Lucas Watson

Engineering & Design Portfolio

01 Engineering

02 Design

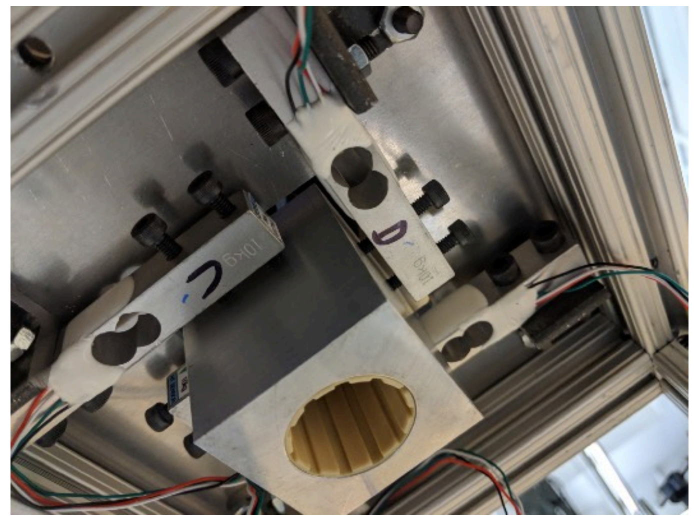
01.1 Multi-Robot System for Collaborative Object Transport

Background
With a team of three of my peers, we developed a technical proposal for a system of robots capable of collectively transporting objects. We then presented this proposal to Amazon Robotics, and received funding to pursuing it as our senior design project.

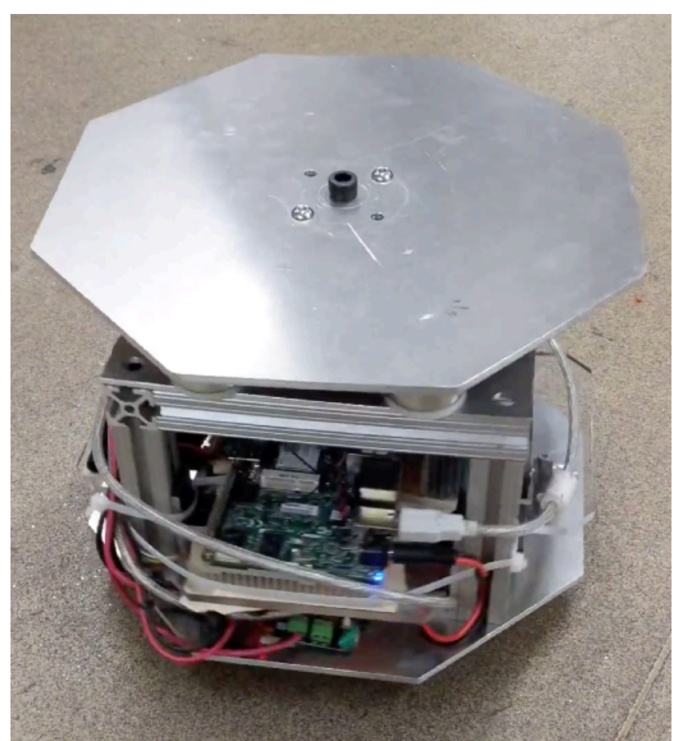
Our motivation for the project was to develop a robotic system capable of working alongside humans in a warehouse environment. Present robotic solutions are most often partitioned from human workers, and fully take over a set of tasks. Automation is easily applied to structured tasks, while relatively unstructured tasks need to be regularized in some form to be automated. We saw the transport of large, irregular loads as a good area to tackle, and accordingly designed a robotic system capable of handling an unstructured task with human aid.

System Design

The system is centered around the compliance mechanism in the loading platform. The mechanism allows for force to be sensed for an object placed on top of the robot, allowing the robot to follow where a human push guides it.



The mechanism consists of four load cells around a chuck which translates force from the platform to the cells.



Controls
I chiefly took charge of the controls system for the robot. Given a measured push, the robot then needs to respond by aligning itself in the direction of the push and acceleration accordingly. A two degree-of-freedom PID control is employed along with a state machine. When a push event is measured, the control is entered and the robot complies to a push. When the robot senses it's been release, it slows to a stop.

Perception
A stretch goal for our project has been advanced perception. Each robot is equipped with an Intel RealSense D435i depth sensor. I've been working to develop an algorithm that would allow multiple robots to perceive an object that a human is holding above the system, and then conform themselves into a formation appropriate for carrying the object. Effectively, this involves each robot localizing itself with respect to the object, and then inferring their distance from fellow robots via the common object the system is tasked with carrying.

01.2 Gita

Background
I currently work at Piaggio Fast Forward as a Robot Software Intern. My work focuses on Gita, a cargo-carrying robot that can follow a person.

User Experience
I became one of the chief operators for demoing Gita. This lead to me communicating what the robot does and how it works to all sorts of people.

A large part of this involved observing user's initial impressions of Gita. These observations motivate our design of Gita's movement, sounds, and behavior.

Lagrangian Dynamics
Gita is a 3-body dynamic system, and uses several methods to balance itself as it drives. Part of my work involved deriving equations of motion for Gita, with the goal of better understanding how Gita would react to various physical situations.

