ME 333 Introduction to Mechatronics
Assignment 2

1. You are designing a feedback control system for a robot joint using op amps. Let V_{ref} be a voltage that indicates the desired (reference) angle for the joint. Let V_{sens} be the voltage from a potentiometer on the joint that indicates the actual angle of the joint. You decide to use PID (proportional-integral-derivative) control to keep V_{sens} as close as possible to V_{ref}. This means that the control voltage you will send to the motor is equal to the sum of three terms:

1. K_P multiplied by the current error $V_{err} = V_{ref} - V_{sens}$, ($K_P$ is a constant)
2. K_I times the time-integral of the error (K_P is a constant)
3. K_D times the time-derivative of the error (the rate of change of the error).

K_P, K_I, and K_D are all constants. The proportional term is to try to correct the current error (like a spring pulling the joint to the desired angle), the derivative term is to try to anticipate future error (like a damper on the joint velocity error), and the integral term allows the control voltage to be non-zero even when there is no error. This is necessary, for example, for the robot joint to be stationary with zero error when it needs to apply a torque in a gravity field. Choosing K_P, K_I, and K_D is a topic for ME 391 or ECE 360.

For all of the following questions, use realistic resistor and/or capacitor values.
a. Design a circuit using op amps that calculates V_{err} from the inputs V_{ref} and V_{sens}.
b. Design an op amp circuit that takes in V_{err} and outputs $V_P = -10\ V_{err}$.
c. Design an op amp circuit that takes in V_{err} and outputs V_I, which is -2 times the time-integral of V_{err}.
d. Design an op amp circuit that takes in V_{err} and outputs V_D, which is -5 times the time-derivative of V_{err}.
e. Design an op amp circuit that takes in V_P, V_I, and V_D and outputs $V_{control} = -V_P - V_I - V_D$.

You have designed a PID control circuit. In practice, you could make a PID controller with fewer op-amps. You might use potentiometers instead of fixed resistors in the op amp circuits so you can easily change the controller gains K_P, K_I, and K_D. Also, you would likely need a low-pass filter on your error signal, or on the output of the derivative circuit, so there is not too much high-frequency noise due to the derivative term.

2. Calculate V_{out} as a function of V_1 and V_2 in the circuit below.