ECE-320 Lab 7:

Utilizing a dsPIC30F6015 to control the speed of a wheel

<u>Overview:</u> *In this lab we will utilize the dsPIC30F6015 to implement P, I, and PI controllers to control the speed of a wheel. Most of the initial code will be given to you (see the class website), and you will have to modify the code as you go on. One of the things you will discover is that you often need to be aware of limitations of both hardware and software when you try to implement a controller. The dsPIC30F6015 has been mounted on a carrier board that allows us to communicate with a terminal (your laptop) via a USB cable. In what follows you will need to make reference to the pin out of the dsPIC30F6015 (shown in Figure 1) and the corresponding pins on the carrier (shown in Figure 2)*

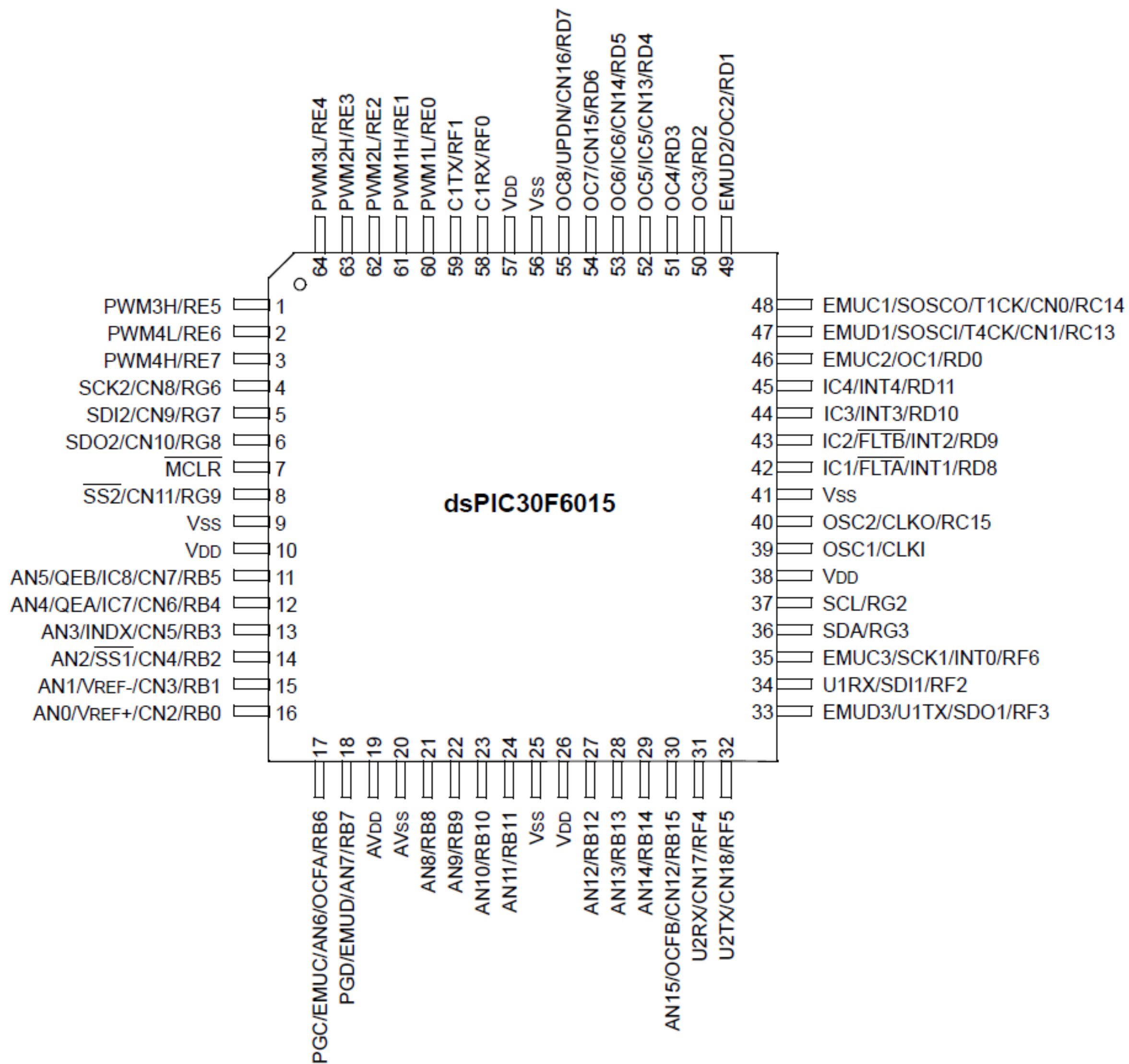


Figure 1. dsPIC30F6015 64-PIN pinout.