I derived the Lagrangian for each body, and solved for equations of motion. I used SymPy's physics library to aid in solving and linearizing these equations, such that we could analyze them numerically.

Drive Controller
The first part of my work during the summer consisted of improving the drive controller and odometry ROS nodes. This involved code cleanup and improvement of the filtering of sensor data. Within the drive controller, I improved and tuned several PID controllers.

From my knowledge of the drive controller, I was also able to improve Gita's static calibration on slopes, and dynamic calibration while driving. I added instability detection, and a corresponding behavior for recovery.

Physical Awareness
My work then continued to focus on Gita's physical awareness. By combining data from various sensors, I enabled the robot to make conclusions about its physical state. This was accomplished by first processing data from several sensors, inferring discrete events, and then combining events from several sensors in order to make a conclusion about our state.

Perception
Following work on physical awareness, I switched to begin work on a perception algorithm. This algorithm used a neural network to inference sections of what the robot was perceiving, and then compared those inferences in order to make a conclusion about what we were perceiving.

Message Transport
I've additionally worked on researching methods of message serialization and transport for our constrained computer system.

01.3 Sonic Levitator

Background

My first project with Professor Glynn Holt, working with a fellow peer, was to improve an apparatus that demonstrates the phenomena of acoustical levitation.

Levitation of a styrofoam ball is accomplished by using 4 speakers to drive waves in the 1kHz range into the chamber. The chamber's X and Y dimensions are equal, while the Z dimension is slightly larger. In order to levitate the ball, we create resonance in the chamber. One frequency is used to create resonance in the XY plane, and a slightly higher frequency is used for the Z axis. The XY plane stabilize the ball, while the Z axis provides the levitating force on the ball.

Development

Previously, a setup including a frequency generator, mixing circuit, amplifier and oscilloscope was used to drive the speakers. To improve this, we decided to experiment with moving all frequency generation into software on an Arduino, eliminating much of the bulky setup. We can also use the Arduino to find the resonance through a feedback loop.

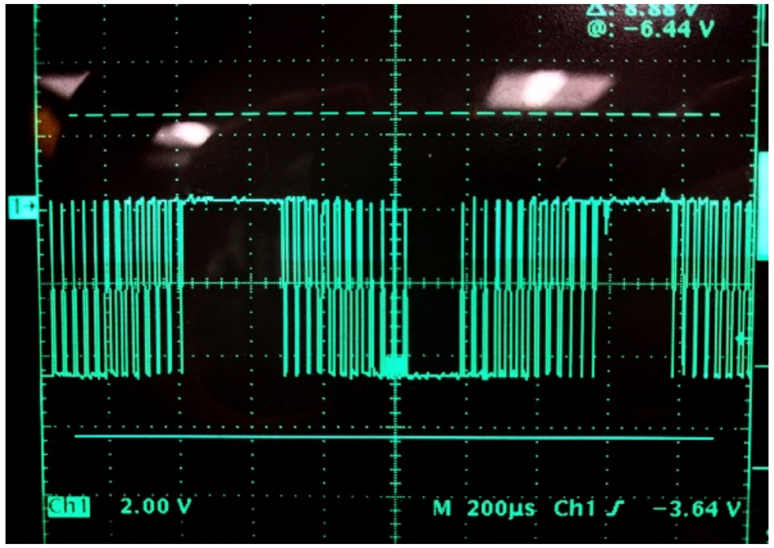
1. DDS Sinewave Generator — http://interface.khm.de/

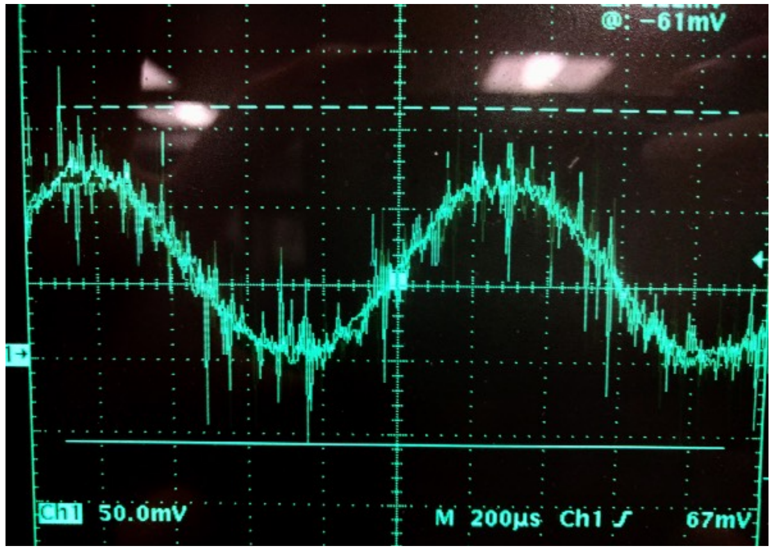
The first iteration of this attempt was an extension of a project from a lab at KHM. A PWM pin on the Arduino outputs a combination of both frequencies, and a Chebyshef filter is used to "smooth" this into a sine wave. As visible in the pictures, another High pass filter is needed to further smooth the curve, but the overall shape is decent.

