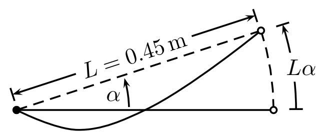
ECE 557: *Control, Signals, and Systems Laboratory*

Notes for Labs 8 and 9 (Position Control for a Flexible Link and a Flexible Joint)

1. Return PID pre-lab and give some notes (as in class, use **fixed-step** `ode45/ode5` solver in *Simulink*).
2. Return lead compensation post-lab and give notes (not just for speed: adds phase margin (and **noise**!)).
3. Review PID tuning rules (proportional/potential/power, integral/introduces, derivative/damping).
   - **P**roportional sets available control effort (think ***p**otential*/***p**ower*). Big impact on ω_d & *rise time*.
   - **I**ntegral reduces steady-state error but ***i**ntroduces* overshoot/lag (systems today are already slow).
   - **D**erivative reduces overshoot but can increase steady-state error (think ***d**amping*).
     - By damping *transients*, derivative can make system faster with respect to *settling time*.
     - A fast system *tracks* the input faster – transients quickly die out.
     - This statement does not simply involve the system's bandwidth.
     - If the system simply has high bandwidth but no damping, its transients may *ring* for a long time causing annoyance or instability.
     - But **too much** derivative can amplify noise or demand too much control effort.
4. Explain strain gage gain.
   - Book asks you to explain "how we obtained the strain [gage] gain" of 0.0254/0.45.
   - The book notes the length of the link is $L = 0.45\,\text{m}$ and hopes that you'll know the strain gage is calibrated to give you deflection in inches (note: $1\,\text{in} = 0.0254\,\text{m}$).
   - Despite what it seems, the strain gage gain is *not* simply a unit conversion from inches to meters.



     (i) As the link deflects, its shape changes and the strain gage, which is located near the axis of rotation, is stretched (or compressed). We measure the magnitude of this stretch.
     (ii) For **small** deflection α, the arc length $L\alpha$ is approximately equal to the elongation of the link under the bending stress.
     (iii) Given an approximation of the arc length $L\alpha$, dividing it by L gives an approximation of α.
     (iv) The strain gage is calibrated so that 1 in of deflection corresponds to 1 V of measurement.
   - So

$$\alpha \approx \overbrace{(\text{Measurement in V}) \times \frac{1\,\text{in}}{1\,\text{V}} \times \frac{0.0254\,\text{m}}{1\,\text{in}}}^{\sim L\alpha} \times \overbrace{\frac{1\,\text{radian}}{L = 0.45\,\text{m}}}^{\frac{\alpha}{L\alpha}} = \overbrace{(\text{Measurement in V}) \times \frac{0.0254}{0.45} \frac{\text{radians}}{\text{V}}}^{\sim\alpha}$$

   This **linear approximation** is only valid for **small** α. The actual relationship is nonlinear.

5. We use a **low** gear ratio, which is one reason why the system is **slower**.
   - The book uses the wrong term (i.e., references gearbox from unconventional side).
   - The **low** gear ratio causes a relatively high reduction in the speed of the motor compared to the **high** gear ratio.
   - The slow system is easier to control.

6. Complete the *Position Control for a Flexible Link and a Flexible Joint* labs.
   - ⋆ FOR PRACTICE, partners should **switch roles** between **joint** and **link** labs.
   - Implement PID control for position regulation of both **joint** *and* **link**.
     - In *Simulink*, choose Summers from Math section of library (change |++; adjust shape).
     - Do **not** use PID block. Use components from **Math** and **Continuous** (note: $K_i = 0$).
       - ∗ Implement K_p with gain.
       - ∗ **If needed**, implement K_i with (very small) gain and *integrator*.
       - ∗ Implement K_d with (very small) gain and **transfer function**.
         - · Use **transfer function** to implement $as/(s + a)$ "derivative+filter." Set $a = 200$.
         - · Wire from **output** and *not* error. Control will start far too high otherwise.
         - · Make sure you **subtract** eventual result (because we're wiring from *output*).
         - · These modifications slow response, but they make derivative *safe* and *realizable*.
     - *If you wish,* wire up a simulated system for comparison. Capture its output as well.
       - ∗ You might relate this to using an *observer* (a subject of ECE 650 and ECE 750).
     - ⋆ Because it is upside down, encoder for angle α for the ***JOINT*** needs a $\times -1$ gain as well.
     - ⋆ You **MUST** implement a **SAFETY STOP** to stop simulation on an extreme measurement.
       - ∗ Make sure DAC block has 0 V *Termination* checked **ON**.
       - ∗ Use *relational operator* to compare output to *constant* and trigger a *stop simulation*.
     - ⋆ **MAKE SURE** you change **saturation** settings to ±5 and **rate limiter** slew rate to ±1000.
   - For **link** configuration, adjust **alpha offset** so that $\alpha = 0$ at initial rest.
     - Run control with $K_p = K_i = K_d = 0$. Adjust **alpha offset** with *numeric input* until $\alpha = 0$.
   - PID tuning: **joint** ($t_s \leq 0.6\,\text{s}$ / P.O. $\leq 2\,\%$ / $e_{\text{ss}} \leq 0.5\,\%$) and **link** ($t_s \leq 0.6\,\text{s}$ / P.O. $\leq 5\,\%$ / $e_{\text{ss}} \leq 1\,\%$)
     - Initial output magnitude is K_p. If $K_p > 5$, initial output will be clipped.
     - Quantization noise from encoder makes derivative very noisy. Keep K_d very low.
     - Use numeric inputs in *ControlDesk* for tuning K_p and K_d gains.
     - **Save YOUR FINAL ITERATION** for the **joint** and for the **link**.
     - While tuning, recall the similar process in the gain compensation lab. Is PID more flexible?
   - You do not need separate controllers for the slow version of system, but keep slow system in mind when analyzing data in report! (e.g., compare expected *slow* response to data)
   - ⋆ AT ANY TIME, IF MOTOR STARTS CLICKING VERY QUICKLY, STOP THE EXPERIMENT – DISCONNECT THE MOTOR IF NECESSARY!! High-frequency switching can cause **permanent damage**! It can be caused by unstable systems (e.g., high gains or positive poles).
   - ⋆ This nominally type-1 system may still have some steady-state error due to nonlinearities. Because it is already slow and has a low gear ratio, only a **very little** integral control should be needed.
   - ⋆ The **dangling cables** can add significant dynamics. Keep them loose and out of the way.

- Tips:
  - Do **work** out of directory on **local** hard drive – use as MATLAB working directory.
  - In *Simulink*, the hotkey for building a model is Ctrl - B.
  - Start *dSPACE ControlDesk* before doing *Simulink* builds.
  - In MATLAB, change *Termination* settings for DAC block – check box to set 0 V stop value.
  - In *dSPACE* add a simState control.
    (i) Wire simState to 2-option radio button – Setup options "Run" (2) and "Stop" (0).
    (ii) Set Capture Settings to *automatically* restart and set *capture time* to simulation time.

    Restart simulation as needed by using simState control (i.e., no need to change modes).
    (i) To stop early, change simState to Stop.
    (ii) Before restarting, re-initialize Capture Settings by clicking Stop and then Start.
    (iii) When you're ready to start (e.g., after changing gains), set simState to Run.