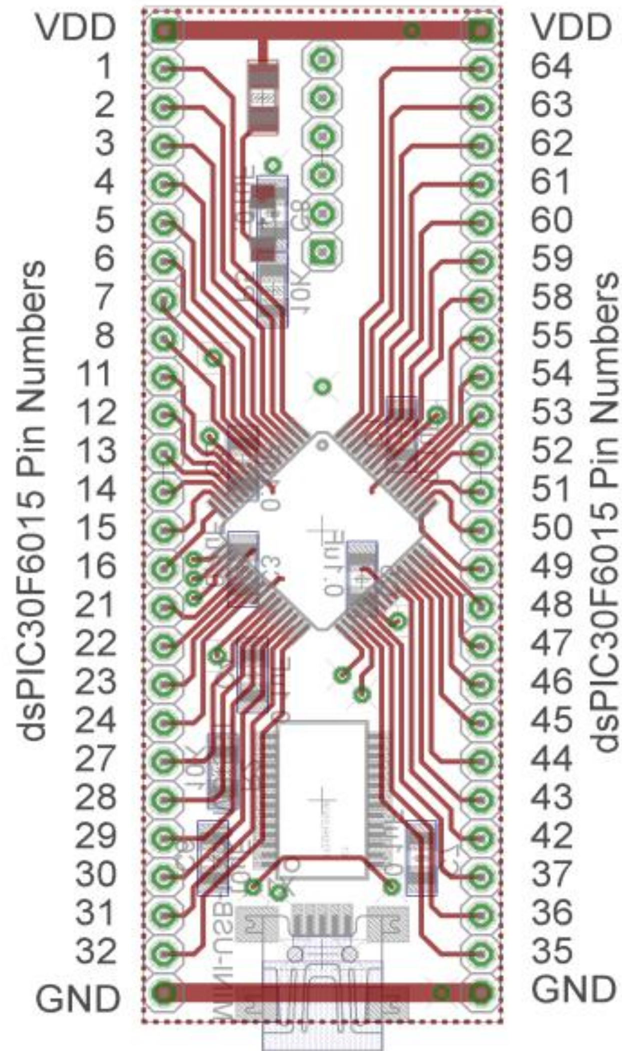


Figure 2. dsPIC30F6015 carrier. Note that the pin numbers are not consecutive.

Part A (Copying the initial files)

Set up a new folder for this lab, and copy the files for this lab from the class website to this folder.

Part B (Putting it all together)

Now we are ready to start. Note that at some point in the following process you may need to let the system download firmware. Be sure you have selected the correct device (or it will do this twice).

Start **MPLAB X IDE (not IPE)**

Select **File**, then **New Project** (the screen should default to Mocrochip Embedded and Standalone Project)

Click on **Next**

In the *Select Device* section, select the following:

Family: **16-bit DSCs (dsPIC30)**

Device: **dsPIC30F6015**

Click on **Next**

In the *Select Tool* section, select **PICkit3**

Click on **Next**

In the *Select Compiler* section, select **XC16**

Click on **Next**

In the Select Project Name and Folder section, choose a name and project location

Click on **Finish**

Make sure the file lab7.c is in the Project folder. Right click on **Source Files**, then on **Add Existing Item**, then select lab7.c

Double click on lab7.c and the code will open in a new window.

You should **build (compile)** the existing program**, download** it to the dsPIC**,** and **run** it**.** You should see a sequence of numbers on your screen (the secure CRT screen). These correspond to sample times.

If you see the following message

You are trying to change protected boot and secure memory. In order to do this you must select the "Boot, Secure and General Segments" option on the debug tool Secure Segment properties page.

