General Discussion for Lab 2

For this lab, I setup the following tasks.

The Trajectory Interpolator, running in the ISR for timer 0, a 10ms CTC timer.

The PDController, running in the ISR for timer 3, a 20ms CTC timer.

A millisecond timer, accurate to within %0.03, running in the ISR for timer 1, a 100us CTC timer.

A console user interface task, running in the main loop.

General functions for setting up CTC timers are in ktimers.[ch] You may specify a period in msec, a timer number (0, 1, or 3), a callback function and an argument to pass to the callback function. The callback function is invoked from the ISR. In this way, you can easily setup a function to be called and not remember the specifics of how to define an ISR. There is also an option to setup timer 1 or 3 as a millisecond timer, to replace the pololou functions like get_ms() that use timer 2 (which is being used for the motor speed) adjustment.

The kserial.[ch] files specify functions that perform serial I/O, including s_printf, used exactly like standard printf, except it writes to the serial output.

The kutils.[ch] files contain some useful functions, including functions to return whether interrupts are currently enabled, and macros BEGIN_ATOMIC and END_ATOMIC, which ensure that interrupts are disabled between them, and that interrupts are restored to their previous state afterward.

The kcmd.[ch] files contain functions that poll serial input each time they are called, accumulating characters until the user hits the enter key, when they return a value indicate a command has been entered. The command line is parsed into an argc/argv and a pre-registered function associated with argv[0], the command name, is invoked. This is easily extended to additional commands. The final list of commands I have written is

```
help or '?' {displays the following}
commands:
        L {start/stop logging Pr, Pm, and T}
        l {same as L}
        kp new_value {set/get current value of Kp}
        kd new_value {set/get current value of Kd}
        info {displays the following info}
                kp
                kd
                torque
                target-angle
                current-angle
```

max-acceleration
PDControl-period
acceleration factor {max acceleration will be MAX_TORQUE/factor}
torque new_value
rotate degrees {rotate the motor}
period {set msec period of PDControl task}
zero {stop motor, handlers, set angle to 0}
go
stop
xprog {run the canned program}
clock period nloops numerator denominator {test the 1 ms timer by setting a period}

You may notice that I removed the P, p, D, and d commands in favor of the kp/kd commands that allow setting of Kp or Kd to specific values rather than nudging them up or down. Other useful commands include

- period: for adjusting the period of the PDController
- acceleration: for adjusting the maximum allowed change in torque for each iteration of the PDController (this avoids jackrabbit starts and sudden stops)
- xprog: run the specified program (rotate 360, pause 0.5s, rotate -360, pause 0.5s, rotate 5).

I modified the logging output from what you asked. A line of log output looks like this:

19 Pr=2131, Pm=1954, T=1000, TC=1416, 8.00*177 + 0.00*0.0238, 1416 + 0, exceeds max

The first number is a line number. TC is the calculated torque, 1416 in this case. You can see that 8.00 is Kp, 177 is (Pr-Pm), 0.00 is Kd, and 0.0238 is the velocity, in degrees/ms. The 8.00*177 + 0.00*0.0238 simplifies to 1416 + 0, so you can easily see how all factors contribute. In addition, there may be additional adjustments made to the torque. In this case, "exceeds max" indicates the the value computed, 1416, exceeds the maximum allowed. In my system, torque must be in the range [-1000,1000].

Questions

1. Experiment with the speed of the motor: Run your motor at full speed. Modify your gains to achieve position control at that speed (as best you can). Slow the motor down as much as possible. Modify your gains to acheive position control. Repeat with one or two speeds in between. For each, record the approximate speed in rotations per second, record your equation (gains), and report on the behavior of the system and your ability to control the position.

My program allows dynamic setting of the period of the PDControl task. At 1 KHz, a period of 1 msec, the speed is not interesting because it is always measured as 0. You recommended checking the speed only sometimes during the task, but doing it this way means that you are

setting new torque every 1 msec but using a speed that was determined in the past. I opted instead to modify the period of the PDControl task. I experimented with this period, and a 100 msec there is significant overshoot in positioning, but at 20 msec the positioning is clean, and there is a measurable velocity. So I went with 20 msec.

My torque calculation uses the formula as given, with some additional modifications

T = Kp*(Pr-Pm) + Kd*Vm

Modification 1: I limit the change in torque from the previous iteration.

