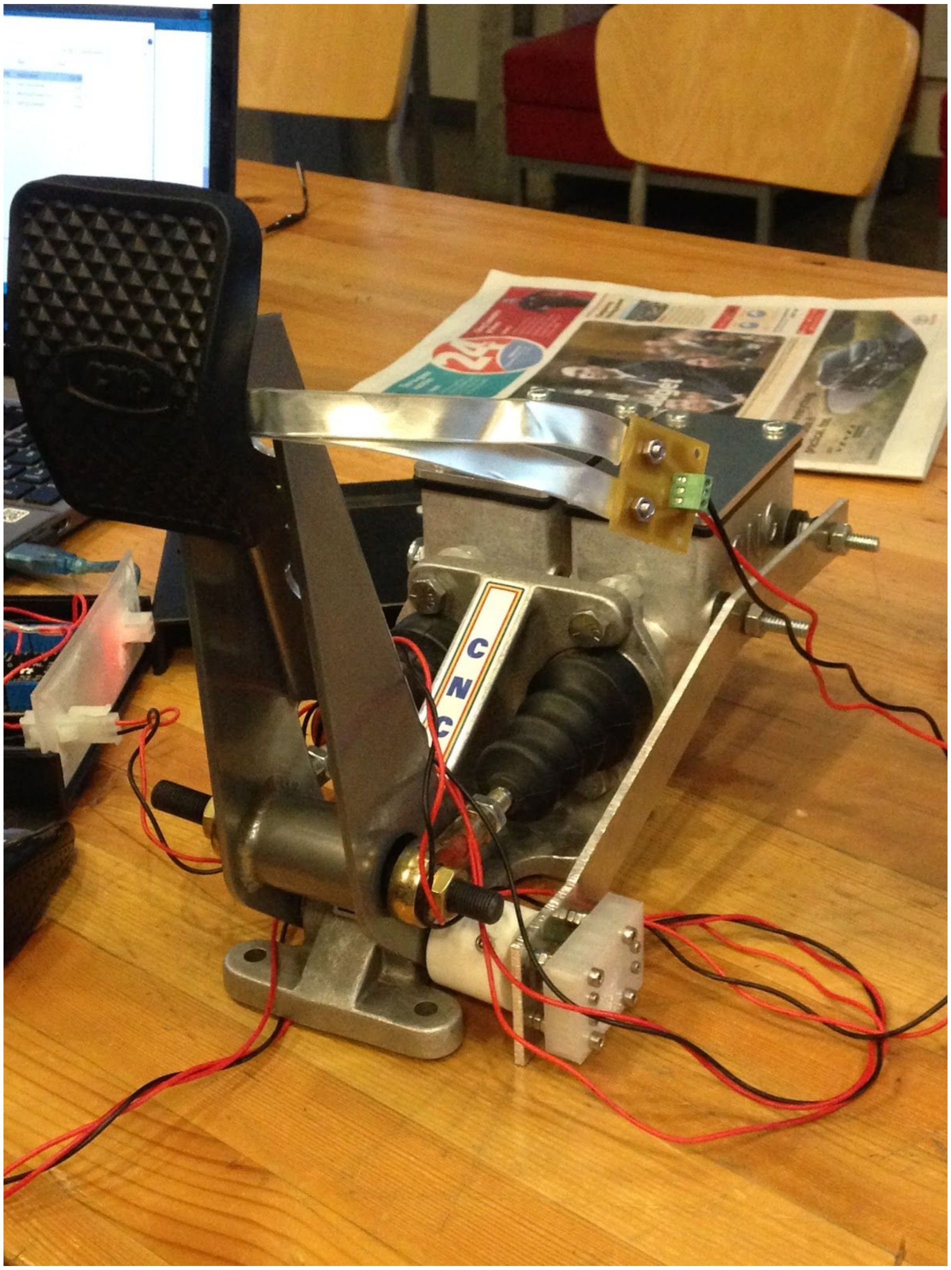
THROTTLE LOCKOUT

By Jacob Brunette and Juliana Hamada



UBC Solar

ABSTRACT

"Throttle Lockout" By Jacob Brunette and Juliana Hamada

The Throttle Lockout project was motivated by conflicts that could arise from the acceleration and braking systems. After acknowledging the problem, the Throttle Lockout was intended as a system that would detect when the brake pedal was pressed and send a message to the motor and other relevant parts of the car through the car's CAN bus system.