Failed to program device

Then

- Right Click on the **Project Name** and select **Properties**
- Under **Categories** in the left panel**,** click on **PICkit3**
- Under **Option categories** at the top, select **Secure Segment**
- On the right select **Boot, Secure, and General Segments**
- Then select ok at the bottom.

Your program should now compile.

Part C: Reading in the sensor transducer

In order to determine how fast the motor is spinning, we will need to use the QEI interface. The sensor is connected to the center of the wheel, and the other end of the sensor plugs into the breadboard. The pins for the interface are shown in Figure 3. You need to connect this interface to +5 volts (red), ground (blue), and the QEA Channel A input (pin 12), and the QEA Channel B input (pin 11).

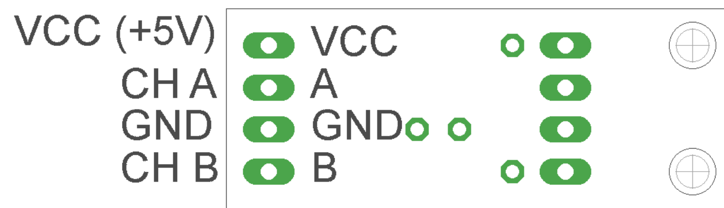


Figure 3. Encoder pin outs.

Part D (Reading in an A/D value)

Now we want to be able to connect a potentiometer as shown in Figure 4 so we can have a variable reference. The software is currently set up for A/D input on AN3/RB3 (pin 13). You will need to do the following things:

- Connect the potentiometer as shown below
- Set the appropriate TRIS bits for an input signal

Note that this is the same set-up as was used in Lab6.

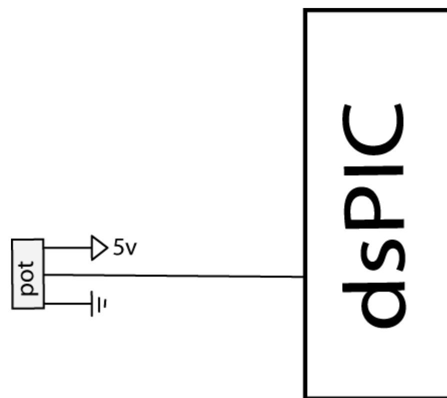


Figure 4. Connecting the potentiometer

Part E: Connecting the power entry

Plug in both the 5 volt (green) and 12 volt (red) power supplies, as shown in Figure 5. Do not turn on the supplies yet (the LEDs should be off) .

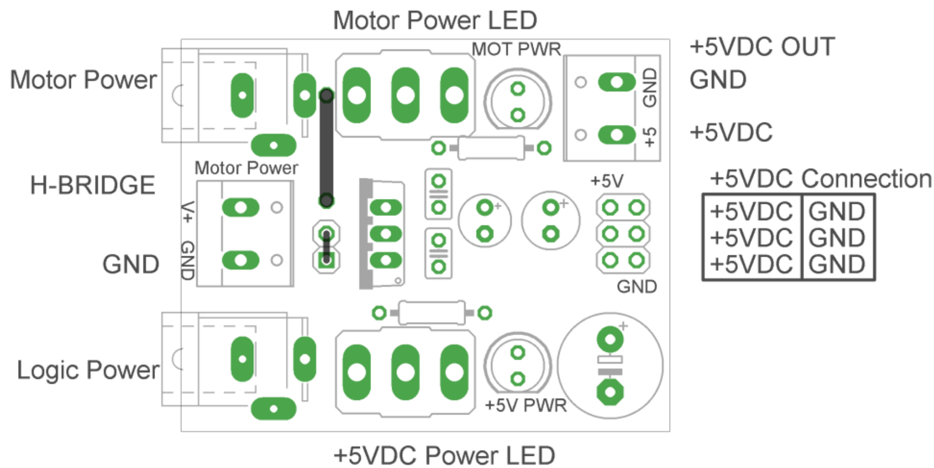


Figure 5. Power entry module.

Part F: Connecting the H bridge

Plug in the H-bridge, shown in Figure 6. You are going to need access to the different pins, so be sure it is located in a place you can easily get wires to.

