STUDIO II
MACHINING & MECHATRONICS PROJECT: DRIVEN DOUBLE PENDULUM

A detailed understanding of the capabilities and limitations of the available hardware, software and fabrication tools is a requirement for successful design and development programs. For example, knowledge of the capabilities and limitations of the motors and sensors is needed to design mechatronic systems. Knowledge of manufacturing processes, such as machining with milling machines, lathes, bandsaws, and drill presses, is required to guide the design and assessment of feasible, manufacturable design concepts. This studio will help develop an understanding of the equipment and manufacturing processes available in ME 2110.

Pendulums are commonly utilized in engineering. Some useful pendulum systems include cranes, clocks, and the human walking gait. The dynamics of pendulum systems become complicated as the number of links is increased. Such systems may exhibit nonlinear effects such as bifurcations and chaos. The goal of this studio is to build a machine to demonstrate some of the nonlinear effects associated with pendulum systems.

You will build a motor-driven double pendulum with a LED mounted near the tip of the second link. A photograph of the Driven Double Pendulum System is shown in Figure 1. Once your pendulum system is completed, a long-exposure photograph will be taken while your pendulum rotates. This photograph will capture the path that the tip-mounted LED travels during the pendulum’s motion. Figure 2 shows a sample of such an exposure photograph.

You will be assigned a team for this project. Your team will be split into two subgroups, Group A and Group B, and the subgroups will perform the mechatronics and machining components of this studio independently, with Group A beginning with mechatronics and Group B beginning with machining.

This studio is pass/fail. You must complete the assigned tasks to pass the course.
Week 4 (January 26 - 30)

Group A:

In Week 4 of the semester, Group A will learn how to program the National Instruments myRIO controller to use the sensors and actuators in the mechatronics kit. You will have to complete the tasks found in Mechatronics Lab Tasks: Group A in the Mechatronics Section of this document. You will have to demonstrate proper execution of the tasks to your Studio Instructor or TA. They will sign your assignment sheet, indicating the tasks have been completed.

Group B:

In Week 4 of the semester, Group B will learn how to use the machine tools in the ME 2110 machine shop. An instructional seminar will take place in which the TA will instruct the group on proper lab safety, tool checkout procedures, and proper use of the machine tools. You will then begin to construct the components needed to complete the pendulum. A detailed process plan and mechanical drawings for the components are provided in the Manual Machining Section of this document. You will receive plastic (Delrin) and wood (Poplar) workpieces from which you will machine your pendulum components.

Week 5 (February 2 - 6)

Group A:

In Week 5, Group A will move on to the machining section of the project. They will undergo the same machining seminar as Group B and receive their own workpieces.

Group B:

In Week 5, Group B will learn how to use the mechatronics kit. They will complete the Mechatronics Lab Tasks: Group B found in the Mechatronics Section of this document.

Outside of Studio

In addition to doing work during your scheduled studio time, the lab will be open for other periods of time throughout the week. These periods are known as “Open Lab.” Any ME 2110 student may use the ME 2110 Design Studio and Machine Shop during Open Lab. The Open Lab schedule is posted on the ME 2110 website. Due to limited time during scheduled studio, you will need to utilize Open Lab to complete your deliverables.

You will also need to create a drawing for a nameplate that will be laser-engraved onto your pendulum link. This task is detailed in the Automated Machining Section of this document.
**Week 6 (February 9 - 13)**

By Week 6 of the semester, you will need to have completed the pendulum link and nameplate drawing. You will write your initials on the back of the pendulum link and turn it in to your TA. Before studio, you must email a nameplate drawing file to your TA. Your TA will engrave your pendulum link using your nameplate drawing. The rest of this week will give you time to finish the Pendulum Coupler and mechatronics exercises.

**Week 7 in Studio (February 16 - 20) – Machining Contest**

By Week 7, you will have completed your pendulum components and gained sufficient knowledge of the operation of the mechatronics kit. You will use your pendulum components to compete against other students in your studio to determine who can create the “best” exposure photo trace of their pendulum. The instructor and TA will nominate the top three photos, and the studio section will vote to decide which photo wins.