To then implement this frequency generation method, I created four sub circuits with ATTiny85 microcontrollers. Each is connected to a parent Arduino which can set both the frequency and the phase of each generator, allowing for independent control of each of the four speakers.

Future Work

The next steps in this project are to create a clear chamber for the apparatus to sit, such that the very loud sound is dampened, but the experiment is still visible. Preliminary designs for this are being developed, based upon the three medium problem in acoustics.





01.4 Stranger Lights

Background
Inspired by popular Netflix show Stranger Things, I created a controllable alphabet wall in an apartment window, opposite of BU's central campus. Similar to a Ouija board, one can enter a message, and have it blinked out by LEDs behind each alphabet letter.

Development
To make it easily to interact with, I developed a site (which is still up), strangerlights.com, where anyone could go and enter a message. The server hosting the website would store the messages, and then allow them to be fetched by the board, controlled by an ESP8266 IoT chip.

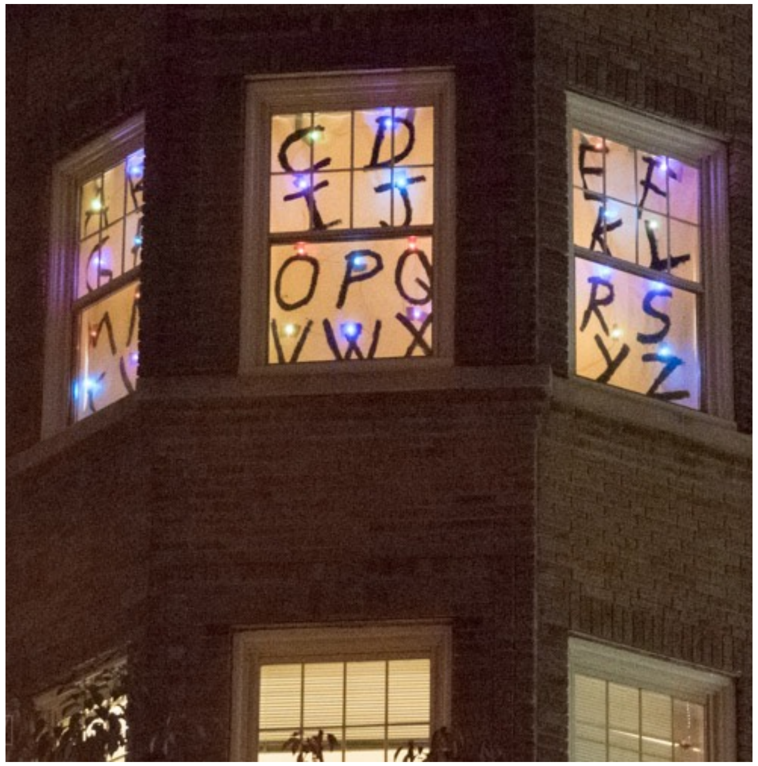
From there, I set out to build the physical board. I decided to get canvas, and paint on the letters in black. For the lights, I got some individually addressable RGB LEDs, and (tediously) soldered them in a long string.

To create a greater contrast between the letters and canvas, I modified two lamps with aluminum foil reflectors to backlight the display.

To control the board, I wrote code on a server that would accept messages and store them in a queue. Additionally, it filters out any bad words. To play a message, the IoT board requests the top message in the queue from the server. If there are no messages to display, it goes into an idle mode. The idle mode lights all the letters, and flickers them eerily

Results
The board was very popular, and many messages got sent to it. Visibility was decent, and people who didn't know about it were able to recognizing it on first sight. The only problem was, if they didn't know about the website beforehand, there was no visible way to see that they could interact with the board.

Source code and more details can be found at <u>www.strangerlights.com</u>



01.5 Emergency Medicinal Refrigerator

Background
In Product Design, a course focused on the development and creation of products, myself and 3 other students were tasked with creating a device that could keep 4 vials of medicine chilled at 40 F for 96 hours in the case of an emergency. The device could not rely on grid electricity, so we needed to find a solution that used little or no energy.

My chief responsibilities in this project were designing and machining the vial holder, coding the Arduino controller, and performing FEA analysis.

Design Space
After refining our constraints and objectives, we came upon defining the design space we had to work with. We took into consideration methods of cooling, insulation, and if needed, power generation. As well, we considered portability and ease of use. After consideration and preliminary experimentation, we decided to use vacuum insulated panels (VIP), along with a thermoelectric cooler (TEC), and either a hand crank or solar cell for energy creation.

Experimentation
The critical path in our design was the ability of the combination of the VIP and TEC to keep the vials cool. In testing, the VIP comes as a vacuum walled Thermos.

