Laboratory 5 – Whack'em All

Goals:

In this laboratory you will:

1) Develop a set of Desired Performance Specifications.
2) Identify and validate a model for your system.
3) Design and tune a PID-Controller for to meet these Performance Specifications.
4) Validate the dynamic performance of your Controller design.

Equipment:

As shown in Figure 1, the laboratory apparatus consists of 2 parts: a Motor and Encoder with a Disc attached and the Electronic Hardware Module. The Disc Plant also has 4 Optical Sensors that are used to sense the slot in the Disc. The purpose of this setup, in general terms, is to rotate between positions, typically less than 2*pi radians.

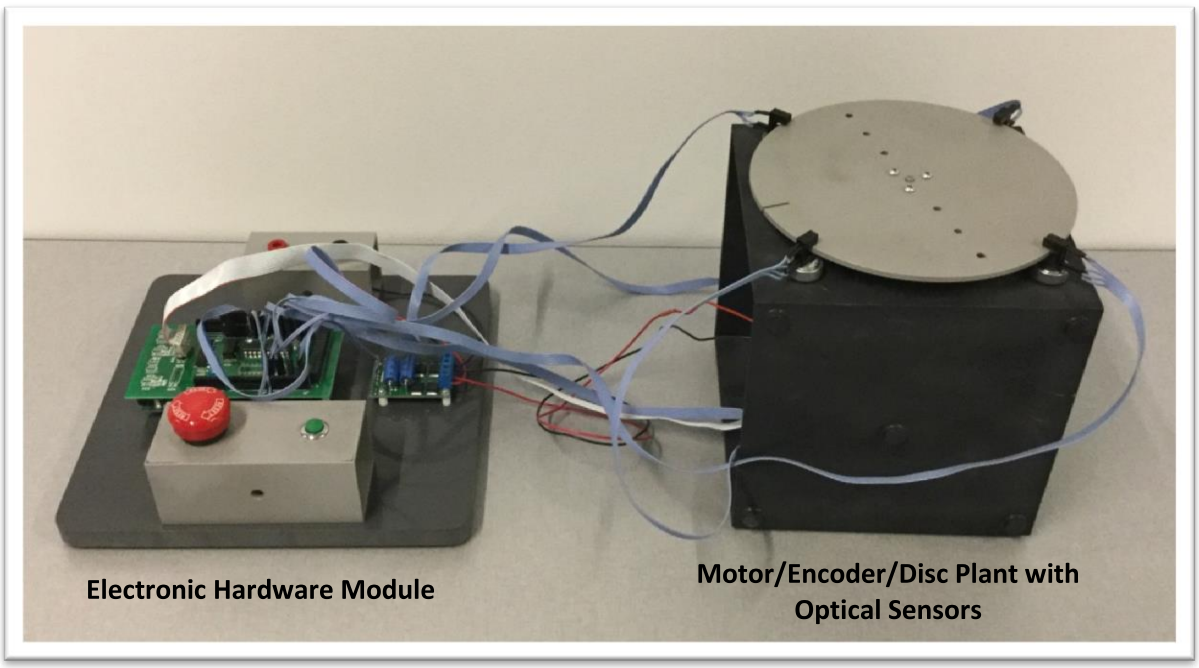

Figure 1 – Electronic Hardware Module with Motor/Encoder/Disc Plant with Optical Sensors

The Electronic Hardware Module consists of:

a) A Microcontroller Unit
b) A Motor Controller
c) A User Input Module
d) A Voltage Input Module