During the primary phase of brainstorming most of the ideas were related to sensing the pressure placed on the pedal. Afterwards, a potentiometer attached to one of the brake pedal bolts was added as a possible solution. Finally, the potentiometer and a pressure sensor mounted to the brake pedal were selected as the primary ideas of the project to serve as a redundant system that makes the Throttle Lockout more reliable.

After deciding on the ideas of the project, the components were modeled. Using TinyCAD, the wiring from both the pressure sensor and the potentiometer were modeled. The enclosure for the Arduino Uno, mounting support, potentiometer-bolt connector and the potentiometer base were modeled using SolidWorks. The models served as a base for the fabrication process.

During fabrication, the main machines used were the PCB Milling Machine (LPKF), 3D Printer and other hand-tools for wiring and small adjustments. Many changes were made to our initial concepts during the fabrication process. The next step was testing. Tests were done by analyzing values for both the potentiometer and the pressure sensor, and adjusting both the sensors and the code to make sure the throttle lockout system correctly detected when the brake was pressed.

The overall process took 7 months (2 weeks for brainstorming, 3 months modeling and 3 months fabricating), in which both members spent approximately 20 hours a month working on the project.

This report will further explore the processes of conceptualization, fabrication and testing of the Throttle Lockout, as well as the challenges faced during the process.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1. CONCEPTUALIZATION

This section explains how the main ideas for this project were conceived and why they are important for the solar car.

1.1 MOTIVATION

Raven I's acceleration system acts on the back wheels and its braking system, in the front wheels. This situation creates a possibility for conflict between the two systems. If the car brakes while accelerating, it could drift from its normal trajectory causing the pilot to lose control; therefore presenting a risk to the driver's life.

To prevent this hazard from happening, the Throttle Lockout was intended to detect when the brake pedal is being pressed and send a message to the motor to stop it. This project increases driver safety and improves energy conservation.

1.2 RESEARCH

Essentially, fours options of pressure sensors were considered: home made version from velostat and conductive thread, a flexiforce pressure sensor from SparkFun, off-the-shelf force sensors and a pressure sensor DIY kit. The last option was chosen because it was cheaper than off-the-shelf sensors, instructions and troubleshooting information was provided at the seller's website, it is simple to assemble and it is easily made into different shapes if needed. The detailed information of our research that includes prices, pros and cons of each of the sensors is enclosed.

The potentiometer was chosen among different classes of rotary potentiometers. The price range for the options was fairly the same for all the options. A decision for the EVU-E2JFK4B14 rotary potentiometer from Panasonic was made based on the shape of the head pin that facilitated building a connector that could be properly attached to the potentiometer. In the next section, detailed descriptions of the final ideas are provided.

1.3 FINAL IDEAS

Pressure sensor:

