Middle Level Control

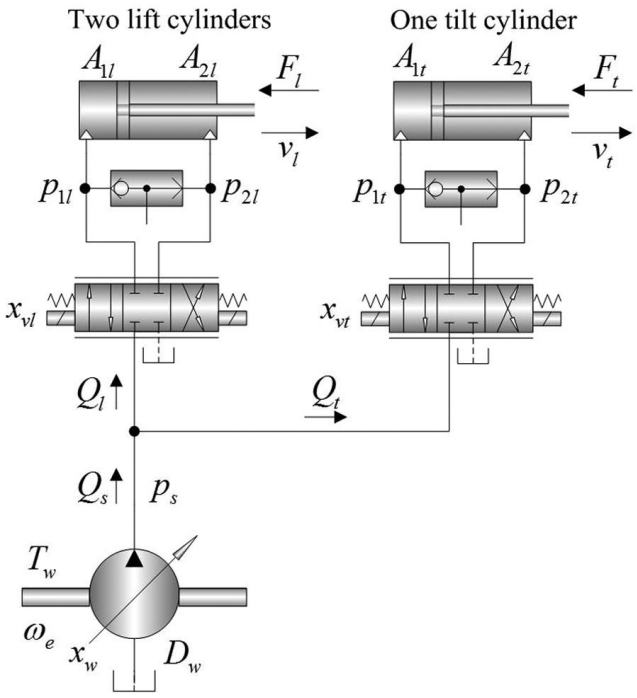


Figure. Working circuit model

The electric-hydraulic servo system is

$$m_l\ddot{x}_l = -k_l x_l - b_l\dot{x}_l + \bar{A}_L p_L - F_L \tag{1}$$

Define the load pressure as

$$p_L = \frac{A_{1l}}{\bar{A}_L}p_{1l} - \frac{A_{2l}}{\bar{A}_L}p_{2l} \tag{2}$$

Where $\bar{A}_L = \frac{A_{1l}+A_{2l}}{2}$

It is observed that the flow rates satisfy the following relationships

$$\frac{1}{A_{1l}}|Q_{1l}| = \frac{1}{A_{2l}}|Q_{2l}| \tag{3}$$

$$\dot{p}_L = \frac{E_h}{V_{LA}\bar{A}_L}\left(A_{1l}^2 + A_{2l}^2\right)\left(C_d A_{spool,l} u_L \sqrt{\frac{2}{\rho(A_{1l}^3 + A_{2l}^3)}\left(\bar{A}_L p_s + \text{sign}(u_L)\left(\Delta A_L p_s - \bar{A}_L p_L\right)\right)} - \dot{x}_l\right) \tag{4}$$

Where $\Delta A_L = \frac{A_{1l}-A_{2l}}{2}$

Define the state as $x = [x_l \quad \dot{x}_l \quad p_L]^T$.

The system can be expressed in the following state space representation:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -a_1 x_1 - a_2 x_2 + a_3 x_3 \\ \dot{x}_3 = -h_1 x_2 + h_2 u_L \sqrt{\bar{A}_L p_s - sgn(u_L)(\Delta A_L p_s - \bar{A}_L x_3)} \\ y = x_1 \end{cases} \quad (5)$$

Where

$$a_1 = \frac{k}{m}, a_2 = \frac{b}{m}, a_3 = \frac{\bar{A}_L}{m}$$

$$h_1 = \frac{E_h}{V_{LA}\bar{A}_L}(A_{1l}^2 + A_{2l}^2)$$

$$h_2 = \frac{E_h}{V_{LA}\bar{A}_L}(A_{1l}^2 + A_{2l}^2) C_d A_{spool,l} \sqrt{\frac{2}{\rho(A_{1l}^3 + A_{2l}^3)}}$$

Lift plant and tilt plant are both the system described above.

From lift and tilt position, we can get bucket trajectory.