You will get three opportunities to run your pendulum for 10 seconds, during which an 8-second exposure photo will be taken using an iPad. You must complete the pendulum assembly using the Coupler and Secondary Pendulum Link that you machined during this studio. You can mount your Secondary Pendulum Link to the Primary Link pivot using any of the three holes you drilled.

A high-torque, low-speed DC motor will drive the pendulum system. The speed of this DC motor will be controlled using the National Instruments myRIO controller. Each student will need to program his or her own 10-second speed profile to run on the team’s myRIO controller. Your myRIO will then be connected to the motor driver using the ribbon cable. The myRIO should output to the motor driver on the ‘Motor 1’ port. The program should begin executing your motor speed profile when a switch is pressed, and stop the motor after 10 seconds. The pendulum system will be available for testing in the machine shop throughout the duration of this studio. You should practice assembling the pendulum with your parts and test your program to determine what sort of speed profiles and pivot hole locations create the most interesting motion of the LED.

**Deliverables**

Table 1 shows the deliverable schedule for this project.

<table>
<thead>
<tr>
<th>Deliverable Schedule</th>
<th><strong>Group A</strong></th>
<th><strong>Group B</strong></th>
</tr>
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<tbody>
<tr>
<td><strong>Week 5 Deliverables, due at the Beginning of studio (February 3 - 7)</strong></td>
<td>1) 4 of 6 completed and signed Mechatronics Lab Tasks: <em>Group A</em></td>
<td>1) Secondary Pendulum Link 2) 1 Drawing for a Nameplate</td>
</tr>
<tr>
<td><strong>Week 6 Deliverables, due at the Beginning of studio (February 10 - 14)</strong></td>
<td>1) Secondary Pendulum Link 2) 1 Drawing for a Nameplate</td>
<td>1) Pendulum Coupler 2) 4 of 6 completed and signed Mechatronics Lab Tasks: <em>Group B</em></td>
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<tr>
<td><strong>Week 7 Deliverables, due at the Beginning of studio (February 17 - 21)</strong></td>
<td>1) Pendulum Coupler 2) All 6 completed and signed Mechatronics Lab Tasks: <em>Group A</em> 3) Motor Speed Profile Program for Machining Contest</td>
<td>1) All 6 completed and signed Mechatronics Lab Tasks: <em>Group B</em> 2) Motor Speed Profile Program for Machining Contest</td>
</tr>
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</table>
**Mechatronics Section**

This lab will provide experience with integrating electrical, mechanical, and pneumatic systems. The lab comprises of two sections performed over two weeks. During the first week, Group A will complete one part of the lab, labeled "Mechatronics Lab Tasks: Group A"; during the second week, Group B will complete "Mechatronics Lab Tasks: Group B". Although the programming style will not be graded, the programs written during these two labs should be helpful in developing the programs for the final project. Therefore, it is important to program using standard structure and commenting practices so that the program will be easy to follow when used as a reference later in the semester.

Before attempting to perform these programming tasks, read through the **Mechatronics and Pneumatics Manual** which is available on the course website. The manual provides a good background to the layout of the National Instruments myRIO controller and how to implement the electro-mechanical-pneumatic components in a design.

At the time of each checkpoint, each student is responsible for showing progress through the assignment as indicated by a signed task checklist. The tasks for Group A and Group B, and the associated checklists, are provided on the subsequent two pages. After each task is completed, the operation must be successfully demonstrated to either the section instructor or TA. The instructor or TA will initial the checklist confirming that the team has successfully completed that task element. Remember that each individual needs a separately signed checklist. Feel free to ask the professor, TA, or peers for help in completion of this assignment, however each student in the team must be prepared to answer questions about the program before the instructor or TA will initial the checklist.
Mechatronics Lab Tasks: Group A, Name:

1. Connect 2 DC motors, 2 solenoids and 2 valves to the driver board. Connect all the sensors to the sensor board. Study the LabVIEW programming template, and use the template to verify that every component operates correctly.