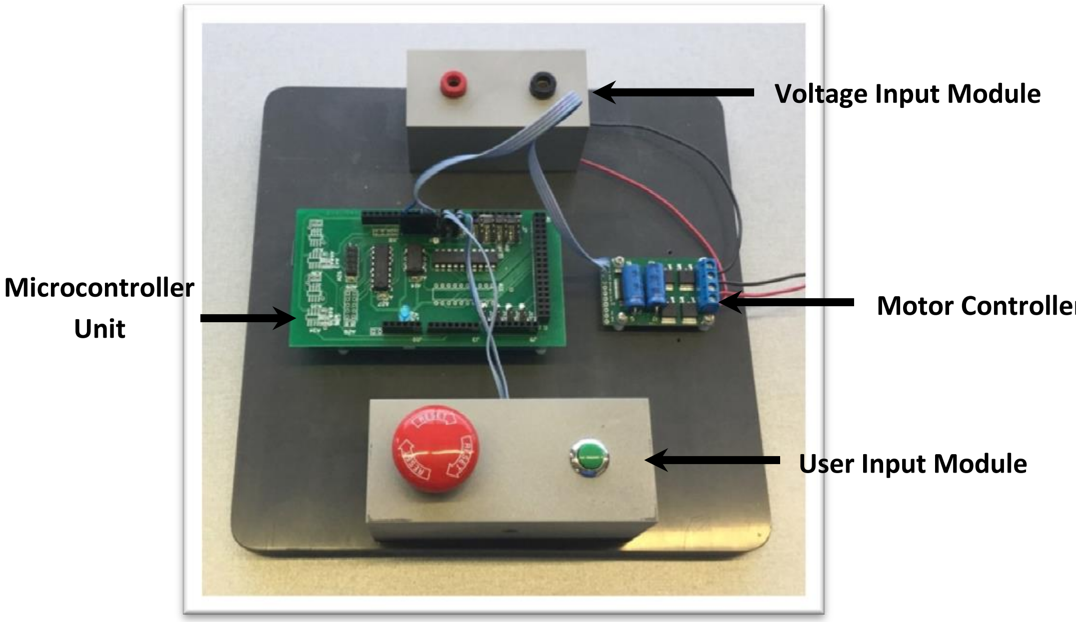

Figure 2 – Electronic Hardware Module

Microcontroller Unit

The Microcontroller Unit consists of an Arduino Mega 2560 and a custom Piggy-Back Board. A USB cable is provided to interface between the Arduino Mega and the computer. The custom Piggy-Back Board contains the Encoder Counter (HCTL-2022) and accompanying circuitry. The Piggy-Back Board interfaces with the Encoder via the white ribbon cable shown in Figure 3. Please insure that the red stripe on the ribbon cable is oriented as shown in Figure 3 for proper operation.

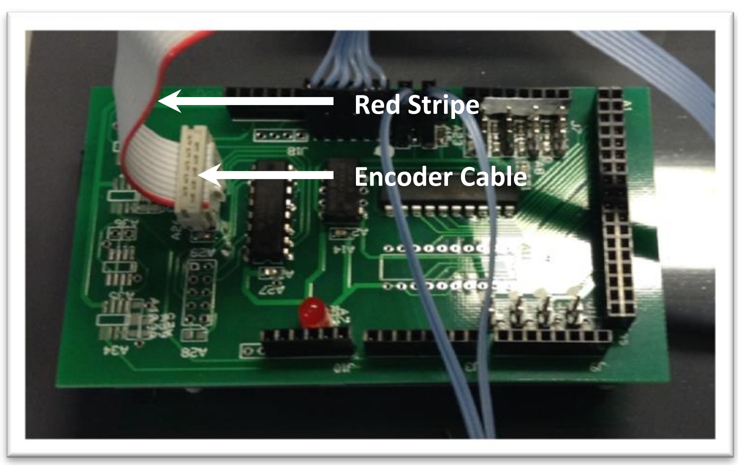

Figure 3 – Encoder Cable Close-Up

Optical Sensors

As mentioned previously, there are 4 Optical Sensors that are used to sense the slot in the Disc. They can be placed at arbitrary positions around the Disc and are held in place by rare earth magnets on the underside of the aluminum extrusion. These rare earth magnets are very strong, so be careful when using them.