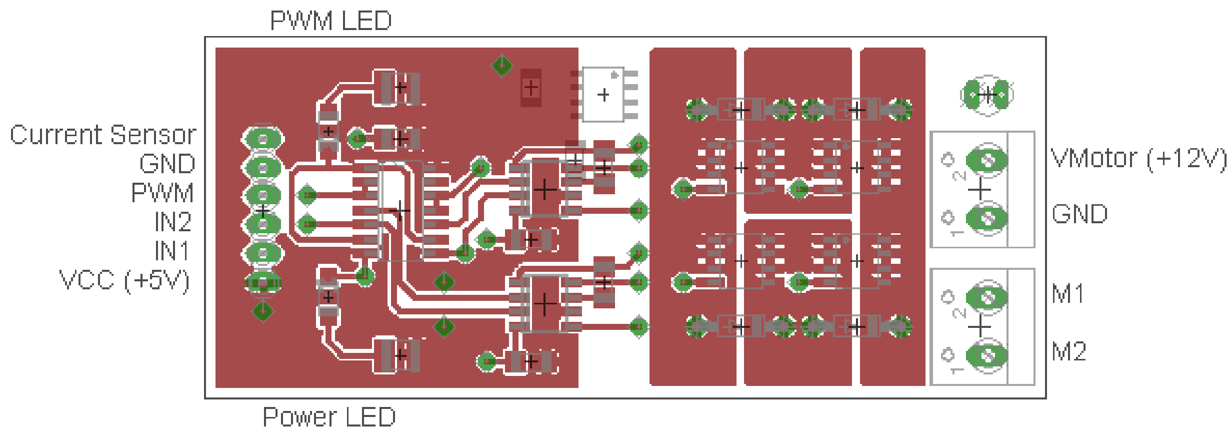


Figure 6. H Bridge connections

Starting on the left, connect the ground and +5 volt supplies. Next, connect IN1 to RE6 (pin 2) and IN2 to RE7 (pin 3). (Note that if the motor speed is negative you may want to reverse these connections.) Finally connect PWM to PWM 3 high (pin 1).

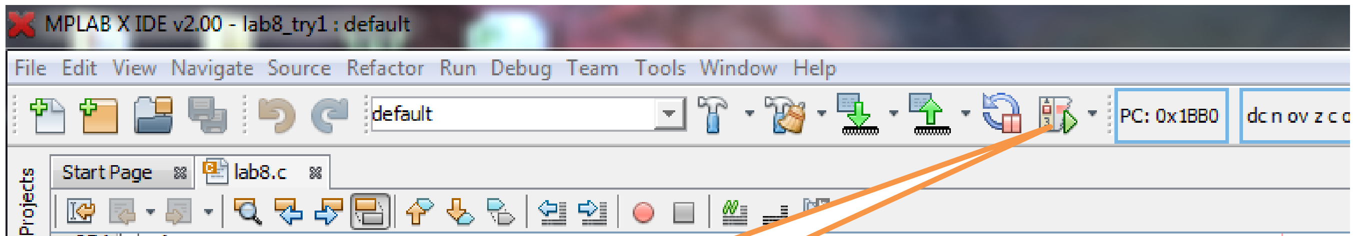
Starting on the right, connect (with the twisted wires) the 12 volt power from the power entry module to the 12 volt input. Be sure to connect ground to ground and +12 to +12. Next, connect M1 and M2 (using the twisted wires from the wheel) to the motor input.

At this point all of your wiring should be done. You should check it over before you go on.

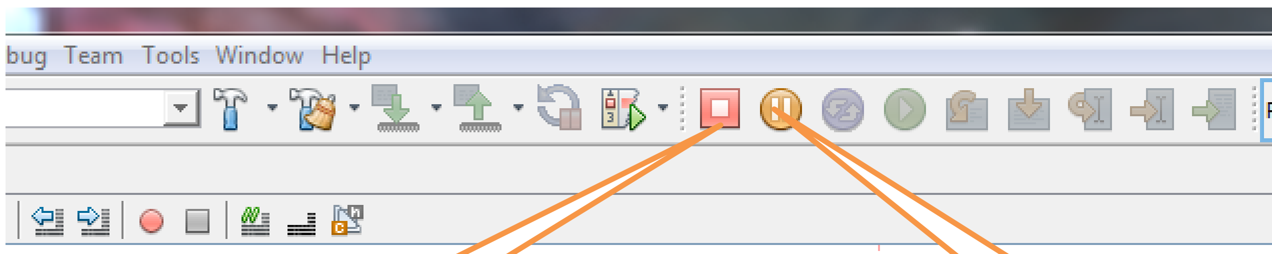
Two important things to keep in mind as you do the remainder of this lab:

- *Use the red switch to shut off power to the motor. Sometimes stopping the dsPIC does not stop the motor, in which case you will need to use the switch.*
- *Unless you are told otherwise (and later in the lab you will be), turn the pot fairly slowly.*

For this lab, it is probably much easier to use the debugging features in MPLABX

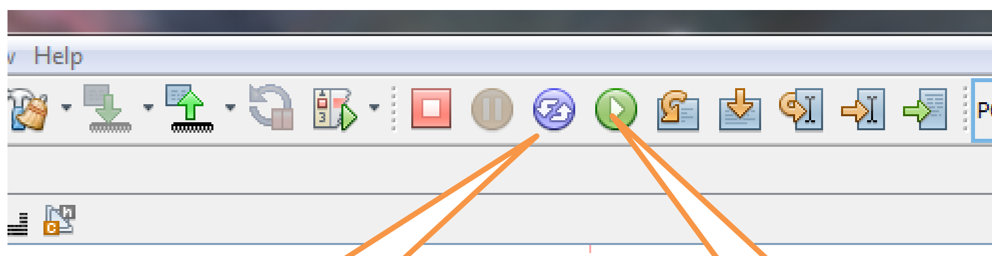


Click here to compile and download to PIC



Click here to exit (stop)

Click here to pause



Click here to reset, this will stop the motor and reset the time to zero

Click here to resume

PART G: Determining initial scaling

We need a new program now to control the motor. You will modify **lab7.c** for the remainder of this lab.

Now we will start to determine some of our parameters. Turn on the power to the motor (the red LED should turn on) and open SecureCRT. When the program starts to run, the output to the screen is the current time, the value read from the pot, the dutycycle, and the speed of the wheel in radians/sec.

With the system at rest start the program and slowly turn the pot so the motor is spinning. Turn the pot so the motor is spinning at less than or equal to 30 rad/sec. Let the motor come to a reasonably steady value (it will likely keep getting faster). Wait until the motor speed is fairly constant and the input reading from the pot is also fairly constant. Record the reading from the pot and the speed of the motor. Do this for three different positions of the pot where the steady state speed is less than 80 rad/sec. (Note that it is likely to be easiest to use the session log file than look at the screen output.)

We now want to determine the proportionality constant between the A/D value read from the pot and the motor speed in rad/sec. Compute the three scaling factors and average them (mine was approximately 0.170).

Change the parameter **AD_scale** (in your code) to this value. Run the system again at various input values. It may take a while for the system to reach steady state. Compare your reference input to the actual output. They should be fairly close for some speeds but they will not be exact. For other speeds they may be off by a significant amount. This is open loop control.

PART H: Proportional control

We now want to start with our first control scheme, proportional control. You will need to declare the variable **kp** as a double (at the top of the main routine). Outside of the main loop set **kp = 1.0**, and inside the main loop, after both the speed and reference input are determined, compute the error as **error = R-speed**. Here **R** is the reference input and **speed** is the measured output speed of the wheel in rad/sec. The control effort is then proportional to this error, so **u = kp *error**.

Recompile and download the code onto the microcontroller. Now start the system again. Move the pot to a number of different set points, and wait until the system comes to steady state. Most likely the steady state value will be approximately one half of the set point.

Stop the system and change the value of **kp** to 5, and then to 10. (Be sure to recompile and download after each time). Run the system again for each value of **kp**. You should notice that the steady state error gets smaller as kp increases.

PART I: Plotting results

In the remainder of this lab you are to plot your results in Matlab. Once you have a good design, you need to log your data (File->Log Session in the SecureCRT window) so you can make a Matlab plot. If you have saved your data in a file named (for example) play3.log, then in Matlab type

data = load('play3.log');

t = data(:,1);

y = data(:,5);

You may have to edit your files to make nice plots (like using t = t-t(1)). Be sure to include labels on your axes.