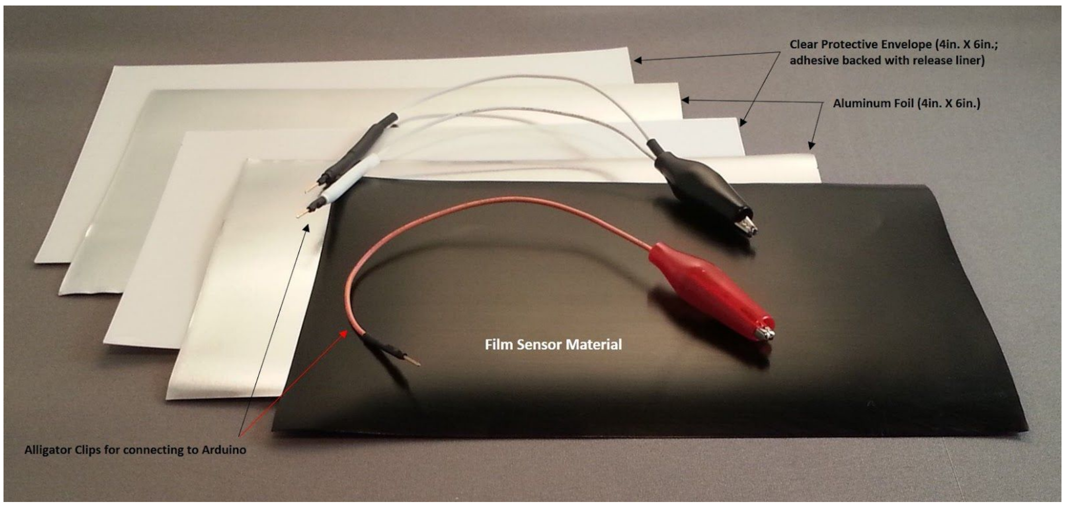


Figure 1. Pressure sensor components <www.sensorfilmkit.com>

The assembly, functioning and components of the pressure sensor are specified in section 3.1.

Potentiometer:

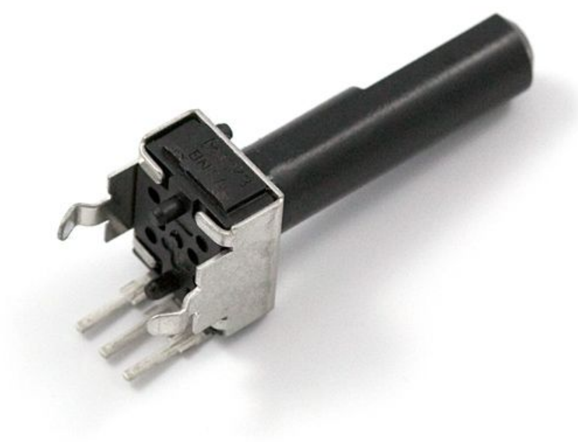


Figure 2. Rotary Potentiometer model EVUF3K. < https://www.sparkfun.com/products/9288>

EVU-E2JFK4B14 model EVUF3K rotary potentiometer from Panasonic.

The mechanism description of the potentiometer is specified in section 3.2.

Data sheet enclosed.

2. FABRICATION

In this section the fabrication and mounting of the pressure sensor, potentiometer and enclosures of the Throttle Lockout are detailed.

2.1 PRESSURE SENSOR

One of the components of the redundant system of the Throttle Lockout, the pressure sensor, is detailed in this section, which is divided in assembly, prototype and final design.

2.1.1 Assembly

The pressure sensor is composed of three main parts: (Refer to Image 1)

- Sheets of sensor film, an off-brand version of Velostat, the material used to make static-resistant bags used to transport electronics.
- Sheets of brass
- Sheets of clear adhesive-backed polyester film
- 100k Resistor

The sensor film is placed in between two conductive sheets of brass, with wires soldered to each. Two sheets of the adhesive film are placed on either side to keep the assembly together. The entire assembly is then placed under the rubber covering of the brake pedal, which fits tightly enough to secure the sensor to the pedal. The assembly functions as a variable resistor, with its resistance dependent on the pressure applied to the brake. We fed the sensor a constant voltage from the Arduino microcontroller as an input, and measured variations in resistance. A side view of the final assembly is illustrated below.

