1 Mechanical Structure Module

Module Due: 18JAN2018

Pre-Lab Due: 10JAN2018

1.1 Module Overview

The primary output of this module is a prototype of the pinball machine enclosure, a design plan for the intended layout of the playfield, and a testing platform for the plunger system.

In addition to design, fabrication and characterization of the functional mechanical structure of the pinball machine and the plunger system, this module has other activities (see section 0) that build relevant skills both inside and outside of the lab sessions. These other activities include introductions to system design principles, iterative prototyping, CAD, laser cutting, and 3D printing.

1.1 Module Overview 1

1.1.1 Learning goals 2

1.2 Deliverables 2

1.3 Activities 3

1.3.1 System-level design: Block diagrams, system requirements, and design specifications 3

1.3.2 Mechanical Prototyping Tools: CAD, 3D printing and laser cutting 6

1.3.3 Pinball System Design Plan 11

1.3.4 Pinball Machine Playfield Mechanical Design Cycle 11

1.3.5 Pinball Plunger Testbed Mechanical Design Cycle 12

1.1.1 Learning goals

Purposes ('What this module's activities seek to develop')

- Prepare students/teams for independent design project work
    - Systematic approach to prototyping and concept evaluation
    - Mechanical prototyping skills
    - Knowledge of available tools, materials, and methods
- Develop/practice a disciplined and systematic approach to the design process that includes iteration and directed prototyping with clear metrics and learning
    - Asking and answering questions with prototypes
    - Documenting design progression

Knowledge/Functional goals ("Students/teams will (be able to)…")

- Create a design based on system requirements
- Identify potential challenges/questions about a design and test them through prototyping and experiments
- Document and evaluate test results appropriately
- Create plans for next-step prototype(s)/experiments based on existing prototypes/experiments
- Create 3D drawings of parts and an assembly in CAD (Autodesk Fusion 360)
- Use rapid prototyping tools, including hand tools, laser cutter and 3D printer, to create parts and assemblies using drawings and CAD files
- Know common practical limitations of rapid prototyping techniques, including resolution, tolerances, etc.
- Understanding and follow safe mechanical prototyping practices

1.2 Deliverables

The list below summarizes the deliverables (or sections with deliverables) for this module. Except where otherwise noted, they are due 18JAN2018. See separate "**Module Deliverables Instructions**" document on Coursework for further instructions on submitting deliverables.

- Sign up for Piazza: https://piazza.com/ucsd/winter2018/ece115 (due 10JAN2018)
- Download Autodesk Fusion 360 with an education license: https://www.autodesk.com/products/fusion-360/students-teachers-educators (due 10JAN2018)
- Check Module 1 Deliverables sheet on Piazza or TritonED

1.3 Activities

1.3.1 System-level design: Block diagrams, system requirements, and design specifications

This activity introduces the practice of system-level thinking and design, including development and communication of systems using block diagrams.

In this part of the lab you will:

- Practice the process of designing a system to meet system requirements
- Practice creating a block diagram of a system design
- Practice translating system requirements into design specifications

1.3.1.a Step 1: Understanding the problem and system requirements

Problem: The garage door is sometimes open when it should be shut, and nobody inside the house notices until a neighbor works up the resolve to bring the issue to someone's attention.

System requirements: **System requirements** capture the important facets of final system functionality that are necessary to meet the user needs. If the final system does not achieve these functional requirements, it will not be possible to validate the system during user testing, and the system will presumably fail to find user acceptance. One challenge of writing good system requirements is ensuring that the requirements do not lock the design into a specific solution.

The following is a partial/example list of system requirements for a garage door system that you will improve:

1.3.1.a.1 Garage door 'inappropriately-open' time <15 minutes

1.3.1.a.2 Garage door able to be kept open beyond 15 minutes, according to user needs

1.3.1.a.3 Easy to operate, by non-expert users

1.3.1.a.4 …

Exercise: Collect your own thoughts about this issue. Ask at least one potential user other than yourself of such a system to get new insights on the problem. Develop at least one additional system requirement and one 'optional' or 'nice-to-have' constraint to add to the list above, based on your knowledge of the problem. Write the updated complete list of requirements, along with basic notes from the interview, **in your lab notebook.**

1.3.1.b Step 2: System design(s) and block diagram(s)

Now that you have a list of requirements, work with a partner to create at least two different system designs that will meet the requirements from 1.3.1.a.