PART J: Proportional control with no prefilter

Within the main loop, we are going to be setting the value of R so that we can look at a step input of a constant value. *Note that your system will probably not reach the correct steady state value, but try to get as close to the set point as you can while still meeting the settling time and percent overshoot requirements.* Remember that the settling time is within 2% of the final value, not exactly the final value.We will start with a value of R = 45. So you code should look like the following:

```
R = (double) AD_value*AD_scale;  // this is the reference input

R = 45.0;  // the set point is 45 rad/sec
```

For each of the following steps, limit **kp** *to less than 25.*

a) With a set point of 45 rad/sec, adjust the gain kp so the system reaches steady state within 0.5 seconds and with a percent overshoot less than 10%. *Record the value of kp and plot this result in Matlab and put it in your lab memo.*

b) With a set point of 75 rad/sec, adjust the gain kp so the system reaches steady state within 0.75 seconds and with a percent overshoot less than 10%. *Record the value of kp and plot this result in Matlab and put it in your lab memo.*

c) With a set point of 90 rad/sec, adjust the gain kp so the system reaches steady state within 0.75 seconds and with a percent overshoot less than 10%. *Record the value of kp and plot this result in Matlab and put it in your lab memo.*

PART K: Proportional control with a prefilter

Most likely your system did not equal the setpoint in steady state, or not all of them. One way to get around this is to scale the input, which is implementing a prefilter. Define two new (double) variables, Gpf and scaled_R and modify the code so you get

```
scaled_R = Gpf *R;
error = scaled_R – speed;
```

Note that we do not want to just scale R, since we want to know the (original) reference input. The value of Gpf should be assigned once outside the main loop, and now needs to be determined. For previous step in the case where the reference input was 45, determine the ratio of the measured output to the setpoint, and use this as the initial value of Gpf. You may have to modify this value of Gpf, but once you choose one leave it fixed for the remainder of this part.

Now rerun the three cases from the previous part, and *plot the results for each of them in Matlab. Include these plots in your memo. Note that you may not reach the correct steady state values (but you might). You should at least reach the correct steady state value of a reference of 45 rad/sec.*

PART L: Proportional controllers with large gains

Make sure **kp** is set to 50 for this part and the value of the reference input to 45 rad/sec. Let the prefilter as it was. Run the system until it reaches steady state or up to 5 seconds (whichever is shorter). You should notice that the speed of the wheel varies significantly from the reference point. Part of this is due to the fact that the motor is only capable of one direction, but a larger part is due to the fact that small errors are amplified (by 50) and this causes the motor to continually oscillate. *Plot the results for this part in Matlab and include it in your memo.*

PART M: Integral control

Recall that using a prefilter to control steady state error can sometimes be problematic since the prefilter is outside the feedback loop. *At this point, set the prefilter value to 1, but do not remove it since we will use it again.* An alternative, and generally better, solution is to include some form of integral control. Recall that an integral controller has the form

$$G_c(z) = \frac{k_i}{1 - z^{-1}} = \frac{U(z)}{E(z)}$$

Rearranging this we get

$$k_i E(z) = U(z) - z^{-1}\mathrm{U(z)}$$

In the time-domain this becomes

$$k_i e(n) = u(n) - u(n-1)$$

Since we want the control effort as our output, we will write this as

$$u(n) = u(n-1) + k_i e(n)$$

If we assume the initial control effort is zero, we can write this as follows:

$$\begin{aligned}
u(1) &= k_i e(1) + u(0) = k_i e(1) \\
u(2) &= k_i e(2) + u(1) = k_i [e(2) + e(1)] \\
u(3) &= k_i e(3) + u(2) = k_i [e(3) + e(2) + e(1)] \\
&\vdots \\
u(n) &= k_i \sum_{k=1}^{n} e(k)
\end{aligned}$$

Hence to implement the integral control, we need to sum the error terms and then scale them by k_i.