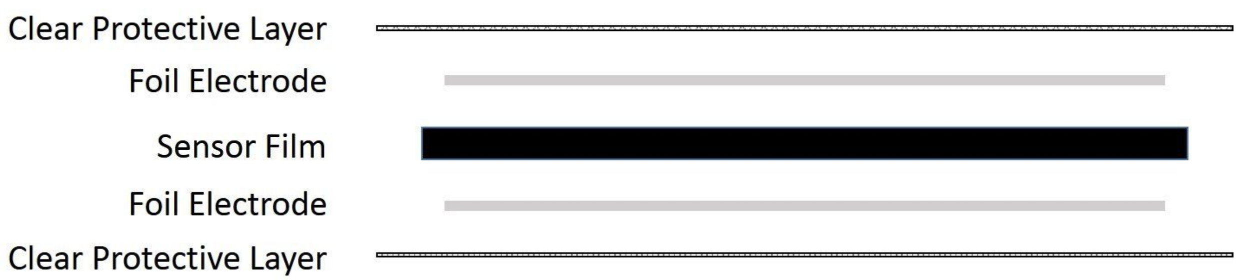


Figure 3. Side view of pressure sensor layers <www.sensorfilmkit.com>

2.1.2 Prototype

The initial prototype of the pressure sensor consisted of a single layer of sensor film between the brass and adhesive, cut to be the same shape and slightly smaller than the pedal, with a single wire connected to each piece of brass. This prototype introduced us to one of the major issues that needed to be overcome with the pressure sensor: both the adhesive film that kept the assembly together and the rubber covering that kept the sensor on the brake pedal exerted significant and non-constant forces on the sensor. This manifested in two major ways: First, the reading for any given amount of pressure fluctuated fairly significantly. Second, if left at a constant pressure, the reading of the output voltage slowly but steadily climbed upward. We believe that this is due to the rubber and adhesive coverings slowly decompressing after being pressed and released, and thus slowly lowering the amount of pressure exerted on the sensor. Unfortunately, these issues meant that the reading that the sensor showed when no pressure was placed on the pedal (i.e. when the driver was not braking) varied wildly, and we could not determine whether or not the brake was being pressed by a simple comparison between the reading of the pressure sensor and a threshold value.

Another, much smaller issue with the prototype was the wiring. Initially, there were single, solid-core wires soldered to each piece of brass foil. In the course of our testing, one of these wires broke off, and even had it been reattached, the wiring would almost certainly not have held up under the duress of actual use in the car.

2.1.3 Final design

Our primary concern with the prototype was the inconsistency of the readings provided by the pressure sensor. This was the driving force for many of the changes we made.

First, we changed the shape. Instead of a rectangle with the same shape as the pedal, we used a thin strip placed horizontally across the pedal. With the old shape, the pressure on the sensor could vary greatly across its surface depending on where the driver placed their foot on the pedal. The smaller sensor was intended to decrease the variability of the pressure across the sensor, while also providing a big enough surface that the driver would not be able to depress the pedal without pushing on the sensor.

Second, we put three layers of sensor film between the strips of brass foil instead of just one. This increased the resistance, and made it so that the sensor required more force to create a corresponding decrease in resistance. This change, as well as the change in shape, meant that the readings from the sensor were now more consistent and fluctuated over a much smaller range than before.

To improve the issue with the wiring, we replaced the old single-core wire with strips of ribbon wire, so that the force placed on the soldered connections would be more spread out, The ribbon wire was then attached to a PCB with two single braided wires coming out the other side, so we could plug the assembly into the Arduino enclosure.

These changes greatly improved the functionality of the pressure sensor. The major issue that still remained was that of the pressure reading steadily increasing while a constant pressure was applied. We attributed this mainly to the rubber covering over the pedal decompressing over time, but we were unsure of how to fix this problem. We considered 3D printing a rigid covering for the pedal, that would hopefully not exhibit this decompression issue, but discarded the idea due to the difficulty of accurately measuring and modeling the shape of the pedal (given that it was somewhat hyperbolic in shape). Even if we were able to do the measuring and modeling, we were not confident in the ability of the 3D printer that we could use to print such a large and precise piece accurately. In the end, we continued to use the rubber covering, and accounted for the effect in the code we wrote for the microcontroller. This is described in more detail in section 4.1.1.