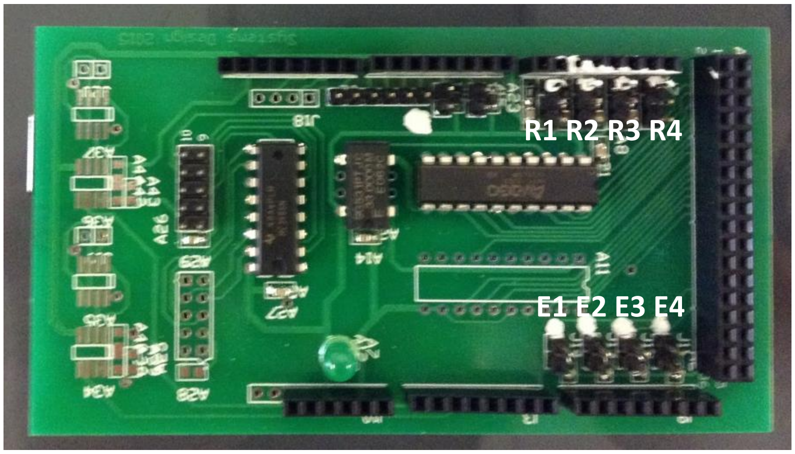

Figure 4 – Piggy Back Board Close-Up

Shown in Figure 4 is a close-up of the Piggy Back Board that sits atop the Arduino Mega microcontroller. Each Optical Sensor has two connectors that need to be plugged into the Piggy Back Board for proper operation. The first connector has two pins and controls the sensor's light emitting function. It needs to be inserted on to the corresponding emitter pins (E1, E2, E3 or E4), with the white paint on the connector and board lined up. The second connector has three pins and controls the sensor's light receiving function. Similarly, it needs to be inserted on the corresponding receiver pins (R1, R2, R3 or R4), with the white paint on the connector and board lined up.

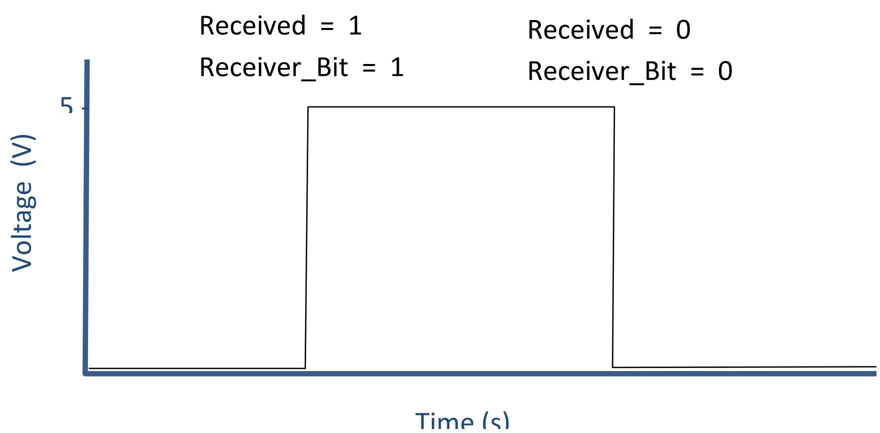

Figure 5 – Optical Sensor Signal as Slot Passes By

As shown in Figure 5, the Optical Sensor outputs 0V when the disk blocks the emitter from the receiver. When the slot is first sensed, the received signal changes from 0V to 5V and the interrupt service routine (ISR) associated with that particular Optical Senor is called. The ISR asserts the Received flag and reads in the associated receiver pin to confirm it is 5V and asserts the Receiver_Bit flag. The Optical Sensor continues to output 5V until the slot has passed by completely, where it changes its output back to 0V. Upon this change in output, the ISR is called again and both the Received flag and the Receiver_Bit are set back to 0.

Motor Controller

The Motor Controller we're using is the Single Motor Driver from Pololu (Robotshop #RB-Pol-169). The heart of the Motor Controller is the 4 N-channel mosfets that make an H-bridge. The Motor Controller is the most delicate part of our system. If you notice it getting hot, give it a few minutes to cool down. If you let the smoke out, please call on the Lab Instructor or TA for a replacement. Cash or cheque is accepted. For our purposes, the voltage will be set to **12.0V** to match the rating of the brushed DC Motor we're using. From Figure 4 you'll notice the sequence of the black and red motor and voltage input leads; for proper operation, please ensure this sequence.