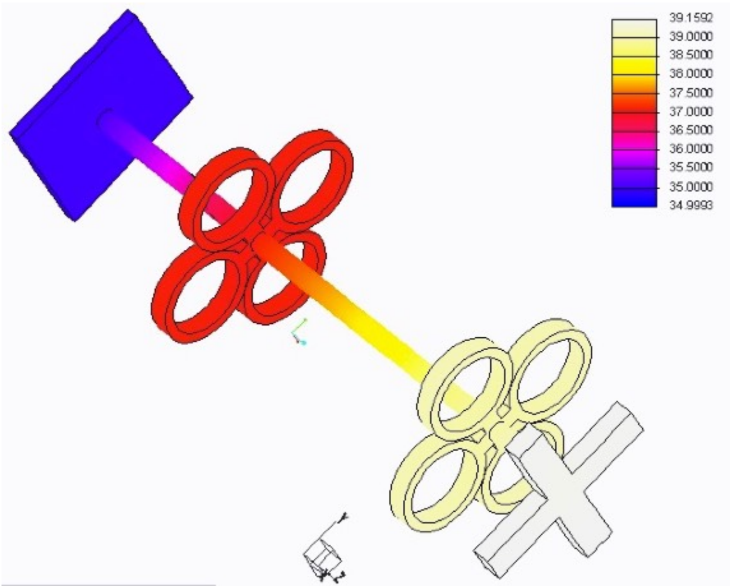
In our first round of testing, we placed the TEC in a makeshift lid for the Thermos. Further rounds used the improved container with several temperature sensors around the container to measure both air and vial temperature.

Our test results were mixed. The Thermos provided very good insulation, only allowing in about 10mW of heat.

However, the TEC proved to be ineffective in cooling the interior container with convection.

Results
To solve the problem of heat transfer to the TEC, we developed a design where the holder interfaces directly with the TEC, acting as a heat sink. An FEA heat transfer analysis is shown. The holder was milled from a copper sheet, and then TIG welded together.

The final design was successful in maintaining 40 F inside the chamber for approximately 40 hours, after which it exceeded this temperature.



01.6 Sonochemiluminescence

Background
Under the mentorship of Professor Glynn Holt, we wrote a project proposal which received a student research award through the Undergraduate Research Opportunities Program (UROP).

Sonoluminescence (SL) describes the phenomena by which acoustically driven cavitation gas bubbles in liquid collapse violently enough to emit light by means of a physical reaction.

This project seeks to study a subset of SL, sonochemiluminescence (SCL). Free radicals are generated in bubble collapse, which luminol scavenges to generate light by chemical means.

Throughout literature on SCL, there is disagreement on the optimal concentration of NaOH to generate the most intense light. This project seeks to determine the relationship of NaOH concentration to SCL intensity while controlling for a variety of factors.

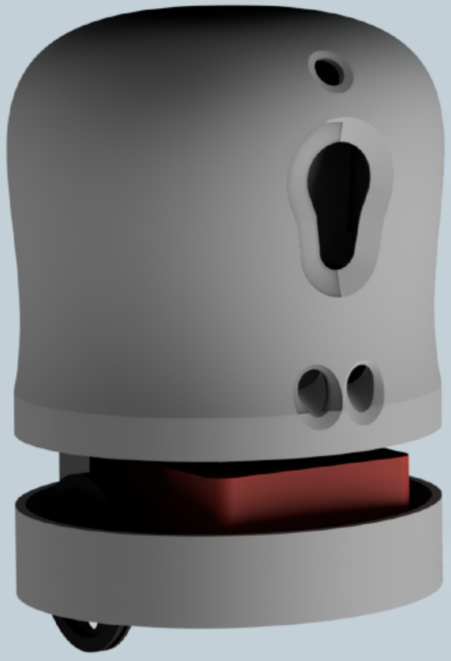
Methods
The first stage of this project concerns experimental setup. Cavitation, and more specifically MBSL, may be generated via ultrasonic resonators.

The first step was to test several ultrasonic transducers. One cylindrical transducer is shown above, with the bubble cloud being the spidery-looking figure. The bubble cloud is backlit, and is generated at the resonant cylindrical mode of the transducer at approximately 26kHz.

By employing computational methods, I'm able to speed up this process. I first compute the modes of the apparatuses with a program I've written, and I then use an automated script I've written that interfaces with lab equipment to sweep a frequency range driving the transducer. Then, by recording the frequency response, the modal calculations can be verified.

Future Work
After determining the best method for generating cavitation, the next steps are describing methods for changing concentrations of NaOH, and controlling for factors like dissolved gas concentration. Measuring SCL intensity will be accomplished either via a photomultiplier tube, or simply with a camera.

02.1 Fasimov



Background
I had always been fascinated by human interaction with robots, and the various factors that can go into one finding a robot cute or creepy. With this project, I wanted to create a robot that was capable of driving around, recognizing people's faces, and then expressing various emotions to them. Accordingly, I decided to name the bot Fasimov.

Design
I wanted to make Fasimov emote in human-like ways without mimicking human features. The first aspect of this I sought out was motion of the "head" of the robot. I designed the head such that it could swivel with two degrees-of-freedom, acting like a human head. In addition to motion, I also added RGB lights to the top of the head (not shown).

On the front face of the robot are three sensors: a camera, ToF depth sensor, and an ultrasonic rangefinder. The camera is utilized to perceive and recognize faces. The depth sensor enables the robot to see its environment and navigate obstacles. Finally, the ultrasonic sensor points to ground in front of the robot to avoid driving into obstacles or off surfaces.

Fasimov is additionally equipped with a microphone and speaker, enabling it to both interpret speech and respond.