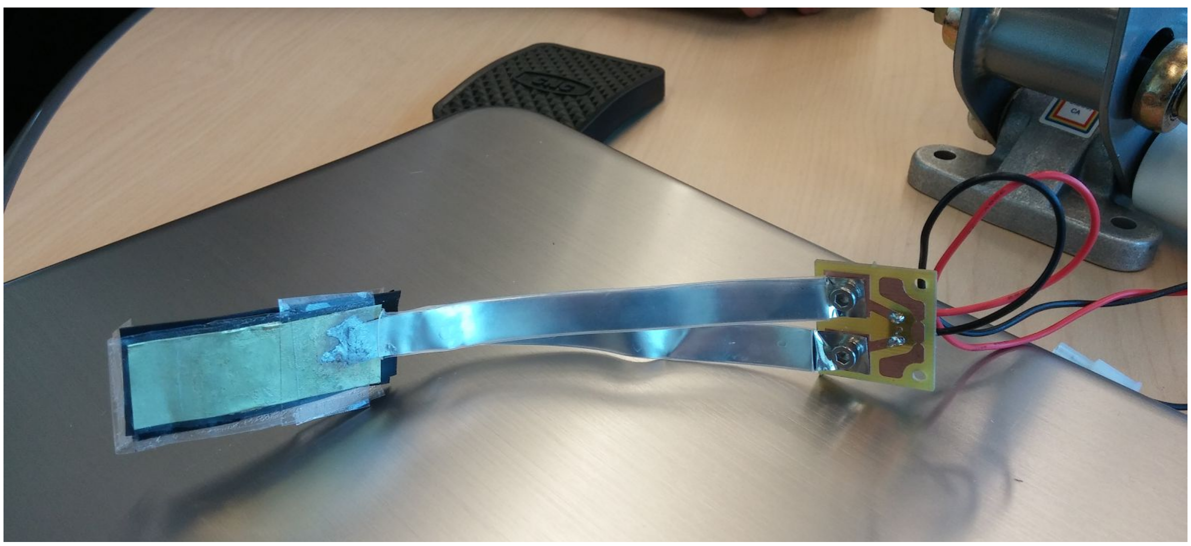


Figure 4. Pressure sensor on its own

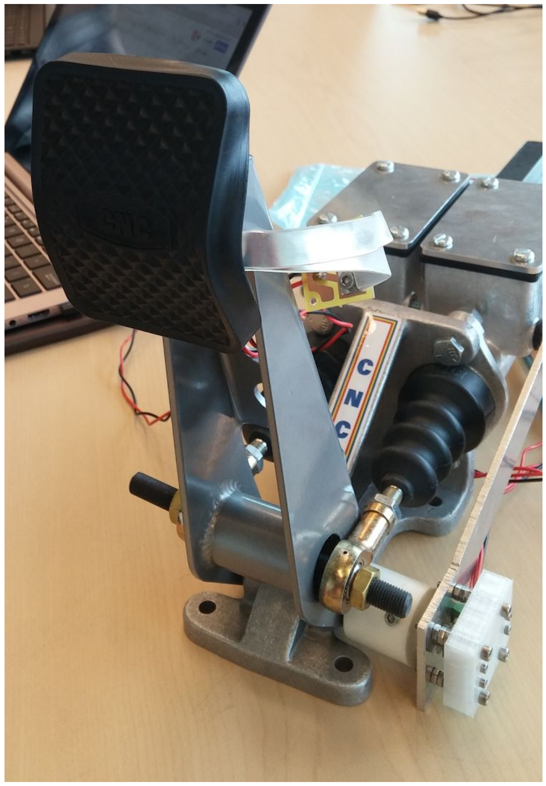


Figure 5. Pressure sensor mounted to brake pedal

2.2 ROTATION SENSOR

Another component of the redundant system of the Throttle Lockout, the rotation sensor, is detailed in this section, which is divided in assembly, prototype and final design.

2.2.1 Overview

The rotation sensor consists of a rotary potentiometer connected to the bolt at the hinge of the brake pedal. It is held in place by a metal arm connected to the hydraulics enclosure of the brake and a 3D-printed enclosure containing a PCB. The potentiometer is connected to the bolt through a 3D-printed connector.