Modification 2: If the computed torque is too small to produce movement, but the target position is not yet reached, the minimum torque is applied.

With Kp=10 and Kd=-20, a rotation of 18000 degrees (18000/360=50 revolutions) takes 28.8 seconds, including the slight ramp-up and ramp-down time. This is 50/28.8=1.74 revolutions/sec. There is a slight overshoot with the gain this high.

This compares with setting the motor torque directly (ignoring the control tasks) and measuring the top speed at 100.0/54.63=1.83 revolutions/sec.

The minimum torque that reliably produces motion is 4.5% of full on. The speed at that setting is 2/37.8=0.053 revolutions/sec. This can be achieved by setting Kp=Kd=0 and relying on the modifications I stated above, that the minimum torque is applied.

Here is sample output with Kp=20, Kd=-1000, performing a rotation of 360 degrees. Note that my torque is specified in a range of [-1000,1000].

```
  1 Pr=180, Pm=0, T=250, TC=3600, 20.00*180 + -1000.00*0.0000, 3600 + 0, rapid acc,
exceeds max
  2 Pr=180, Pm=0, T=500, TC=3600, 20.00*180 + -1000.00*0.0000, 3600 + 0, rapid acc,
exceeds max
  3 Pr=182, Pm=2, T=750, TC=3595, 20.00*180 + -1000.00*0.0043, 3600 + -4, rapid acc,
exceeds max
  4 Pr=185, Pm=5, T=1000, TC=3593, 20.00*180 + -1000.00*0.0065, 3600 + -6, exceeds max
  5 Pr=191, Pm=11, T=1000, TC=3586, 20.00*180 + -1000.00*0.0130, 3600 + -13, exceeds max
  6 Pr=196, Pm=16, T=1000, TC=3589, 20.00*180 + -1000.00*0.0108, 3600 + -10, exceeds max
  7 Pr=205, Pm=25, T=1000, TC=3580, 20.00*180 + -1000.00*0.0194, 3600 + -19, exceeds max
  8 Pr=213, Pm=33, T=1000, TC=3582, 20.00*180 + -1000.00*0.0173, 3600 + -17, exceeds max
  9 Pr=222, Pm=45, T=1000, TC=3514, 20.00*177 + -1000.00*0.0260, 3540 + -25, exceeds max
 10 Pr=233, Pm=56, T=1000, TC=3516, 20.00*177 + -1000.00*0.0238, 3540 + -23, exceeds
max
 11 Pr=244, Pm=64, T=1000, TC=3582, 20.00*180 + -1000.00*0.0173, 3600 + -17, exceeds
max
```

12 Pr=255, Pm=78, T=1000, TC=3509, 20.00*177 + -1000.00*0.0303, 3540 + -30, exceeds max
13 Pr=267, Pm=87, T=1000, TC=3580, 20.00*180 + -1000.00*0.0194, 3600 + -19, exceeds max
14 Pr=278, Pm=101, T=1000, TC=3509, 20.00*177 + -1000.00*0.0303, 3540 + -30, exceeds max
15 Pr=289, Pm=109, T=1000, TC=3582, 20.00*180 + -1000.00*0.0173, 3600 + -17, exceeds max
16 Pr=300, Pm=123, T=1000, TC=3509, 20.00*177 + -1000.00*0.0303, 3540 + -30, exceeds max
17 Pr=312, Pm=135, T=1000, TC=3514, 20.00*177 + -1000.00*0.0259, 3540 + -25, exceeds max
18 Pr=323, Pm=146, T=1000, TC=3516, 20.00*177 + -1000.00*0.0238, 3540 + -23, exceeds max
19 Pr=334, Pm=157, T=1000, TC=3516, 20.00*177 + -1000.00*0.0238, 3540 + -23, exceeds max
20 Pr=345, Pm=168, T=1000, TC=3516, 20.00*177 + -1000.00*0.0238, 3540 + -23, exceeds max
21 Pr=360, Pm=182, T=1000, TC=3529, 20.00*178 + -1000.00*0.0303, 3560 + -30, exceeds max
22 Pr=360, Pm=194, T=1000, TC=3294, 20.00*166 + -1000.00*0.0260, 3320 + -25, exceeds max
23 Pr=360, Pm=205, T=1000, TC=3076, 20.00*155 + -1000.00*0.0238, 3100 + -23, exceeds max
24 Pr=360, Pm=216, T=1000, TC=2856, 20.00*144 + -1000.00*0.0238, 2880 + -23, exceeds max
25 Pr=360, Pm=227, T=1000, TC=2636, 20.00*133 + -1000.00*0.0238, 2660 + -23, exceeds max
26 Pr=360, Pm=239, T=1000, TC=2394, 20.00*121 + -1000.00*0.0260, 2420 + -25, exceeds max
27 Pr=360, Pm=253, T=1000, TC=2109, 20.00*107 + -1000.00*0.0302, 2140 + -30, exceeds max
28 Pr=360, Pm=264, T=1000, TC=1896, 20.00*96 + -1000.00*0.0238, 1920 + -23, exceeds max
29 Pr=360, Pm=275, T=1000, TC=1676, 20.00*85 + -1000.00*0.0238, 1700 + -23, exceeds max
30 Pr=360, Pm=286, T=1000, TC=1456, 20.00*74 + -1000.00*0.0238, 1480 + -23, exceeds max
31 Pr=360, Pm=300, T=1000, TC=1169, 20.00*60 + -1000.00*0.0302, 1200 + -30, exceeds max
32 Pr=360, Pm=312, T=934, TC=934, 20.00*48 + -1000.00*0.0260, 960 + -25
33 Pr=360, Pm=323, T=716, TC=716, 20.00*37 + -1000.00*0.0239, 740 + -23
34 Pr=360, Pm=334, T=496, TC=496, 20.00*26 + -1000.00*0.0239, 520 + -23