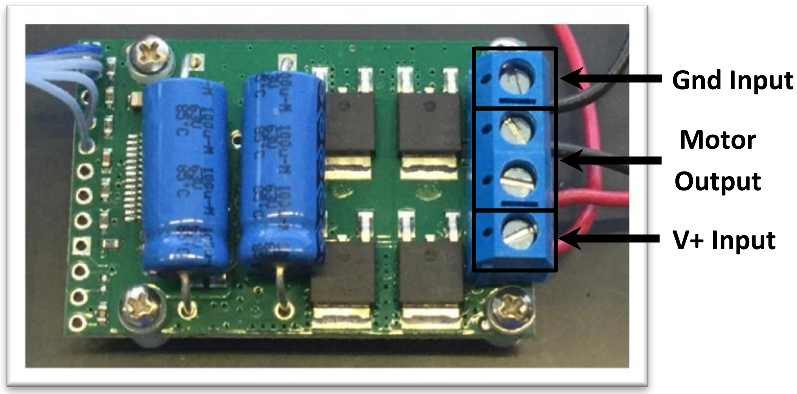

Figure 6 – Motor Controller Close-Up

User Input Module

The User Input Module consists of the Emergency Stop Button (E-Stop) and the Start Button. During operation, have your hand near the E-Stop at all times to shut your system down in case it acts in an uncontrolled/unsafe manner. Reset the E-Stop by rotating it clockwise. The Start Button is used to initiate operation.

Figure 7 – User Input Module Close-Up

Voltage Input Module

The Voltage Input Module consists of a red and black banana jack that is used in conjunction with a pair of banana leads to connect the Power Supply to the Electronic Hardware Module. Please insure that the Power Supply is set to 12.0V and that the positive (+) terminal is connected to the red banana jack and that the negative (-) terminal is connected to the black banana jack.

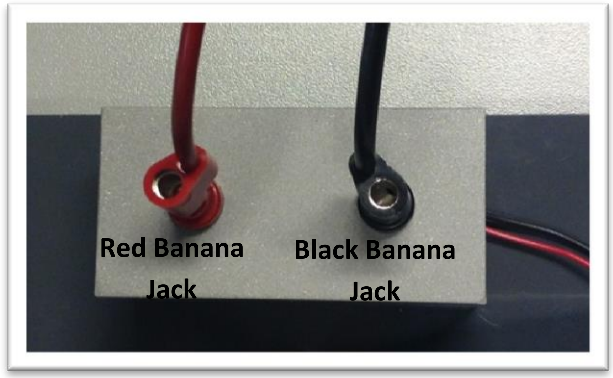

Figure 8 – Voltage Input Module Close-Up

The Motor/Encoder/Disc Plant consists of:

a) A Motor
b) An Encoder
c) A Disc

Motor

The actuator in our Plant is a Maxon A-max 32 brushed DC Motor (#353222). It's has a 12.0V operating voltage and a maximum continuous torque of 37.2 mN·m.

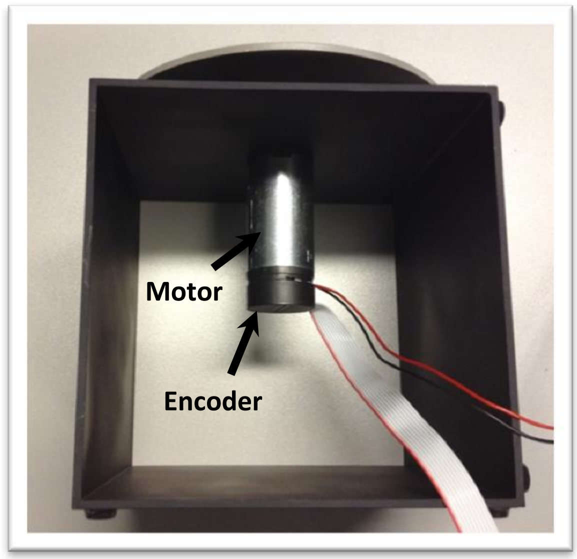

Figure 9–Motor/Encoder Close-Up

Encoder

The feedback for our system is a Maxon MR, 3-channel optical encoder (#225787) that has been attached to the shaft of the motor. It provides angular position with a resolution of 1024 pulses per revolution.