Draw a functional block diagram for each of these distinct system designs, including inputs/outputs/connections between blocks. Figure 1 includes an example that is at an appropriate level of detail for this exercise.

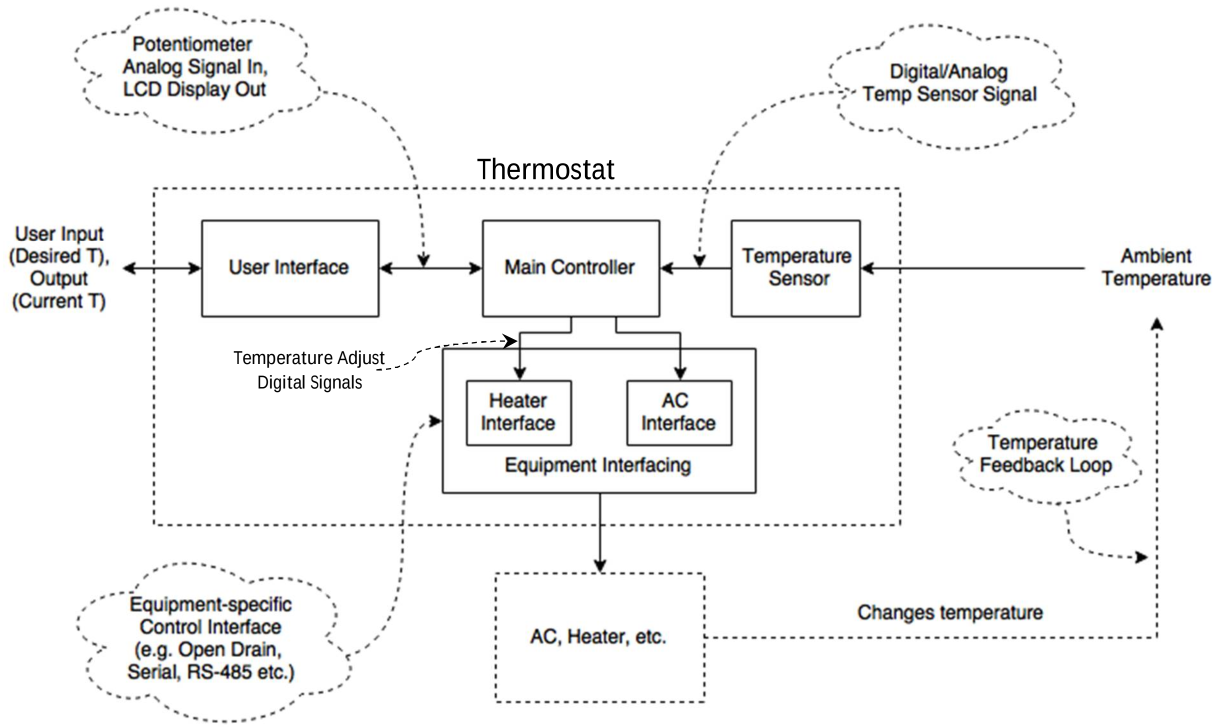


Figure 1: Example functional (system level) block diagram of a household thermostat. Key components: A suitable level of detail is provided without specifying exactly what will be used, and all inputs/outputs from each block are labelled and directions are shown to know what blocks are passing back and forth.

1.3.1.c Step 3: Translating system requirements into design specifications

Using one of the system functional block diagrams that you created in 1.3.1.b, and the system requirements from 1.3.1.a, create a set of design specifications for your system.

Design specifications are the measurable characteristics of the design/system, with associated acceptable/not acceptable value thresholds, that you will use to determine if the design is built and behaving as you intend (at both intermediate and final stages of development). Design specifications always have a clear metric, including units of measurement, which objectively determine if the prototype/design meets the specification. See Table 1.