35 Pr=360, Pm=345, T=276, TC=276, 20.00*15 + -1000.00*0.0239, 300 + -23
36 Pr=360, Pm=357, T=45, TC=33, 20.00*3 + -1000.00*0.0261, 60 + -26, no movement
37 Pr=360, Pm=362, T=-50, TC=-50, 20.00*-2 + -1000.00*0.0109, -40 + -10
38 Pr=360, Pm=368, T=-173, TC=-173, 20.00*-8 + -1000.00*0.0130, -160 + -13
39 Pr=360, Pm=371, T=-226, TC=-226, 20.00*-11 + -1000.00*0.0065, -220 + -6
40 Pr=360, Pm=371, T=-220, TC=-220, 20.00*-11 + -1000.00*0.0000, -220 + 0
41 Pr=360, Pm=368, T=-153, TC=-153, 20.00*-8 + -1000.00*-0.0065, -160 + 6
42 Pr=360, Pm=365, T=-93, TC=-93, 20.00*-5 + -1000.00*-0.0065, -100 + 6
43 Pr=360, Pm=365, T=-100, TC=-100, 20.00*-5 + -1000.00*0.0000, -100 + 0
44 Pr=360, Pm=362, T=-45, TC=-33, 20.00*-2 + -1000.00*-0.0065, -40 + 6, no movement
45 Pr=360, Pm=362, T=-45, TC=-40, 20.00*-2 + -1000.00*0.0000, -40 + 0, no movement
46 Pr=360, Pm=360, T=0, TC=0, 20.00*0 + -1000.00*0.0000, 0 + 0

As you can see, Pr starts out at 180 and gradually moves to 360. That is because the trajectory interpolator gives PDControl a max delta of 180. You can see the effect of limiting the acceleration in the first few iterations. The calculated torque (given as TC), is larger than the max, and the change from zero can be at most 1/4 of 1000, or 250. That is why the torque used, T, goes from 0, to 250, to 500, to 750, and finally to 1000. Once the torque reaches 1000, it maxes out, despite the formula producing larger calculations. As we near the target of 360, the torque drops, but you can see that it overshoots to a maximum of 371 degrees. You also see that several times the computed torque was too small to produce motion, and so the minimum (+-45) was used.

Testing various values for Kd seem to make little difference. Here are the results with Kd=-2000.