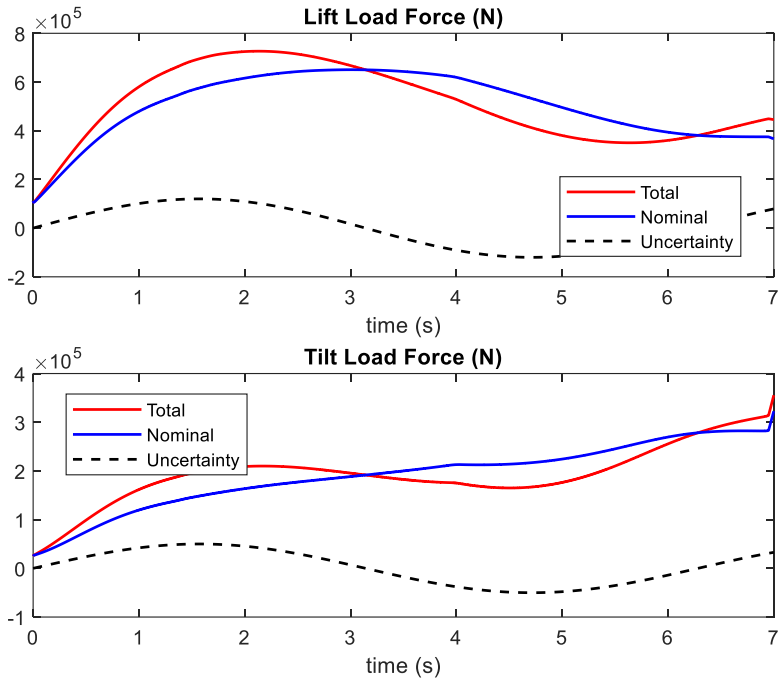
The force acting on the bucket tip is estimated using a model (fundamental earth moving equation) given the bucket tip trajectory. [1]

Then the load force on lift and tilt piston can be obtained through linkage mechanism, which is done by TAMU collaborators.

[1] Force-balancing algorithm to remove the discontinuity in soil force during wheel loader excavation

Tracking digging trajectory

The lift load on lift piston and tilt load force on tilt piston are shown below. Uncertainties are added.



Just Feedback controller (FB). In this case, a PI controller is adopted. The block diagram of the control architecture is shown below.

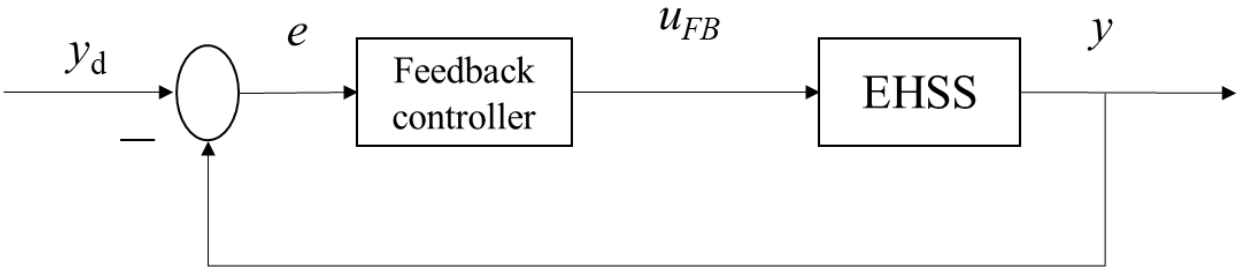
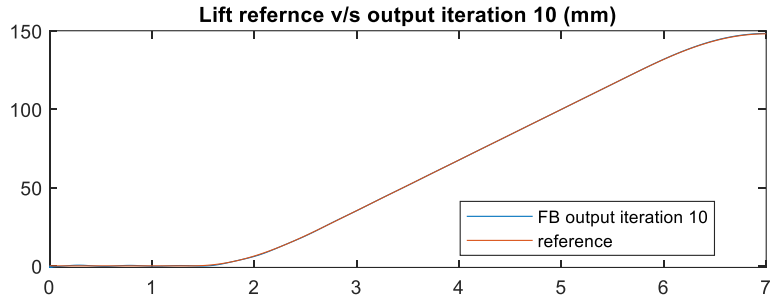
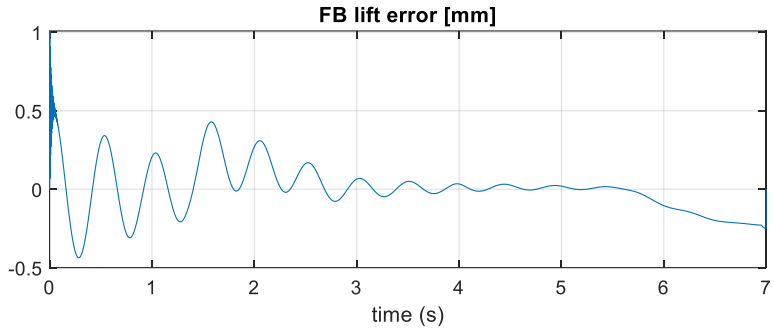
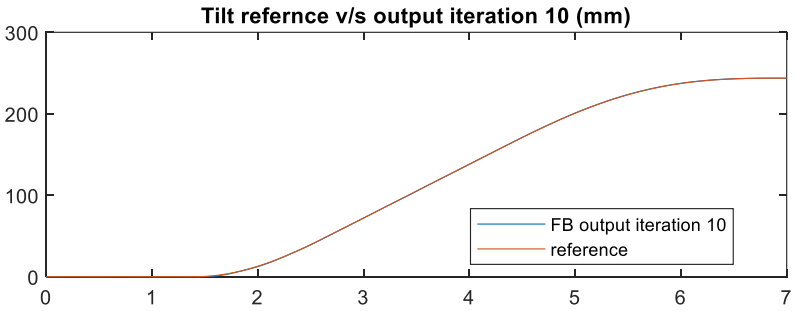