TABLE 1: EXAMPLE TABLE THAT RELATES HIGH-LEVEL SYSTEM REQUIREMENTS TO THEIR LOWER-LEVEL SPECIFICATIONS.

Specification number	Specification description	Test to perform	Relevant requirement	Specification [units]	Measured Value [units]
1.1	Ball propelling distance	Fire the ball across the playfield, measure its peak travel distance	1*	Greater than 50 cm	
…	…	…	…	…	…

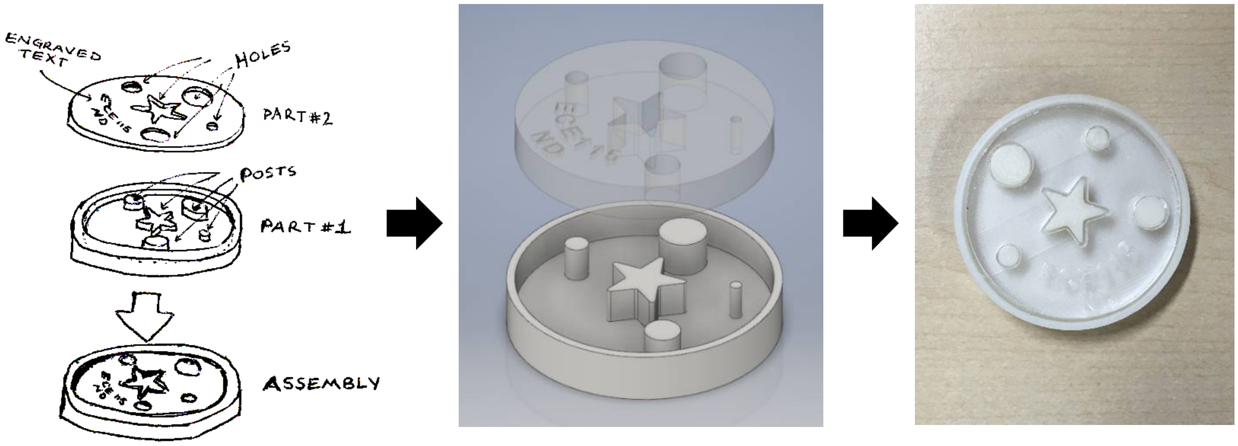
* Note: 'Relevant requirements' refers to the requirements list in the Project Description

Note: While it is sometimes trivial to create a specification based on a requirement, the translation from system requirements into design specifications is frequently challenging, and it takes iteration, attention to detail, and collaboration to achieve an efficient and sufficient set of specifications.

To document your design specifications, please create a 'trace matrix' that describes the specifications and traces them to their relevant requirement (see *Module Deliverables Instructions* document).

A way to start this process is by making a list of all of the system functional block inputs and outputs and asking/answering: 'what are the units and approximate value ranges for each of the inputs/outputs?'

1.3.2 Mechanical Prototyping Tools: CAD, 3D printing and laser cutting



1.3.2.a CAD for 3D printing and laser cutting: Pre-lab

This part of the lab introduces CAD tools (in this case, Fusion 360) as a method for rapid prototyping.

The goal is for each student to produce a specific two-part assembly using Fusion 360 that meets the stated requirements. Each student will prepare files for production of the two parts—one for the laser cutter and one for the 3D printer—according the specific instructions in the following steps.

We will use the laser cutter and the 3D printer during our lab session on 11JAN2017 to make the parts in these files, and you will be using these tools for future lab assignments and beyond.

1.3.2.a.1 CAD for 3D printing and laser cutting: Pre-lab Outputs

Please submit the following files on TritonED by 11:59PM on Wednesday, 10JAN2018 (so that we can pre-print and pre-cut some of the parts for use during lab on Thursday):

1. Screen capture of completed tutorial assembly in Fusion 360.
2. Sketch (hand-drawn) of Parts #1 and #2 **in your lab notebook** (from steps 3a-c, below)
3. Screen capture of parts #1 and #2 in Fusion 360.
4. Files of assembly of parts #1 and #2 (*.f3d).
5. File of Part #1 (the bottom piece), formatted for the 3D printer (.stl)
6. Drawing file of Part #2 (top piece), formatted for laser cutter (.pdf)
7. Questions/answers about cost estimates (1.3.2.a.2, #6)