Results
Overall, the robot was successful. It was capable of navigating basic environments with its depth sensor, could recognize faces, and perform basic emotive interactions.

However, I did run into several issues with the drivetrain of the robot. I didn't put a lot of effort into the design for the wheels and motors, so they were prone to slipping and eventually broke.

On the day of presenting the project for the Imagineering competition, the Arduino which controlled some sensors and the motors also broke. However, the project still won the Best in Class award.

02.2 Automated Coffee Maker

Background
For the engineering department's annual Imagineering competition, I set out to create a better automatic coffee maker. Inspired by the design of the Aeropress, I wanted to make a device that would brew good coffee and be highly controllable while creating no waste.

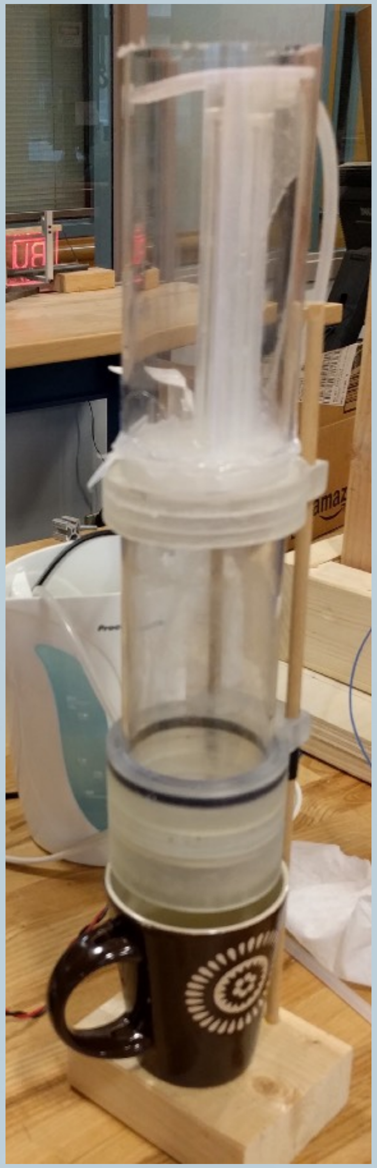
Design
I began by determining the design space for the features I wanted. Given the time constraints for the project, I settled on an electric kettle for heating the water, a peristaltic pump for pumping the water, and a vacuum pump for pushing the water into the brewing chamber.

My design utilized two chambers, one for filling in water, and one for brewing the coffee. The water chamber is necessary, as the pump takes around 2 minutes to pump 12oz of water for a cup of coffee. This chamber consists of two sub-chambers, each with an automatic siphon released when the chamber is filled. The smaller chamber releases 30 s before the other to "bloom" the coffee grounds. The bloom stage improves brewing by allowing the grounds to be evenly wetted before the main brewing stage occurs.

The brewing chamber is connected to the water chamber by a mount, which houses a porous divider to allow water through. The porous divider exhibits a hill-like shape to promote even distribution of water dropping into the brewing chamber. The bottom chamber houses a metal filter for the grounds. A vacuum pump is connected to the brewing chamber, such that it can press the brewed coffee down into the cup.

The kettle, water pump, and vacuum pump are all controlled by an Arduino, which can be commanded by a mobile app, in which brew time and temperature can be varied. The kettle is connected via a relay, and uses PID control to reach a given temperature.

Results
I 3D printed my design, and put it all together with a few rubber seals. The water chamber was a bit leaky, but the device worked! I won the Best in Class award following a presentation for the Imagineering Competition.



02.3 Fall Detector

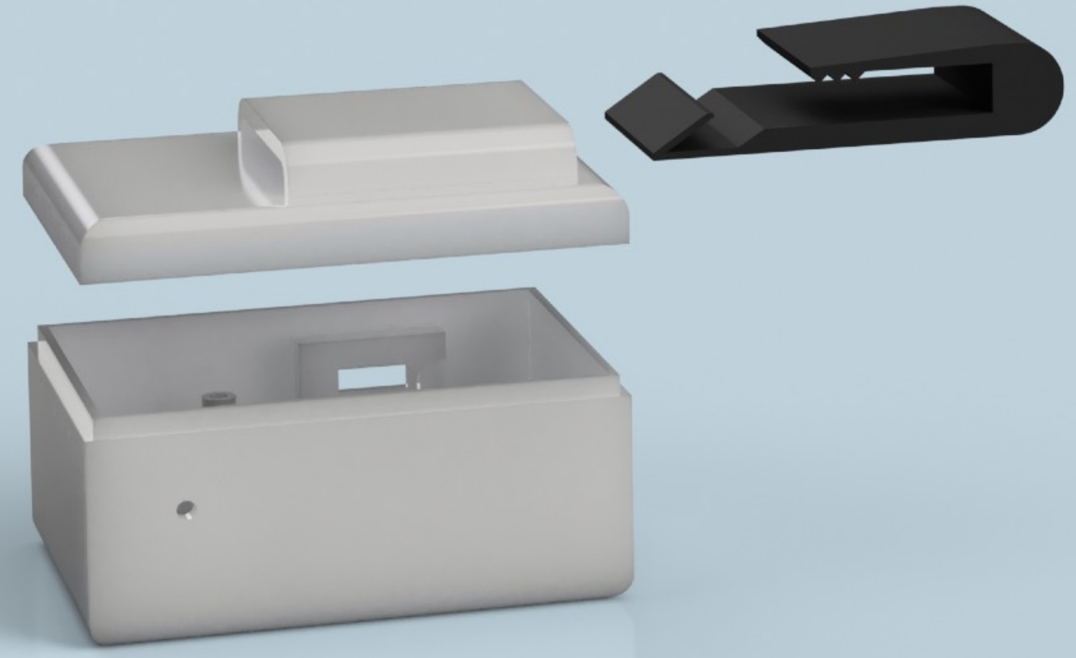
Background
For a group project in our introduction to engineering design class, our team of four was tasked with creating a wearable device for the elderly which would detect a fall, and notify a caretaker when a fall occurs.