1 Pr=180, Pm=0, T=250, TC=3600, 20.00*180 + -2000.00*0.0000, 3600 + 0, rapid acc, exceeds max

2 Pr=180, Pm=0, T=500, TC=3600, 20.00*180 + -2000.00*0.0000, 3600 + 0, rapid acc, exceeds max

3 Pr=182, Pm=2, T=750, TC=3591, 20.00*180 + -2000.00*0.0043, 3600 + -8, rapid acc, exceeds max

4 Pr=185, Pm=5, T=1000, TC=3586, 20.00*180 + -2000.00*0.0065, 3600 + -13, exceeds max

5 Pr=191, Pm=11, T=1000, TC=3573, 20.00*180 + -2000.00*0.0130, 3600 + -26, exceeds max

6 Pr=196, Pm=19, T=1000, TC=3505, 20.00*177 + -2000.00*0.0173, 3540 + -34, exceeds max

7 Pr=208, Pm=28, T=1000, TC=3561, 20.00*180 + -2000.00*0.0194, 3600 + -38, exceeds max

8 Pr=216, Pm=36, T=1000, TC=3565, 20.00*180 + -2000.00*0.0173, 3600 + -34, exceeds max

9 Pr=225, Pm=47, T=1000, TC=3512, 20.00*178 + -2000.00*0.0238, 3560 + -47, exceeds max

10 Pr=236, Pm=56, T=1000, TC=3561, 20.00*180 + -2000.00*0.0194, 3600 + -38, exceeds max

11 Pr=247, Pm=67, T=1000, TC=3552, 20.00*180 + -2000.00*0.0238, 3600 + -47, exceeds max

12 Pr=255, Pm=78, T=1000, TC=3492, 20.00*177 + -2000.00*0.0238, 3540 + -47, exceeds max

13 Pr=267, Pm=90, T=1000, TC=3488, 20.00*177 + -2000.00*0.0260, 3540 + -51, exceeds max

14 Pr=278, Pm=101, T=1000, TC=3492, 20.00*177 + -2000.00*0.0238, 3540 + -47, exceeds max

15 Pr=289, Pm=112, T=1000, TC=3492, 20.00*177 + -2000.00*0.0238, 3540 + -47, exceeds max

16 Pr=303, Pm=123, T=1000, TC=3552, 20.00*180 + -2000.00*0.0238, 3600 + -47, exceeds max

17 Pr=315, Pm=135, T=1000, TC=3548, 20.00*180 + -2000.00*0.0259, 3600 + -51, exceeds max

18 Pr=326, Pm=146, T=1000, TC=3552, 20.00*180 + -2000.00*0.0238, 3600 + -47, exceeds max

19 Pr=337, Pm=157, T=1000, TC=3552, 20.00*180 + -2000.00*0.0238, 3600 + -47, exceeds max

20 Pr=348, Pm=171, T=1000, TC=3479, 20.00*177 + -2000.00*0.0302, 3540 + -60, exceeds max

21 Pr=360, Pm=182, T=1000, TC=3512, 20.00*178 + -2000.00*0.0238, 3560 + -47, exceeds max

22 Pr=360, Pm=194, T=1000, TC=3268, 20.00*166 + -2000.00*0.0260, 3320 + -51, exceeds max

23 Pr=360, Pm=205, T=1000, TC=3052, 20.00*155 + -2000.00*0.0238, 3100 + -47, exceeds max

24 Pr=360, Pm=216, T=1000, TC=2832, 20.00*144 + -2000.00*0.0238, 2880 + -47, exceeds max

25 Pr=360, Pm=227, T=1000, TC=2612, 20.00*133 + -2000.00*0.0238, 2660 + -47, exceeds max

26 Pr=360, Pm=239, T=1000, TC=2368, 20.00*121 + -2000.00*0.0260, 2420 + -51, exceeds max

27 Pr=360, Pm=250, T=1000, TC=2152, 20.00*110 + -2000.00*0.0238, 2200 + -47, exceeds max

28 Pr=360, Pm=264, T=1000, TC=1859, 20.00*96 + -2000.00*0.0303, 1920 + -60, exceeds max

29 Pr=360, Pm=275, T=1000, TC=1652, 20.00*85 + -2000.00*0.0238, 1700 + -47, exceeds max

30 Pr=360, Pm=286, T=1000, TC=1432, 20.00*74 + -2000.00*0.0238, 1480 + -47, exceeds max

31 Pr=360, Pm=300, T=1000, TC=1139, 20.00*60 + -2000.00*0.0302, 1200 + -60, exceeds max

32 Pr=360, Pm=312, T=908, TC=908, 20.00*48 + -2000.00*0.0260, 960 + -51

33 Pr=360, Pm=323, T=692, TC=692, 20.00*37 + -2000.00*0.0239, 740 + -47