1.3.2.a.2 CAD for 3D printing and laser cutting: Pre-lab Steps

1. Install Fusion 360 on your computer (or find it on a cluster computer) (~45 minutes)
2. Complete (at least) the following Fusion 360 tutorial. Save a screen capture of your assembly as "assembly_<yourname>_ece115_tutorial.jpg":
3. Create an assembly, comprising two mating parts, according to the following specifications/diagrams. Export the assembly as "assembly_<yourname>_ece115_prelab1.f3d" and save a screenshot of the assembly as "assembly_<yourname>_ece115_prelab1.jpg" (estimated time ~2 hours)
    a. Part #1 (we will manufacture this during the lab session using ABS plastic, via an FDM process, using a Zortrax M200 printer)

i. Cylindrical form factor, with outer diameter <=55mm
ii. Has a central ‘cutaway’ region with uniform depth and diameter >= 41mm
iii. Has a lip to the central ‘cutaway’ with minimum width of 2mm
iv. ‘Cutaway’ has raised unique shape design, that has feature height flush with the top surface of the ‘cutaway’ lip (Figure 2 uses a star as an example)
v. ‘Cutaway’ contains 3-5 cylindrical posts, each with different diameter, covering the range of 2mm-8mm
vi. Has nominal material cost ~$5 or less (see 5a, below)

b. Part #2 (we will laser cut this during the lab session out of ¼” extruded acrylic)
   i. Must mate with Part #1 (see Figure 2)
   ii. Has cut or etching that contains ‘ECE115’ and your initials

c. The mated assembly of parts #1 and #2 will have a height of <=12mm”

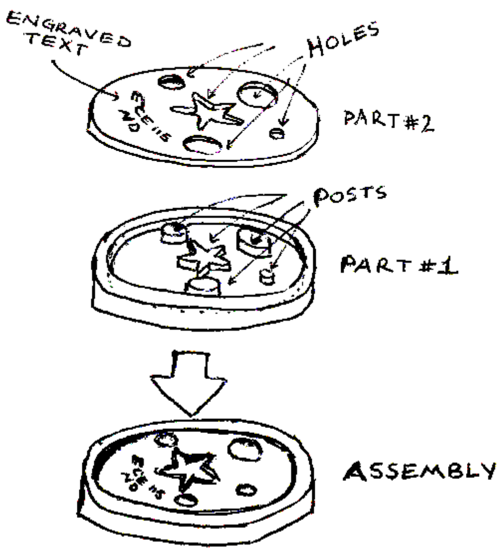
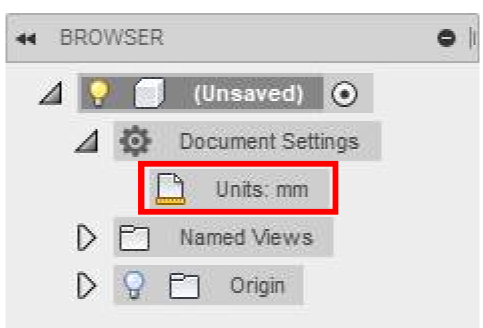


Figure 2: Rough sketches of Parts #1 and #2 (top), with assembly (bottom)

4. Export a .stl file of Part #1 from Step 3a. We will load this on the Zortrax 3D printing software to make your part. **Ensure your units are set to mm prior to exporting, otherwise your scaling may be off.**



   a. Please name it according to the following: “part1_<yourname>_ece115_prelab1.stl”

5. Create a simple line drawing of Part #2 from Step 3b—see Figure 3 for an example. We will load this on the laser cutter to make your part. You will need to perform a couple of processing steps

to set up the file for laser cutting. **Note: be sure that the size/scaling in the final .pdf is accurate.**