My responsibilities included designing and assembling the electronics, designing and printing the case, and helping write the Arduino code.

Design
We decided on using an accelerometer for fall detection, a cellular breakout board to enable SMS messaging, a GPS module for location, a buzzer for an audible alarm, and a LiPo battery to enable portability. We also decided on using a small Arduino Pro Mini to control it all.

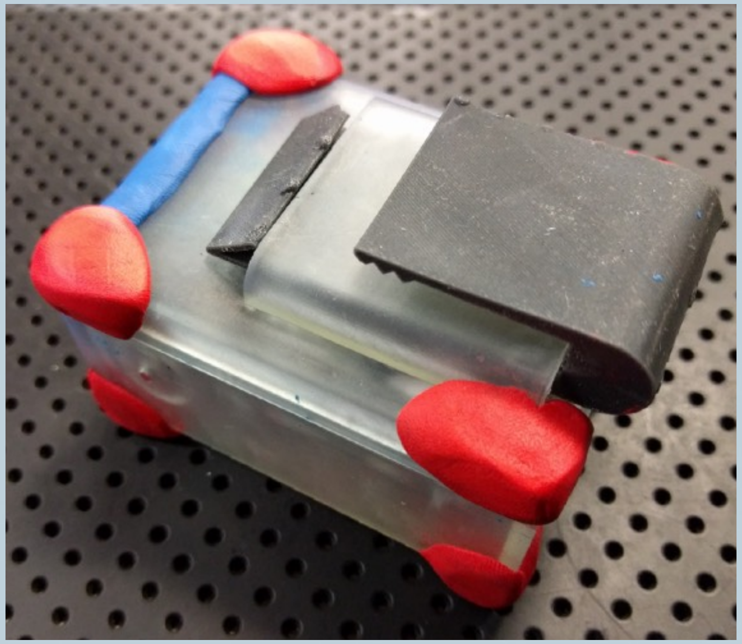
Development and Testing
One major constraint in our project was wearability. While we didn't have much control over weight, we could try and make the device small and easily attachable to clothing.

I designed a two part case (shown left) with an optional clip which could house all of our circuitry and breakout boards, while maintaining a relatively small size. The back panel has a loop which a belt may be fit through, or where the clip may be slid in for attachment to a pocket. The side of the case has an opening for the charging port, allowing the case to be sealed off.



On the Arduino side, we wrote software that would calculate jerk from the acceleration magnitude, and trigger the fall detection if a threshold was passed. This would activate the buzzer, and send a text message to the caretaker with the GPS location of the device.

Results
Our project successfully met the goal we were given. The device was able to reliably detect falls, and notify the caretaker. The GPS module didn't work well indoors, but was always able to give an approximate location.



02.4 Controlled Fall Experiment

Background

For a group project in our fluid dynamics course, we were tasked with creating a 3D printed object which would take exactly 30 seconds to fall in a pipe filled with a height of 6’ of water and 0.25’ of canola oil.

Design

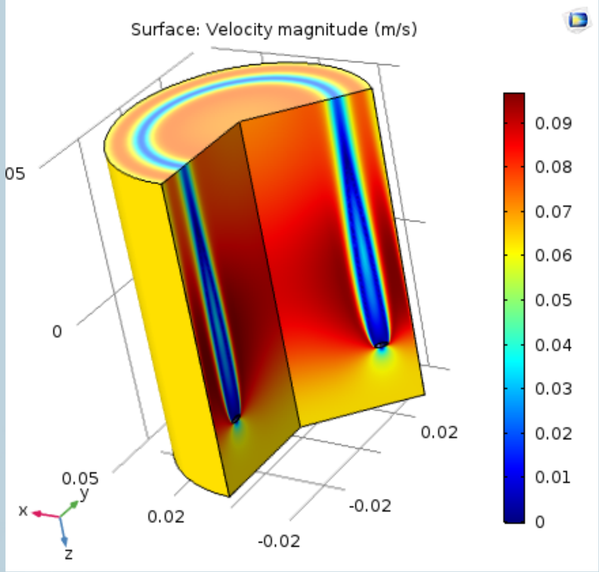
Our intuition was that we would need to try and minimize terminal velocity to achieve this 30 second goal. We calculated the radius of a simple sphere to achieve this length of fall, and found it would need a diameter of 1 mm (prohibitively small).