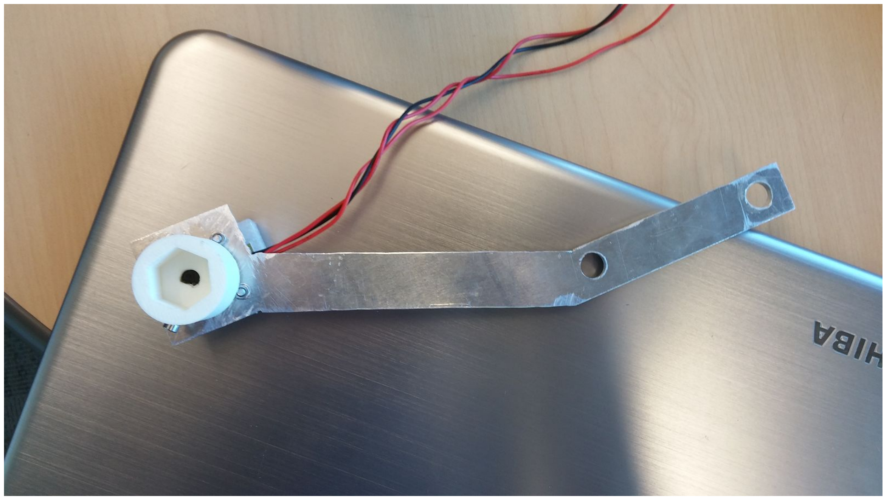


Figure 6. Top view of rotation sensor assembly

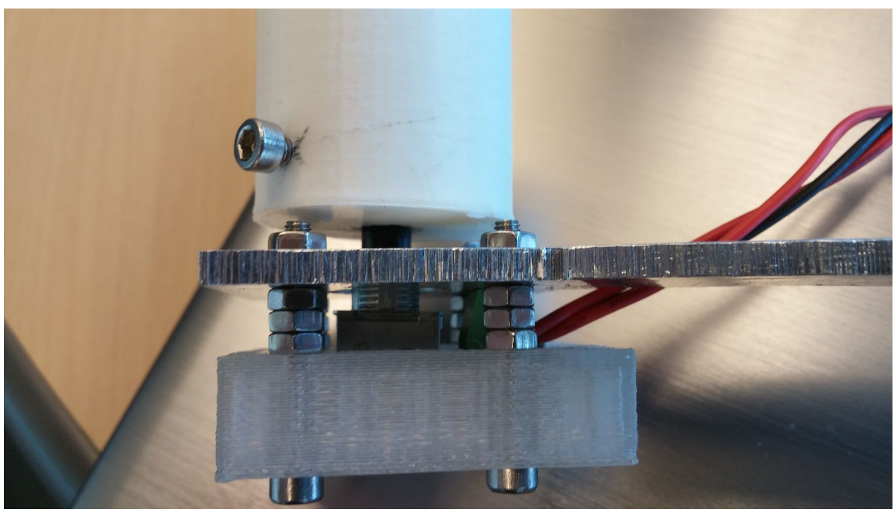


Figure 7. Side view of rotation sensor assembly

2.2.2 Design and prototype

The original designs for the potentiometer were superficially quite different from what we ended up producing, but many elements of the original design ended up in the final product. Our original plan was to have quite a large enclosure for the potentiometer, with a long, straight cylindrical arm that would connect the potentiometer arm and the bolt on the pedal. This assembly would be attached to the chassis of the car directly perpendicular to the pedal, so that there would be a straight line between the bolt and the enclosure. All the pieces would be 3D printed. We went all the way as to design SolidWorks models for all of the various pieces before drastically altering the idea, because of a number of problems. First, the 3D printer we were using probably would be unable to print all of the large pieces without warping them. Second, the final placement of the brake pedal in relation to the chassis was still undecided for this entire process, so we would have had to guess where to place the potentiometer enclosure and how long to make the connector, as well as find a way to affix the enclosure to one of the chassis bars. (Later in the project, other members of the team decided to make the placement of the pedal adjustable, so this design wouldn't have worked anyway.) We changed our design, still using the idea of the potentiometer enclosure and connector arm, but on a much smaller scale, designed to be attached to the brake pedal directly, so that the pedal's placement and orientation wouldn't be factors that we needed to consider. This led to the current design of a metal arm holding the potentiometer enclosure and connector on one end, with the other attached to the hydraulics box of the brake.