6. Save the layer/sketch as a .dxf. **Ensure your units are set to mm prior to saving.**
    a. Open the .dxf file in Inkscape.
    b. Remove any stray marks or words, center the drawing, and crop the document to fit the drawing (File > Document Properties > Resize Page to Content).
    c. Export simple line drawing as a .pdf: "part2_<yourname>_ece115_prelab1.pdf". Use the highest quality settings when saving your PDF.
    d. Finally, since the cutter uses line color and width to encode its cutting operation, edit the .pdf line drawing so that it has the following properties (Object > Fill and Stroke):
        i. The *only* lines or marks in the file are the cut/etch lines for the part (no header/footer/border/measurement lines, etc.)
        ii. Cutting line color is true red (R,G,B = 255,0,0)
        iii. Cutting line width is 0.02mm
        iv. (optional) Etching line color is blue (R,G,B = 0,0,255), and etching line width is not important, so set it to ~0.1mm
        v. File name: "part2_<yourname>_ece115_prelab1.pdf"

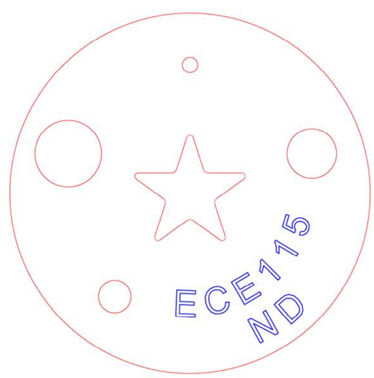


Figure 3: Example of a correctly-formatted .pdf file for laser cutting. Note that there are no stray marks and the lines are specific colors and thicknesses (per the instructions).

7. Answer the following questions about the above part designs (**in your lab notebook**):
    a. What is the approximate minimum material cost and build time of Part #1 (from Step 3), if produced using the Zortrax **FDM 3D printer** (use Google)?
    b. What is the approximate minimum material cost and build time of Part #1 (from Step 3), if produced using the Formlabs Form 1+ **SLA 3D printer** (use Google)?

1.3.2.b CAD, 3D printing and laser cutting: Lab work

This module includes three parts, each of which provides an introduction to rapid prototyping methods and tools. You will work (with assistance from the teaching staff as necessary) to complete the activities and deliverables for each part. **Each individual should include the lab notebook deliverables in his/her own lab notebook**.

1.3.2.b.1 Laser cutting

In this part of the lab you will:

- Use your Fusion-generated and Inkscape-modified file from the pre-lab exercise (Part #2; .pdf file) to cut your part from ¼" cast acrylic using a laser engraver/cutter
- Learn about file format requirements first-hand
- Learn about the process and limitations of laser cutting acrylic

As the laser cutter requires files exactly in a particular format and character (as described in the pre-lab) so that it knows what kinds of cuts or marks to make on which lines. Please make the file with the correct scaling, line widths, and line color(s).

Note: Because the laser cutter requires specific training, you will need a qualified TA or instructor to actually use the equipment—no students will be independently operating the laser cutter in this lab session, regardless of your level of experience with the equipment, unless your name is on the list of approved users.

Laser cutting deliverables

- A properly formatted .pdf file, **on TritonED**, named: 'part2_<yourname>_ece115_lab1.pdf'

1.3.2.b.2 3D printing

In this part of the lab you will:

- Use your Fusion-generated file from the pre-lab exercise (Part #1; .stl file) to make your part from ABS plastic using the 3D printer in the lab
- Learn about the process and limitations of 3D printing with FDM technology

Note: Because the 3D printer requires some training to use effectively, you will need a qualified TA or instructor to actually use the equipment today—no students will be independently operating the 3D printer in this lab session, regardless of your level of experience with the equipment.

3D printing deliverables

- A working .stl file, **on TritonED**, named 'part1_<yourname>_ece115_lab1.stl'

1.3.2.b.3 Measurements of Laser Cut and 3D Printed Parts

In this part of the lab you will:

- Use measurement tools in the lab with your (or your teammate's) already-cut/printed parts
- Table how measurements of the parts compare with both the design specification from the pre-lab and with your part file(s) in Fusion 360, including your measurement accuracy (e.g. "+/-1mm")
- Compare the measurements with the CAD file(s). Where there are mismatches, please explain or hypothesize how to improve any discrepancies.