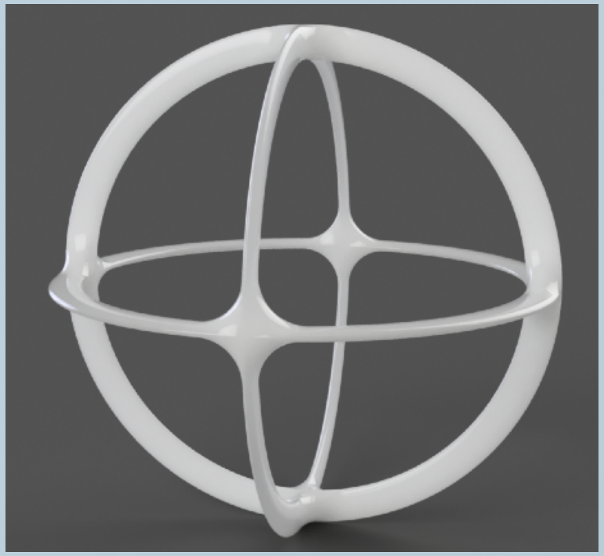
Given that the drag force is a function of surface area, and that the weight is a function of volume, we tried to maximize surface area while minimizing volume. We came up with several complex designs inspired by nature, but these were difficult to predict drag for, either analytically or computationally.

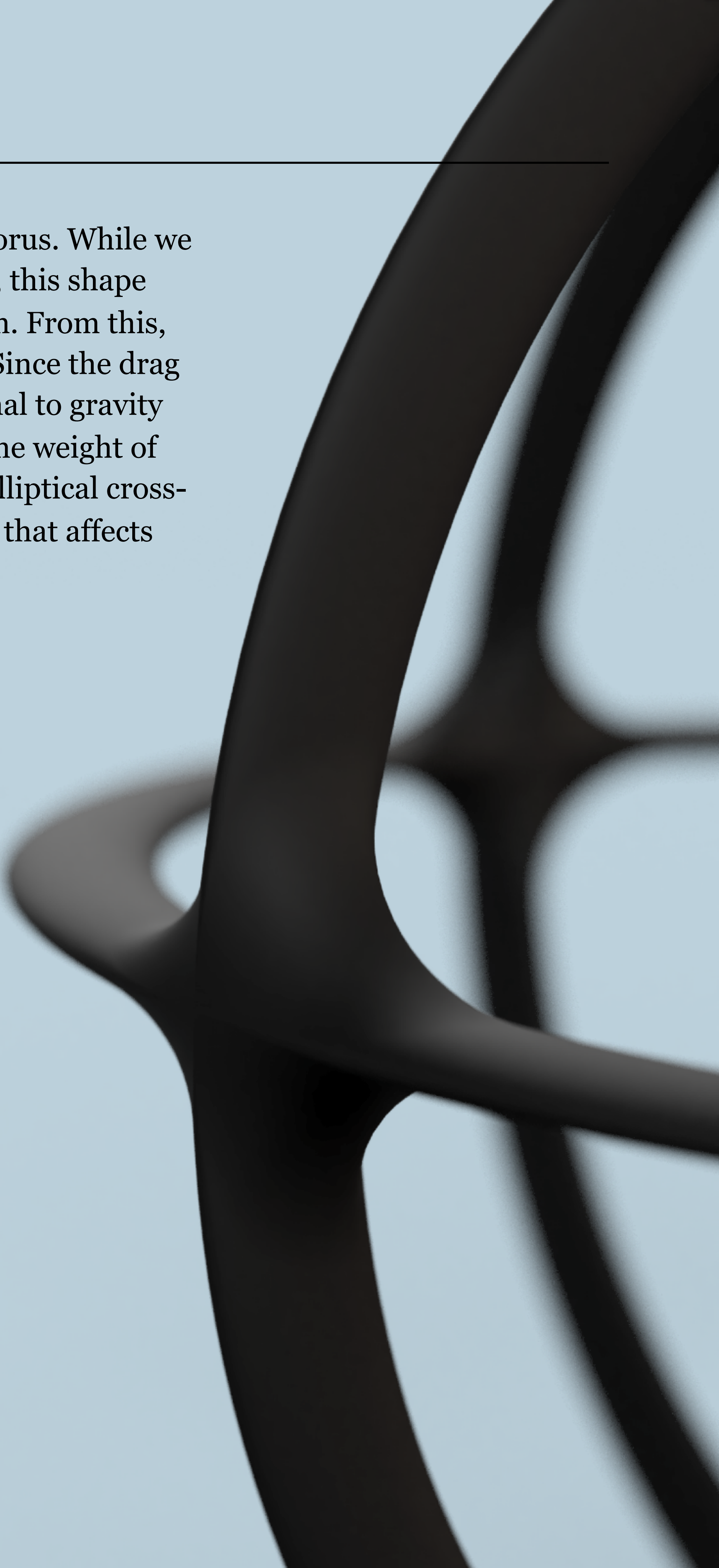
We came about the shape of a torus, and by simulating the flow and drag of a torus in COMSOL, found that we were approaching the appropriate regime for a slow terminal velocity.