34 Pr=360, Pm=334, T=472, TC=472, 20.00*26 + -2000.00*0.0239, 520 + -47

35 Pr=360, Pm=345, T=252, TC=252, 20.00*15 + -2000.00*0.0239, 300 + -47

36 Pr=360, Pm=354, T=80, TC=80, 20.00*6 + -2000.00*0.0196, 120 + -39

37 Pr=360, Pm=362, T=-74, TC=-74, 20.00*-2 + -2000.00*0.0174, -40 + -34

38 Pr=360, Pm=365, T=-113, TC=-113, 20.00*-5 + -2000.00*0.0065, -100 + -13

39 Pr=360, Pm=368, T=-173, TC=-173, 20.00*-8 + -2000.00*0.0065, -160 + -13

40 Pr=360, Pm=368, T=-160, TC=-160, 20.00*-8 + -2000.00*0.0000, -160 + 0

41 Pr=360, Pm=365, T=-87, TC=-87, 20.00*-5 + -2000.00*-0.0065, -100 + 12

42 Pr=360, Pm=365, T=-100, TC=-100, 20.00*-5 + -2000.00*0.0000, -100 + 0

43 Pr=360, Pm=362, T=-45, TC=-27, 20.00*-2 + -2000.00*-0.0065, -40 + 12, no movement

44 Pr=360, Pm=362, T=-45, TC=-40, 20.00*-2 + -2000.00*0.0000, -40 + 0, no movement

45 Pr=360, Pm=360, T=0, TC=0, 20.00*0 + -2000.00*0.0000, 0 + 0

You can see that the overshoot is slightly smaller with Kd=-2000, but it gets to the target sooner, with 45 lines of log output rather than 46 previously.

Experimenting with various values shows that a value of Kp=10 and Kd=-1000 produce very smooth results:

```
  1 Pr=180, Pm=0, T=250, TC=1800, 10.00*180 + -1000.00*0.0000, 1800 + 0, rapid acc, exceeds max
  2 Pr=180, Pm=0, T=500, TC=1800, 10.00*180 + -1000.00*0.0000, 1800 + 0, rapid acc, exceeds max
  3 Pr=182, Pm=2, T=750, TC=1795, 10.00*180 + -1000.00*0.0043, 1800 + -4, rapid acc, exceeds max
  4 Pr=185, Pm=5, T=1000, TC=1793, 10.00*180 + -1000.00*0.0065, 1800 + -6, exceeds max
  5 Pr=191, Pm=11, T=1000, TC=1786, 10.00*180 + -1000.00*0.0130, 1800 + -13, exceeds max
  6 Pr=196, Pm=19, T=1000, TC=1752, 10.00*177 + -1000.00*0.0173, 1770 + -17, exceeds max
  7 Pr=205, Pm=28, T=1000, TC=1750, 10.00*177 + -1000.00*0.0195, 1770 + -19, exceeds max
  8 Pr=213, Pm=36, T=1000, TC=1752, 10.00*177 + -1000.00*0.0173, 1770 + -17, exceeds max
  9 Pr=225, Pm=45, T=1000, TC=1780, 10.00*180 + -1000.00*0.0194, 1800 + -19, exceeds max
 10 Pr=236, Pm=56, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds max
 11 Pr=244, Pm=67, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
 12 Pr=255, Pm=78, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
 13 Pr=267, Pm=90, T=1000, TC=1744, 10.00*177 + -1000.00*0.0259, 1770 + -25, exceeds max
 14 Pr=281, Pm=101, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds max
 15 Pr=292, Pm=115, T=1000, TC=1739, 10.00*177 + -1000.00*0.0303, 1770 + -30, exceeds max
 16 Pr=303, Pm=126, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
 17 Pr=315, Pm=137, T=1000, TC=1756, 10.00*178 + -1000.00*0.0238, 1780 + -23, exceeds max
 18 Pr=329, Pm=149, T=1000, TC=1774, 10.00*180 + -1000.00*0.0260, 1800 + -25, exceeds max
 19 Pr=340, Pm=160, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds max
 20 Pr=351, Pm=171, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds max
 21 Pr=360, Pm=182, T=1000, TC=1756, 10.00*178 + -1000.00*0.0238, 1780 + -23, exceeds max
```