2. Connect a DC motor and the potentiometer. Make the speed of the motor proportional to the value you read from the potentiometer. Use a waveform chart indicator on the front panel to plot the potentiometer voltage reading in real time.

3. Connect the push-button switch to a Digital Input and have the DC motor run at full speed when the switch is held down and turn off when the button is released. Each time the switch is pressed turn on LED1 for 1 second.
   - Hint: Connect the switch to a Digital Input, read in the value of the Digital Input when the button is pressed and the value of digital input when the button is released.

4. Connect two switches and the pneumatics. The program starts with the cylinder retracted. When one switch is pressed, the cylinder should extend and remain extended after the switch is released. When the other switch is pressed, the cylinder should retract and remain retracted. This process should run indefinitely. Set this program to run automatically on startup (without being connected to the computer).

5. Connect two solenoids and two switches. When one switch is pressed, one solenoid is activated for 2 seconds and then deactivated. When the other switch is pressed, the other solenoid is activated for 500 ms and then deactivated. When one actuator is active the other cannot be activated. Use LED1 and LED2 to indicate when each actuator is active.
   - Hint: You can use “Elapsed Time” and “Time Delay” Express VIs.

6. Connect two solenoids and two switches. At the start, activate one solenoid. After both switches have been pressed (doesn’t matter how many times or in which order), deactivate the solenoid and activate the other solenoid for 1 second. After the 1 second, re-activate the first solenoid. This cycle should continue indefinitely. Use two LEDs to show the states of the switches.
   - Hint: Use shift registers to pass values from one loop iteration to the next.
   - Hint: You can use “Elapsed Time” and “Time Delay” Express VIs. You can also use the duration of the while loop to count time and local variables to transfer data, which you probably need to initialize as well.

Checklist for Group A:

1. __________
2. __________
3. __________
4. __________
5. __________
6. __________
Mechatronics Lab Tasks: Group B, Name:

1. Connect 2 DC motors, 2 solenoids and 2 valves to the driver board. Connect all the sensors to the sensor board. Study the LabVIEW programming template, and use the template to verify that every component operates correctly.

2. Connect both DC motors. Make them run clockwise for five seconds, stop for 2.5 seconds, run counter-clockwise for five seconds, and then stop for 2.5 seconds. Repeat this sequence four times.
   - Hint: You can use “Elapsed Time” and “Time Delay” Express VIs.

3. Perform the same act as #3, but use the four onboard LEDs each time the motor is active to indicate the current iteration (i.e. turn on LED1 the first time the motor is turned on, LED2 the second time, etc) Set the program to run automatically on startup. (without being connected to the computer)

4. Connect the IR distance sensor and one DC motor. Have the motor run if the reading is greater than 2.3 V and have the motor stop if the reading is less than 2.3 V. Use a waveform chart indicator on the front panel to plot the IR sensor voltage reading in real time. Update the speed of the motor at most once every 2 seconds.
   - Hint: You can use a delay after you write to the motors.

5. Connect the encoder and the pneumatics. When the encoder is rotated 5 complete revolutions, the actuator should extend and remain extended until the encoder is rotated another 3 complete revolutions. Use an indicator on the front panel to display how many revolutions have been completed during each stage. The cylinder should only extend 4 times and then remain retracted regardless of how many times the encoder is rotated.
   - Hint: You can use local variables or shift registers to send data between the loop iterations.

6. Connect 2 switches and one motor. At the start, run the motor at 50% speed. After both switches have been pressed (doesn’t matter how many times or in which order), have the motor switch direction for 3 seconds. After the 3 seconds, the cycle should reset.

   Turn off LED 1 when the first switch is pressed, turn off LED 2 when the second switch is pressed. Have LED 0 and LED 3 activated the entire time the program is running.

   - Hint: Use shift registers to pass values from one loop iteration to the next.