Disc

An aluminum Disc is attached to the output shaft of the Motor. A slot has been added to the Disc to work in conjunction with the Optical Sensors. Because we'll be rotating the Disc, the potential for the Disc flying off is a concern. **Always make sure the Disc is securely attached before running any experiment.** If it is loose, please call on the Lab Instructor or TA to re-tighten the Disc.

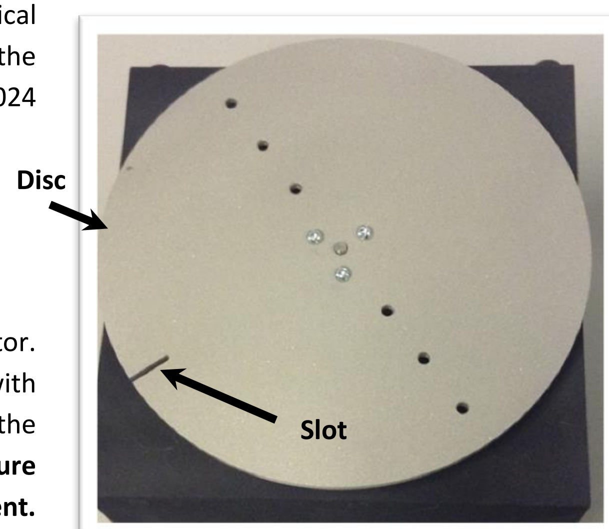

Figure 10 –Disc Close-Up

Safety

- Each person is responsible for their own safety **and** the safety of others. Please point out any unsafe activities you observe in the laboratory. If you cannot, notify the Lab Instructor or TA.
- No safety violation is trivial, and as such, horseplay or joking around in the laboratory will not be tolerated.
  - Major catastrophes are often caused by a series of small safety violations - most of these incidents, if not all, can be avoided.
- Instruments and equipment in the lab should be used carefully and correctly.
- **As mentioned, if your experimental apparatus starts to behave in an uncontrolled manner immediately press the E-Stop button located on the Electronic Hardware Module.**
- **As a safety precaution, keep all loose clothing, jewelry, hair, etc. away from the experimental apparatus.**
- **Never attempt to stop the Disc when it's spinning.**
- **Never attempt to run an experiment when the Disc is still spinning.**
- If you smell something burning or see smoke coming from your apparatus hit the E-Stop and turn off the Power Supply immediately. Then, report the occurrence to the Lab Instructor or TA.
- The experiments for this course involve attaching items to a motor output which are then accelerated. If these items are not securely fastened they can be turned into projectiles. This could result in serious injury – **before starting any experiment make sure any items attached to the motor output are securely fastened**.
- Eating and drinking are not allowed in this lab in order to prevent damage to equipment.
- The fire extinguisher is located across the hall to the left; fire alarms are located by the stairwells. If the fire alarm sounds power down your experiments as you will be instructed to leave the lab and assemble outside the building, bring your coat and any valuables.

Clamping

A clamp has been provided to secure the aluminum extrusion box of the Plant to the desk. **Always make sure the Plant is securely attached to the desk before running any experiment.**