22 Pr=360, Pm=196, T=1000, TC=1609, 10.00*164 + -1000.00*0.0303, 1640 + -30, exceeds max
23 Pr=360, Pm=208, T=1000, TC=1494, 10.00*152 + -1000.00*0.0259, 1520 + -25, exceeds max
24 Pr=360, Pm=219, T=1000, TC=1386, 10.00*141 + -1000.00*0.0238, 1410 + -23, exceeds max
25 Pr=360, Pm=230, T=1000, TC=1276, 10.00*130 + -1000.00*0.0238, 1300 + -23, exceeds max
26 Pr=360, Pm=244, T=1000, TC=1129, 10.00*116 + -1000.00*0.0302, 1160 + -30, exceeds max
27 Pr=360, Pm=255, T=1000, TC=1026, 10.00*105 + -1000.00*0.0238, 1050 + -23, exceeds max
28 Pr=360, Pm=267, T=904, TC=904, 10.00*93 + -1000.00*0.0260, 930 + -25
29 Pr=360, Pm=278, T=796, TC=796, 10.00*82 + -1000.00*0.0239, 820 + -23
30 Pr=360, Pm=289, T=686, TC=686, 10.00*71 + -1000.00*0.0239, 710 + -23
31 Pr=360, Pm=300, T=576, TC=576, 10.00*60 + -1000.00*0.0239, 600 + -23
32 Pr=360, Pm=312, T=453, TC=453, 10.00*48 + -1000.00*0.0261, 480 + -26
33 Pr=360, Pm=323, T=346, TC=346, 10.00*37 + -1000.00*0.0239, 370 + -23
34 Pr=360, Pm=331, T=272, TC=272, 10.00*29 + -1000.00*0.0174, 290 + -17
35 Pr=360, Pm=340, T=180, TC=180, 10.00*20 + -1000.00*0.0196, 200 + -19
36 Pr=360, Pm=345, T=139, TC=139, 10.00*15 + -1000.00*0.0109, 150 + -10
37 Pr=360, Pm=351, T=76, TC=76, 10.00*9 + -1000.00*0.0130, 90 + -13
38 Pr=360, Pm=354, T=53, TC=53, 10.00*6 + -1000.00*0.0065, 60 + -6
39 Pr=360, Pm=357, T=45, TC=23, 10.00*3 + -1000.00*0.0065, 30 + -6, no movement
40 Pr=360, Pm=360, T=0, TC=0, 10.00*0 + -1000.00*0.0000, 0 + 0

You can see that there is no overshoot, and there are only 40 lines of log output.

2. Change the step size to something very large (more than 2pi), and try a reference position of 4pi+current_position. How does system behavior differ from your tuned step size? Try tuning your controller for that very large step size. What happens if you then set the reference position to be very close to the current position (within a few degrees)?

The controller is requires no special tuning for different step sizes. Here is sample output for a rotation of 720 degrees.

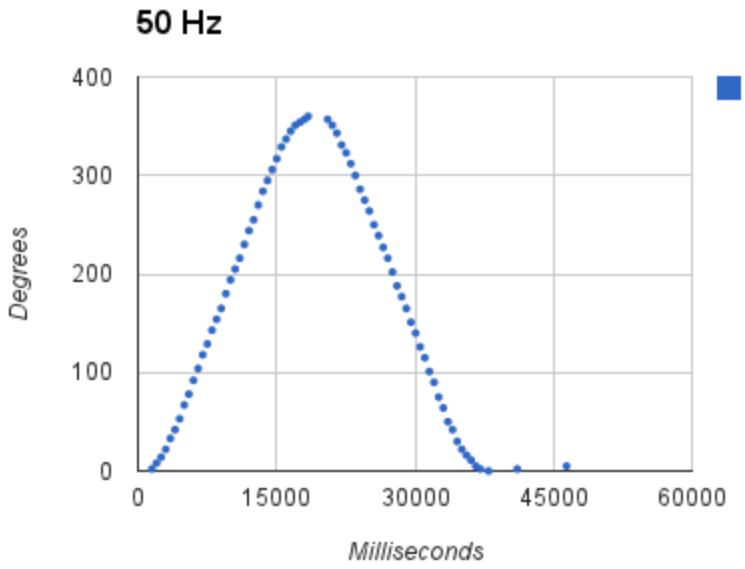
1 Pr=180, Pm=0, T=250, TC=1800, 10.00*180 + -1000.00*0.0000, 1800 + 0, rapid acc, exceeds max
2 Pr=180, Pm=0, T=500, TC=1800, 10.00*180 + -1000.00*0.0000, 1800 + 0, rapid acc, exceeds max
3 Pr=182, Pm=2, T=750, TC=1795, 10.00*180 + -1000.00*0.0043, 1800 + -4, rapid acc, exceeds max
4 Pr=185, Pm=5, T=1000, TC=1793, 10.00*180 + -1000.00*0.0065, 1800 + -6, exceeds max
5 Pr=191, Pm=11, T=1000, TC=1786, 10.00*180 + -1000.00*0.0130, 1800 + -13, exceeds max