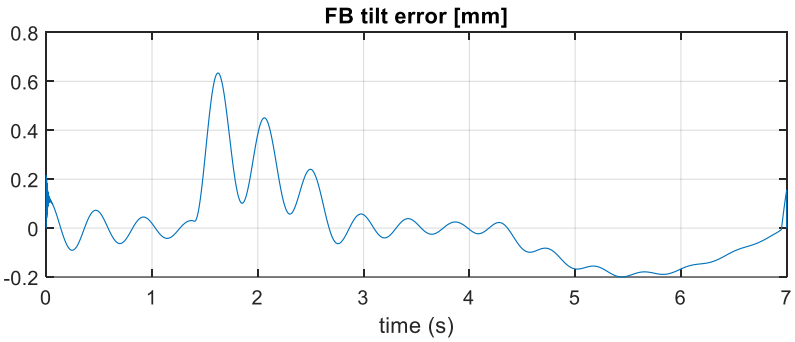
Figure 2. Control architecture

The tracking for lift and tilt piston positions are shown below.

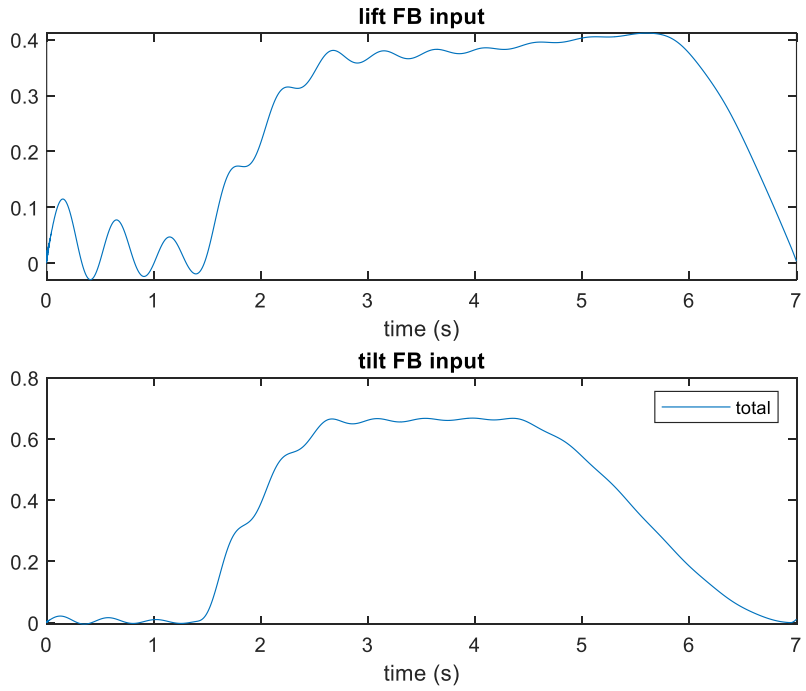








The control inputs for lift and tilt function are shown below.



Through linkage, the lift and tilt piston position can be converted to the bucket trajectory, which is shown below. One is reference, the other is the simulated result.