After the design was finalized, we made our initial prototype, which was very similar to the final product. The changes made were mostly small practical changes instead of any large design revisions.

The metal arm that we used did not change throughout the entire process. It was made by hand using various tools in UBC's machine shop, and is probably the roughest part of the entire assembly. Because it was made by hand instead of machined automatically, many of the holes in the arm are slightly off-center and the arm as a whole is slightly bent. While annoying, these problems were easily designed around, and given the difficulty in getting the arm created, we chose to work around them and use the arm as-is instead of creating a new one, even as other parts of the project evolved.

The original enclosure for the potentiometer was created using a 3D printer. The potentiometer rested in the enclosure directly, with its pins fitting through holes in the connector. Wires were soldered to the pins directly.

The connector that attached the potentiometer to the bolt on the brake pedal was the part of the assembly that required the most iterations. It was a 3D printed cylinder with a large hexagonal hole to fit the bolt on one side, and a much smaller half-moon shaped hole for the potentiometer arm on the other side. This was the most important of the assembly; in order to accurately read the rotation of the bolt (and thus the depression of the pedal), the connector had to fit both the bolt and the potentiometer arm very tightly, so it would not wiggle around on its own and would only move when the brake moved. This required some very precise measurements, and we ended up printing 4 different versions of the connector, each with slight changes to various measurements to get the piece to fit better. The final prototype version fit the hex bolt perfectly, but was still a little loose on the potentiometer side. Instead of printing yet another connector, we put a small amount of sticky putty on the potentiometer head as a half measure to prevent the slippage and get a working prototype.

2.2.3 Final design

The prototype version of the rotation sensor worked very well and was much more precise than the pressure sensor. Our concerns for producing the final version were mainly focused on durability and making sure the sensor would hold up over long term use.

The biggest change we made was to the wiring of the sensor, instead of just soldering the wires directly to the potentiometer's pins, we made a PCB with terminals for wires, as well as a new enclosure for the PCB and potentiometer. Since we were still using the same metal arm to support the assembly, we had to design the PCB and enclosure around the holes already present in the arm, resulting in a tall and skinny design for the PCB instead of a more traditional square shape. The unconventional shape worked well, however, and we were able to fit the new enclosure onto the same metal arm with little difficulty. The enclosure could have stood to be deeper, so there would have been less material jutting out of the top, but we used some nuts as spacers so there would be enough clearance for the terminals between the enclosure and the metal arm.

We also removed the putty that had been keeping the potentiometer arm in place, and instead drilled a hole in the connector so that a bolt could be used to tighten the connector and prevent the potentiometer arm from moving around.

The final connector worked very well and was a much more precise sensor than the pressure sensor. For this reason, it was used as the primary brake detection sensor, with the pressure sensor providing more of a redundant backup role.