6 Pr=196, Pm=19, T=1000, TC=1752, 10.00*177 + -1000.00*0.0173, 1770 + -17, exceeds max
7 Pr=208, Pm=28, T=1000, TC=1780, 10.00*180 + -1000.00*0.0195, 1800 + -19, exceeds max
8 Pr=216, Pm=36, T=1000, TC=1782, 10.00*180 + -1000.00*0.0173, 1800 + -17, exceeds max
9 Pr=225, Pm=47, T=1000, TC=1756, 10.00*178 + -1000.00*0.0238, 1780 + -23, exceeds max
10 Pr=236, Pm=56, T=1000, TC=1780, 10.00*180 + -1000.00*0.0194, 1800 + -19, exceeds max
11 Pr=247, Pm=67, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds max
12 Pr=258, Pm=78, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds max
13 Pr=270, Pm=92, T=1000, TC=1749, 10.00*178 + -1000.00*0.0302, 1780 + -30, exceeds max
14 Pr=281, Pm=104, T=1000, TC=1744, 10.00*177 + -1000.00*0.0260, 1770 + -25, exceeds max
15 Pr=292, Pm=115, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
16 Pr=303, Pm=126, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
17 Pr=317, Pm=137, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds max
18 Pr=329, Pm=149, T=1000, TC=1774, 10.00*180 + -1000.00*0.0260, 1800 + -25, exceeds max
19 Pr=340, Pm=160, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds max
20 Pr=351, Pm=174, T=1000, TC=1739, 10.00*177 + -1000.00*0.0302, 1770 + -30, exceeds max
21 Pr=362, Pm=185, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
22 Pr=374, Pm=196, T=1000, TC=1756, 10.00*178 + -1000.00*0.0238, 1780 + -23, exceeds max
23 Pr=385, Pm=208, T=1000, TC=1744, 10.00*177 + -1000.00*0.0259, 1770 + -25, exceeds max
24 Pr=399, Pm=222, T=1000, TC=1739, 10.00*177 + -1000.00*0.0303, 1770 + -30, exceeds max
25 Pr=410, Pm=233, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
26 Pr=421, Pm=244, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
27 Pr=435, Pm=255, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds max
28 Pr=447, Pm=267, T=1000, TC=1774, 10.00*180 + -1000.00*0.0260, 1800 + -25, exceeds max
29 Pr=458, Pm=278, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds

max
30 Pr=469, Pm=289, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds max
31 Pr=480, Pm=303, T=1000, TC=1739, 10.00*177 + -1000.00*0.0303, 1770 + -30, exceeds max
32 Pr=492, Pm=315, T=1000, TC=1744, 10.00*177 + -1000.00*0.0260, 1770 + -25, exceeds max
33 Pr=506, Pm=329, T=1000, TC=1739, 10.00*177 + -1000.00*0.0303, 1770 + -30, exceeds max
34 Pr=517, Pm=340, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
35 Pr=528, Pm=351, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
36 Pr=542, Pm=365, T=1000, TC=1739, 10.00*177 + -1000.00*0.0303, 1770 + -30, exceeds max
37 Pr=554, Pm=376, T=1000, TC=1756, 10.00*178 + -1000.00*0.0238, 1780 + -23, exceeds max
38 Pr=565, Pm=388, T=1000, TC=1744, 10.00*177 + -1000.00*0.0260, 1770 + -25, exceeds max
39 Pr=579, Pm=399, T=1000, TC=1776, 10.00*180 + -1000.00*0.0238, 1800 + -23, exceeds max
40 Pr=590, Pm=413, T=1000, TC=1739, 10.00*177 + -1000.00*0.0303, 1770 + -30, exceeds max
41 Pr=601, Pm=424, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
42 Pr=615, Pm=438, T=1000, TC=1739, 10.00*177 + -1000.00*0.0303, 1770 + -30, exceeds max
43 Pr=627, Pm=450, T=1000, TC=1744, 10.00*177 + -1000.00*0.0260, 1770 + -25, exceeds max
44 Pr=641, Pm=464, T=1000, TC=1739, 10.00*177 + -1000.00*0.0302, 1770 + -30, exceeds max
45 Pr=652, Pm=475, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
46 Pr=663, Pm=486, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max
47 Pr=677, Pm=500, T=1000, TC=1739, 10.00*177 + -1000.00*0.0302, 1770 + -30, exceeds max
48 Pr=689, Pm=511, T=1000, TC=1756, 10.00*178 + -1000.00*0.0238, 1780 + -23, exceeds max
49 Pr=700, Pm=523, T=1000, TC=1744, 10.00*177 + -1000.00*0.0260, 1770 + -25, exceeds max
50 Pr=711, Pm=534, T=1000, TC=1746, 10.00*177 + -1000.00*0.0238, 1770 + -23, exceeds max