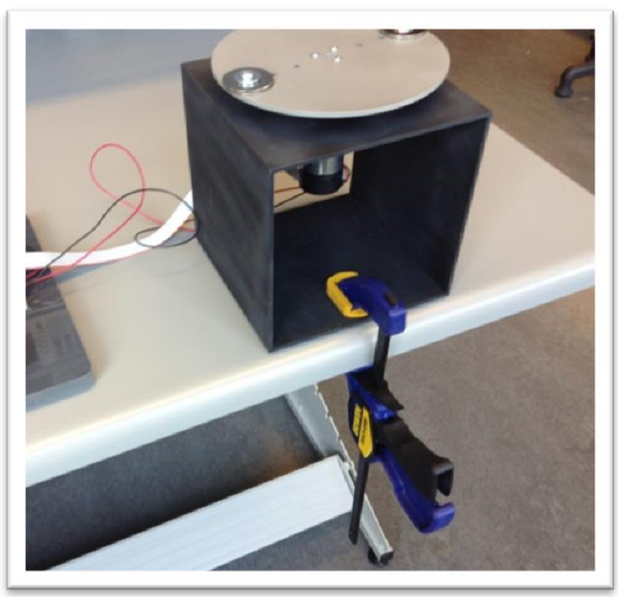

Figure 11 – Clamping Setup

Background – Whack'em All

The concept of this lab is based on the Whac-A-Mole amusement park game where the player is given a large, soft mallet to hit the moles in the head in an effort to force them back into their hole. The moles will pop-up at random and the faster you can whack'em, the more points scored.

Figure 12 – Whac-A-Mole Fun

In our version, the four Optical Sensors, placed randomly around the edge of the Disc plant, will be turned on in a random sequence, and it's your job to program your Controller to find the Optical Senor that's on and keep the slot of the Disc lined up with the Optical Sensor for 2 seconds continuously. Once you've satisfied the 2 second interval, this Optical Sensor is turned off and the next sensor in the sequence is turned on until the Target Sequence is complete.

Part 1 – Desired Performance Specification(s) Development

Based on what your System is trying to achieve, come up with one or more Desired Performance Specifications. State your assumptions and back up your specification development with logic/reasoning. This means that your Specs must be tied to something physical and not pulled out of 'thin air'. If your logic/reasoning is not sound, you will be awarded 0 marks. **(20 Marks)**

Part 2 – System Identification

Using the framework laid out in the flow chart in Figure 2-4 of Practical Controller Design, devise a transfer function of the Disc Plant using Steady-State Response Methods. Be sure your report includes this methodology. **(19 Marks)**

Part 3 – PID Controller Design

Out of the PID-Controller family, choose the most appropriate Controller for this system (P-Controller, PD-Controller, PI-Controller or PID Controller). Using the Desired Performance Specifications you defined previously as a starting point, perform one design attempt using the engineering approaches outlined in Practical Controller Design. Even if this approach meets the Desired Performance Specifications, perform one last design attempt based on your intuition/reasoning and using the same engineering approaches shown in Practical Controller Design. Document how you improved its performance. **(36 Marks)**

Note 1 – For this lab, it is up to you on what value of N, the Filter Coefficient, to use.

Note 2 – Trial and Error should only be used when you've exhausted every possible engineering approach. In the rare case engineering approaches don't work, to receive full marks, document how each approach failed before moving on to Trial and Error.

Part 4 – Controller Validation

Choose an appropriate Control Loop Frequency to test your Controller but make sure not to exceed 500Hz. Run your Controller on the actual physical system and compare the results and discuss any differences with the simulated results of Part 3 using the Simulink file called *base_closed_loop_model_compare.slx*. Don't worry about analyzing your system's stability with this Controller. **(5 Marks)**

Part 5 – Whack'em All **(20 Marks)**

Use the *Whackem_All_Base_Code.ino* Arduino code provided as a framework for your Controller program. At the end of the lab, each team will be given 3 opportunities to demonstrate their Controller; the best time will be used for comparison between other teams. Teams have the option of making subtle/quick code changes in between tests. The 20 marks associated with this part are divided as follows:

- If your solution completes the course, you will automatically receive the first 10 marks.
- The team with the lowest time will be awarded First Place and 100% of the other 10 marks.
- The team with the highest time will be awarded Last Place and 0% of the other 10 marks.
- The marks for the other teams will vary linearly with their placement with respect to the First and Last Place teams.
- Separate highest and lowest times are determined for each lab day.