1.3.3 Pinball System Design Plan

The first step in creating a system is to make a plan that starts with the system requirements and works through to a refined block diagram with subsystem inputs and outputs. You will work with a partner of your choice whom you will work with for the remainder of the quarter.

- Understand the system requirements for the pinball machine
- Create a very high-level block diagram of the pinball system that can meet the system requirements. Details such as specific components used are not necessary at this stage.

This activity should help you plan ahead to understand how the pinball should be laid out, which is the next section.

1.3.4 Pinball Machine Playfield Mechanical Design Cycle

This activity of Module 1 applies the skills and practice from 1.3.1 and 1.3.2, with the pinball system design from, to design the pinball machine playfield design while following a coherent system design cycle through at least two iterations of Planning, Building, Testing, and Assessing.

You and your partner will create a new pinball machine playfield mechanical design, along with appropriate documentation of the following steps in this cycle, including: associated system requirements, block diagram(s), design specifications, prototypes, test measurements, and verification/demonstration of specifications and requirements.

During the lab sessions we will go through two full design cycles on the mechanical subsystem (sections 1.3.4.a-1.3.4.d). In Module 1, you will complete the first design cycle in which you will prototype your design with paper/cardboard to understand how the parts can be made and then integrated. You will complete the second design cycle in a later module where you will integrate your learning from the first cycle to revise and create your design using laser-cut plywood.

1.3.4.a Pinball Machine Playfield Mechanical Design Cycle: Plan

- Sketch playfield on paper with consideration of system requirements
- Write the mechanical design specifications for your pinball machine's mechanical subsystem. These specifications/metrics will be the basis of your verification testing in section 1.3.4.c.

1.3.4.b Pinball Machine Playfield Mechanical Design Cycle: Build

- Fabricate playfield using paper/cardboard
  - Designate locations for each of your intended components
  - Insert paper/cardboard replicas of mechanical structures and moving components
  - Account for placement of motors, wiring

1.3.4.c Pinball Machine Playfield Mechanical Design Cycle: Test

- Perform any mechanical subsystem verification tests you can perform now, based on specifications/plans in 1.3.4.a, using your cardboard system and record results in a trace matrix (see 1.3.1.c). You may leave other specification measurements "not complete" if they aren't measurable at this point.

1.3.4.d Pinball Machine Mechanical Design Cycle: Assess

- Analyze verification test results
- Create notes for potential redesign (in lab notebook)

1.3.5 Pinball Plunger Testbed Mechanical Design Cycle

This activity applies the skills and practice from 1.3.1 and 1.3.2 to create and build the mechanical design for a pinball plunger. This first prototype can be constructed as a module that you drop into your machine later on, or it can be re-implemented in future modules if you do not wish to go with a modular design.

1.3.5.a Pinball Plunger Mechanical Design Cycle: Plan

- Create a specific/refined system and mechanical sub-system design that meets the relevant requirements and uses provided/available electrical and mechanical system components (you will receive a bag of parts in lab)
- Use the sub-system design to write mechanical design specifications for your plunger testbed mechanical design. These specifications/metrics will be the basis of your verification testing in section 1.3.5.c.
- Draw (using CAD tools) your plunger testbed mechanical design

1.3.5.b Pinball Plunger Mechanical Design Cycle: Build

- Create/modify drawings of parts and assemblies by hand or in Fusion 360
- Fabricate parts
- Assemble the testbed
    - Include mechanical components, e.g., motors, springs, fasteners, etc. if necessary
- Document any designs/changes with drawings, files, or pictures, as appropriate

1.3.5.c Pinball Plunger Testbed Mechanical Design Cycle: Test

- Perform mechanical subsystem verification tests, based on specifications/plans in 1.3.5a, and record results in a trace matrix (see 1.3.1.c).

1.3.5.d Pinball Plunger Testbed Mechanical Design Cycle: Assess

- Analyze verification test results
- Create notes for potential redesign (in lab notebook)

A Final Tip: If you designed your plunger to be modular, you can keep what you built here and fit it into your final pinball machine at the end.