Checklist for Group B:

1. __________
2. __________
3. __________
4. __________
5. __________
6. __________
Manual Machining Section

Driven Double Pendulum with LED Tip

In the machining section of this studio, you will machine the components needed to complete the Driven Double Pendulum System. Figure 3 shows a solid model of the pendulum assembly with labeled components. The DC motor drives the primary link via a coupler mounted on a shaft. The secondary link pivots relative to the primary link as it rotates. A LED circuit board with a battery is mounted onto the back of the secondary link, and the LED shines through a hole to the front.

Each student will machine the coupler and the secondary link. A nameplate will be engraved on each student’s secondary link using a laser cutter. Mechanical drawings for these two components and associated detailed machining instructions are provided on the last few pages of this handout. The Automated Machining portion of this document explains the deliverable associated with having your Secondary Link laser-engraved with your nameplate.

Review the machine shop safety rules in the Machine Shop Safety section at the end of this document before you attend the studio session. Be sure to familiarize yourself with these rules and arrive to studio dressed appropriately for working in the machine shop.

Figure 3 – Isometric Assembled View of the Driven Double Pendulum System
Automated Machining Section

Laser-Engraved Nameplate

In addition to machining the plastic coupler and wooden link for the pendulum, you will also create a drawing for a nameplate. The drawing will be used to engrave the nameplate onto your pendulum link using the laser cutting machine in the Invention Studio. Here are some tips and suggestions for constructing your drawing:

**Drawing a Nameplate for Laser Engraving:**

1. This task is most easily accomplished by creating a 2-D drawing in Inkscape of the nameplate profile. Inkscape is a free, open-source vector graphics drawing program for Windows, Mac, and Linux. It is available for download from [https://inkscape.org/en/](https://inkscape.org/en/). Inkscape is also available on the computers in the Design Studio and Machine Shop if you do not wish to install it on your personal machine.

2. The outline of your nameplate does not have to be rectangular, but the design must fit inside a 2”x1” rectangle. When using Inkscape, be sure to set the drawing units to inches for convenience.

3. In general, when creating drawings for the laser cutter, lines that you want to cut completely through the material should be changed to red with the line thickness set to less than 0.001 inches (hairline). Areas that you want to engrave or etch should be set to a fill color of black. The outline of the engraved area should also be black.

4. For your nameplate, the laser will be set to only engrave. All red cut lines will be ignored.

5. Once your nameplate is finished, save it as an Inkscape SVG (*.svg) file. Use the following file name format: SectionLetter_LastName_FirstName.svg (e.g., A_Singhose_William.svg). Email the file to your TA to complete the deliverable. Include your Group letter in your email.

6. Figure 4 shows an example 2-dimensional nameplate drawing created in Inkscape, and the resulting nameplate that would be engraved onto your pendulum link using the laser cutter.

![Figure 4 – Sample Nameplate Inkscape Drawing and Resulting Engraved Nameplate](image)
Suggested Process Plan for Pendulum Coupler:

1. Obtain nominal 1.75” length of round 3/4” diameter Delrin stock.
2. Face one end on the lathe to make it perpendicular to the axis of rotation.
3. Flip the piece over and face the other end, leaving the final length of 1.50”.
4. Mount the tailstock onto the lathe. Chuck the larger center drill into the tailstock Jacobs chuck. Use the center drill to start a centered hole in the end of the workpiece.
5. Replace the center drill in the tailstock chuck with the 5/16” drill bit. Use the tailstock and drill bit to drill a 5/16” diameter hole 1” deep along the cylindrical axis of the part. To keep track of the drill depth, use the graduated markings on the tailstock. Multiple advances of the drill bit and tailstock may be required to obtain the required 1” depth. Also, the drill bit should be advanced and retracted multiple times to clear machining chips from the drill flutes when performing each cut.
6. Flip the piece over, and turn down 0.30” length of the stock on one end to a diameter of 0.39”. Use multiple axial paths with approximately 0.02” radial depths of cut per pass.
7. Using the mill and 1/4” endmill, create the 0.25”-long flat on the 0.39” diameter end of the coupler. Determine the required cut depth from the drawings.
8. Next, on the mill use the small center drill to start a radial hole 0.4” from the end with the 5/16” hole. Then, use the No. 36 drill bit to drill a radial 0.1065” hole. This hole should terminate on the internal face of the 5/16” hole, not clearing the entire piece. Reminder: do not use a drill bit or center drill when side-milling or face-milling.
9. Using the small tap wrench and #6-32 tapered tap, cut internal threads in the 0.1065” hole. This hole will house the provided #6-32 setscrew.
**Suggested Process Plan for Secondary Pendulum Link:**