51 Pr=720, Pm=548, T=1000, TC=1689, 10.00*172 + -1000.00*0.0302, 1720 + -30, exceeds max
52 Pr=720, Pm=559, T=1000, TC=1586, 10.00*161 + -1000.00*0.0238, 1610 + -23, exceeds max
53 Pr=720, Pm=570, T=1000, TC=1476, 10.00*150 + -1000.00*0.0238, 1500 + -23, exceeds max
54 Pr=720, Pm=582, T=1000, TC=1354, 10.00*138 + -1000.00*0.0259, 1380 + -25, exceeds max
55 Pr=720, Pm=596, T=1000, TC=1209, 10.00*124 + -1000.00*0.0303, 1240 + -30, exceeds max
56 Pr=720, Pm=607, T=1000, TC=1106, 10.00*113 + -1000.00*0.0238, 1130 + -23, exceeds max
57 Pr=720, Pm=621, T=959, TC=959, 10.00*99 + -1000.00*0.0303, 990 + -30
58 Pr=720, Pm=632, T=856, TC=856, 10.00*88 + -1000.00*0.0239, 880 + -23
59 Pr=720, Pm=644, T=733, TC=733, 10.00*76 + -1000.00*0.0261, 760 + -26
60 Pr=720, Pm=655, T=626, TC=626, 10.00*65 + -1000.00*0.0239, 650 + -23
61 Pr=720, Pm=666, T=516, TC=516, 10.00*54 + -1000.00*0.0239, 540 + -23
62 Pr=720, Pm=677, T=406, TC=406, 10.00*43 + -1000.00*0.0239, 430 + -23
63 Pr=720, Pm=689, T=283, TC=283, 10.00*31 + -1000.00*0.0261, 310 + -26
64 Pr=720, Pm=694, T=249, TC=249, 10.00*26 + -1000.00*0.0109, 260 + -10
65 Pr=720, Pm=703, T=150, TC=150, 10.00*17 + -1000.00*0.0196, 170 + -19
66 Pr=720, Pm=708, T=109, TC=109, 10.00*12 + -1000.00*0.0109, 120 + -10
67 Pr=720, Pm=714, T=46, TC=46, 10.00*6 + -1000.00*0.0130, 60 + -13
68 Pr=720, Pm=717, T=45, TC=23, 10.00*3 + -1000.00*0.0065, 30 + -6, no movement
69 Pr=720, Pm=717, T=45, TC=30, 10.00*3 + -1000.00*0.0000, 30 + 0, no movement
70 Pr=720, Pm=720, T=0, TC=0, 10.00*0 + -1000.00*0.0000, 0 + 0

3. Using your optimally tuned values for the PD controller running at 1kHz, graph Pm, Pr and T while executing the trajectory: rotate the motor forward 360 degrees, hold for .5 seconds, then rotate backwards for 360 degrees, hold for .5 seconds, rotate forwards for 5 degrees. Be sure to graph the entire trajectory.



4. Run your PD controller at 50Hz and 5Hz while graphing the same variables. Discuss the results.

50 Hz was my default operating mode, graphed in question 3 above.

Note: at this period, in order to get my build-in program to properly realize that the destination angle had been reached, I had to modify SETTLE_TIME in lab2.c to 500 msec. This could have been avoided with a better method of calculating velocity.

In the graph below, you see that it overshoots quite a bit. At 5 Hz, the PDController's measurements are too far behind what is actually happening, so it is always correcting too late.