Declare two new (double) variables **Isum** and **ki**. Set the initial value of **Isum** to zero outside the main loop. Within the main loop update the error summation using something like **Isum = Isum + error.** Within the main loop implement a PI controller as follows:

u = kp*error + ki*Isum;

Set **kp** = 0.0 and **ki** = 0.2. Modify the print statement at the end of your code so the value of **Isum** is also printed out. Set the reference point to 45 rad/sec, recompile and run the system. Your system will probably exhibit some pretty strange behavior and may not reach the correct steady state value (within your lifetime). Look at what is happening to the value of **Isum** during this strange behavior.

The first problem we need to fix is that our motor is only spinning in one direction. When **Isum** becomes large and negative, we would expect the motor to spin in the other direction, but it can't. One way to minimize this effect is to check to be sure that the value of **Isum** is greater than or equal to zero. Modify your code to do this, recompile, and run it again.

The second problem we have is called *integrator windup*. Basically, the accumulated error is becoming too large and causes the system to overshoot, and then undershoot. One way to fix this is to limit the value of **Isum** to a maximum value. There is a defined variable at the beginning of the code **MAX_ISUM**. You need to set a reasonable value for this variable and limit the value of **Isum** be less than this max. Modify your code to do this, recompile, download, and run it again. You will have to use some trial and error to find a good value for **MAX_ISUM** since it is also a function of the value of **ki**.

For this part you should probably keep **ki** 0.2 and then adjust the value of **MAX_ISUM**. I choose a value somewhere between 10 and 800 (I'm not telling you where, but I am suggesting someplace to start looking). Do not move on until you have what you think is a reasonable value of **MAX_ISUM** and your code seems to be working (the wheel converges to the correct value within 10 seconds.) Note that you

will still have some oscillations, and that to get to a large steady state value **MAX_ISUM** will need to be fairly large.

PART N: Integral control

Now we want to implement an integral controller to control the speed of the wheel. Be sure the prefilter is still set to 1.0. As you go through these, you may need to change the value of **MAX_ISUM,** particularly to get to the faster speeds.

For each of the following steps, limit **ki** *to less than 1.0.*

a) With a set point of 45 rad/sec, adjust the gain **ki** so the system reaches steady state within 10.0 seconds and with a percent overshoot less than 10%. *Record the value of ki and plot this result in Matlab and put it in your lab memo.*

b) With a set point of 75 rad/sec, adjust the gain **ki** so the system reaches steady state within 10.0 seconds and with a percent overshoot less than 10%. *Record the value of ki and plot this result in Matlab and put it in your lab memo.*

c) With a set point of 90 rad/sec, adjust the gain **ki** so the system reaches steady state within 10.0 seconds and with a percent overshoot less than 10%. *Record the value of ki and plot this result in Matlab and put it in your lab memo.*

You should note that an integral controller is significantly slower than a proportional controller, but you do not need to fool around with a prefilter. This is because we now have a type 1 system.

PART O: Proportional plus integral (PI) control

For the last part of this lab, we want to combine the speed of a proportional controller with the steady state error properties of an integral controller. The response of such a controller is still usually slower than that of a proportional controller alone.

A general plan for designing a PI controller using a trial and error method (we have no model for the plant) is the following:

- First, set **k**i = **kd** = 0, and try to get a good response for a step input using only **kp**.
- Next, adjust **ki** to get a good steady state error. Since the integral control tends to slow the system down, don't make this any larger than you need to. However, you may need to also change **MAX_ISUM** to get a good response.

For each of the following steps, limit **ki** *to less than 1.0 and* **kp** *to less than 20.*

a) With a set point of 45 rad/sec, adjust the gains **kp** and **ki** so the system reaches steady state within 1.0 seconds and with a percent overshoot less than 10%. *Record the value of kp and ki and plot this result in Matlab and put it in your lab memo.*

b) With a set point of 75 rad/sec, adjust the gains **kp** and **ki** so the system reaches steady state within 1.5 seconds and with a percent overshoot less than 10%. *Record the value of kp and ki and plot this result in Matlab and put it in your lab memo.*

c) With a set point of 90 rad/sec, adjust the gains **kp** and **ki** so the system reaches steady state within 1.5 seconds and with a percent overshoot less than 10%. *Record the value of kp and ki and plot this result in Matlab and put it in your lab memo.*