1. Obtain nominal 9.5”x1.5” piece of 1/4”-thick poplar.

2. Using the bandsaw, cut the piece down to the desired 8” length.

3. Using the mill, create the 2”-long slot on one side of the part. Orient the piece with one of the long, narrow sides facing upwards when performing this milling operation.

4. Using the drill press and size P drill bit, drill up to three 0.323” holes. These holes should be located within the 3.5”x1” area permitted for holes indicated by the dashed rectangle in the secondary pendulum link part drawing.

5. Drill the 5/16” and 0.1065” holes using the LED circuit board drilling template, a drill driver, and the 5/16” and No. 36 drill bits, respectively. A drill driver and the drilling template may be checked out from the TA on duty using your Buzzcard. Before drilling, clamp the part to a workbench, then clamp the drilling template on top of the part in the correct location and orientation. Make sure to place some backing material under the part so you do not drill into the workbench.

6. Using the small tap wrench and #6-32 tapered tap, cut internal threads in the two 0.1065” holes. These threaded holes will be used to mount the LED circuit board to the back of pendulum link. The LED will then shine through the 5/16” hole to the front face of the link.

7. Turn in the nearly-completed secondary pendulum link to your TA. Your TA will then engrave your submitted 2”x1” nameplate drawing onto the pendulum link using a laser cutter.
DRAWN DIMENSIONS ARE IN INCHES
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
UNLESS OTHERWISE INDICATED

C. Adams
12/11/13

Georgia Tech

Coupler

SOLID EDGE ACADEMIC COPY
MACHINE SHOP SAFETY

ALWAYS WEAR SAFETY GLASSES
• Even when you are not working on a machine, you must wear safety glasses. A chip from a machine someone else is working on could fly into your eye.

CLOTHING, JEWELRY, AND HAIR
• Wear long pants (to your shoes).
• Wear short sleeves or roll up sleeves.
• Wear closed toe shoes and socks.
• Remove all jewelry - watches, bracelets, rings, necklaces, dangling earrings, etc.
• Long hair or beards must be tied back.
  • If your hair is caught in spinning machinery, it will be pulled out if you are lucky. If you are unlucky, you will be pulled into the machine.
• No ties, scarves, and dangling clothes.

SAFE CONDUCT IN THE MACHINE SHOP
• Be aware of what's going on around you.
  • For example, be careful not to bump into someone while they're cutting with the bandsaw (they could lose a finger!).
• Concentrate on what you're doing. If you get tired, leave.
• Don't hurry. If you catch yourself rushing, slow down.
• Don't let someone else talk you into doing something dangerous.
• Don't attempt to measure a part that's moving.
• No fooling around.

MACHINING
• Follow directions. If you don’t know how to do something, ask.
• Before you start the machine:
  • Study the machine. Know which parts move, which are stationary, and which are sharp.
  • Double check that your workpiece is securely held.
  • Remove chuck keys and wrenches.
• Don't rush speeds and feeds. You'll end up damaging your part, the tools, and maybe the machine itself.
• Listen to the machine/tool. If something doesn't sound right, turn the machine off.
• Do not leave machines running unattended.
• Clean up machines after you use them: a dirty machine is unsafe and uncomfortable to work on.
• Do not use compressed air to blow machines clean. This endangers people's eyes and can force dirt into machine bearings.
• Report all broken or non-working machines.

VIOLATIONS OF THESE RULES WILL RESULT IN IMMEDIATE EJECCTION FROM THE MACHINE SHOP.