Calculations

From the COMSOL simulation (shown), we found that the drag coefficient increased as we approached the wall of the pipe, and as we increased the minor radius of the torus. While we found a good size for a single torus, this shape isn’t stable in the shown orientation. From this, we decided to interlock three tori. Since the drag on the two additional tori not normal to gravity would have less drag, we reduced the weight of the object by making the tori into elliptical cross-sections, such that the surface area that affects drag was unchanged.







02.5 MagSafe Cable Saver

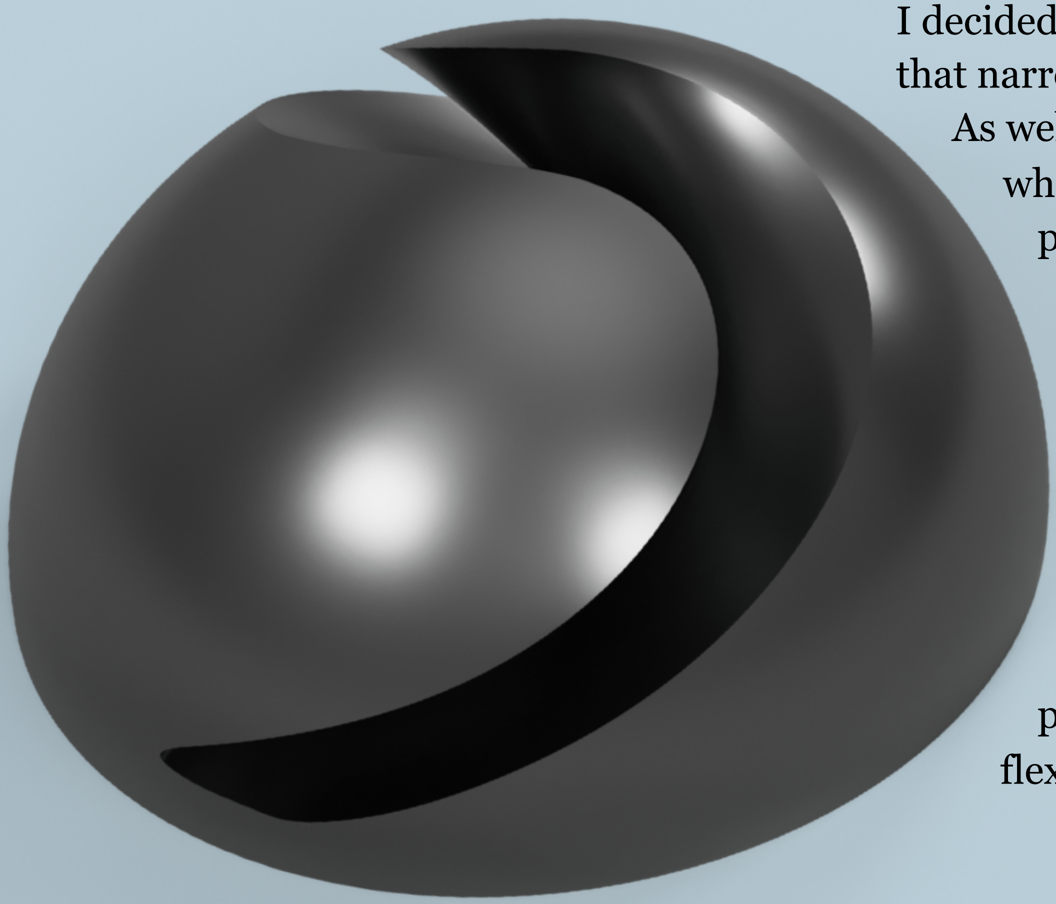
Background
While Apple's cables are known for their sleek design, they aren't known for their durability. My MagSafe cable began to fray, and I set out to solve it.

Development
I started by considering what sort of shape I could create to attach to the metal part of the connector, and extend to support where the cord had begun fraying. Due to it's sleek shape, there was no part of the connector to put snaps that would grab onto the body, so instead I thought to make the entire part a snap. I created a simple casing, and then extruded an opening for the casing to elastically deform, allowing the connector to snap in.

With this, one can press the metal end of the connector into the case, and then press the cord and its potentially frayed parts into the lower portion.

Results and Iteration
After printing the part a few times with varying thicknesses and opening sizes, I found a combination that worked well for me. I further did tolerance analysis on the flexural part of my design to ensure it accommodated variations in MagSafe size. I decided to post it on Shapeways, a 3D printing website, to allow others to buy it (so far, around 70 have).

02.6 Cable Holder



Background
For a product design course, ME360, we were individually tasked with creating a cable holder.

Development
I wanted to create a design that used no snaps or moving parts. I also wanted a cable to be easily inserted and removed but firm when left in place, for cables of any size. Additionally, I sought to further my surface modeling skills through this project.

I decided upon using a slot-like design that narrowed in width towards the base. As well, I added a twist to the slot which servers to keep the cable in place. While this design couldn't be manufactured conventionally, 3D printing it was no problem.

After initial test prints using the Form2 resin-based printer, I had my part printed on via Shapeways on a SLS printer in nylon, which is more flexible than UV-cured resin.

Usage
Using this cable holder is fairly straightforward. One simply aligns the cable with the wide end of the slot, and rotates it. The slot will move the cable downward until it finds a snug spot for the given cable.