m$ [N]	$b_s = -5q_s - 2\dot{q}_s$ [N]
$g_m = 0$ [N]	$g_s = 0$ [N]
$k_{tm} = 0.95(1 + 0.2cos(21t))$ [N]	$k_{ts} = 0.65(1 + 0.25cos(18t))$ [N]
$\tau_{mext} = 0$ [N]	$\tau_{sext} = 0$ [N]

Finally, properties of the operator and the environment at the interaction points are given using

Operator	**Environment**
$M_h = 0$ [kg]	$M_e = 0$ [kg]
$D_h = 5$ [kg/s]	$D_e = 10$ [kg/s]
$k_h = 150000$ [kg/s^2]	$k_e = 225000$ [kg/s^2]

- Design a bilateral control system that allows the slave robot to follow the trajectories of the operator, and allows the operator to sense the interaction forces at a remote environment;
- Comment on your results.