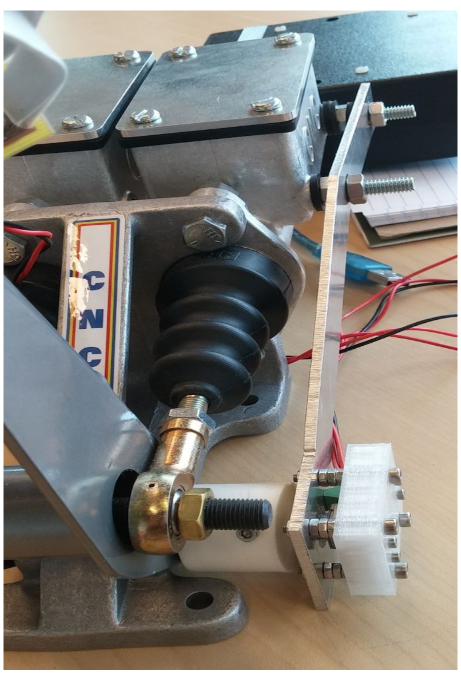


Figure 8. Rotation sensor mounted to brake pedal

2.3 ARDUINO ENCLOSURE

2.3.1 Overview

We needed an enclosure for the Arduino microcontroller that was reading the sensors and responsible for sending the brake/release messages to the rest of the car's electrical systems. This enclosure would need to be able to accommodate the five wires connected to the two sensors, as well as two thicker cables for the CAN bus messaging system. It would also have to be durable enough to protect the Arduino amid the heat and the driver's stomping feet near the pedal, where it would be positioned.

2.3.2 Design process

The designs for the enclosure are probably the most different from the final result of any of the components of the throttle lockout system. Originally, we planned to 3D print the entire Arduino enclosure, in two parts, with bolt holes for all the necessary components. We came up with a SolidWorks model for this design, and even went so far as to try to print one of the two parts before scrapping the idea. The reason that the idea had to be scrapped was because our 3D printer did not have a level printing surface, so any large pieces, like the enclosure, would end up lopsided and would probably be unusable. In the end, instead of 3D printing an entirely new enclosure from scratch, we ended up repurposing an old enclosure that we found lying around the UBC Solar electronics room.

2.3.3 Fabrication

The old enclosure that we repurposed consisted of plastic top and bottom pieces, with two removable solid metal plates that closed off each end. We drilled holes in the bottom piece that fit the layout of the Arduino's bolt holes, and used those to securely attach the microcontroller to the enclosure, using plastic bolts and nuts in order to avoid electrical problems. At first, we considered using a Dremel to create openings in the metal plates for our wiring, but we thought that that might be impractical due to the odd shape of the various connectors that we were using.

The wires from the two sensors would be attached to plastic Molex connectors that would clip into a corresponding connector mounted on the enclosure. The CAN bus cables would attach to two DB-9 connectors also mounted on the enclosure. Due to the odd shapes of these connectors, we decided to 3D print end pieces with correctly sized holes that would replace the existing metal endplates of the enclosure. This plan worked almost perfectly. The pieces that we printed were short and thin enough that warping during the print was not an issue, and using the information provided by the various connectors' datasheets, we were able to model the openings well enough such that the connectors fit after the first print, and we did not need to print many iterations to get workable pieces.

This design allowed for easy removal and reconnection of the various necessary wires, and the connectors present in the wall of the enclosure reduced the stress placed on the wiring, and greatly reduced the likelihood that any of the wires would be pulled out of the Arduino during use. The wiring inside the enclosure was fairly simple. The wires for the two sensors were attached to another plastic Molex connector (which clipped into the enclosure wall), before being plugged directly into the Arduino. The CAN bus wiring involved soldering together three DB-9 connectors in a Y formation, so that the Arduino would function as a node in the CAN bus system without breaking the chain.

Figure 9. Arduino closed enclosure analog inputs

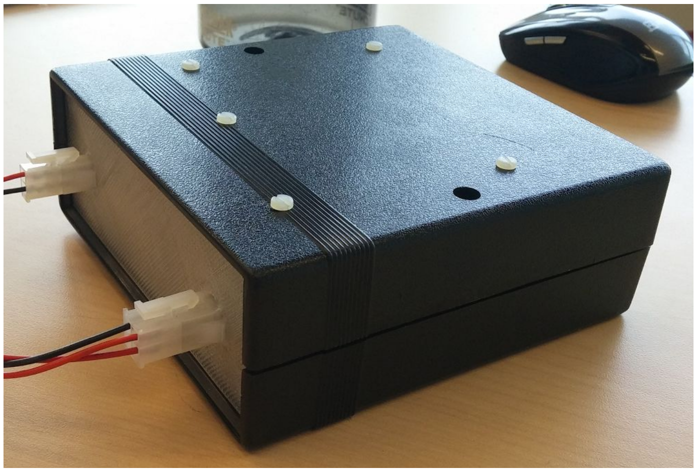


Figure 10. CAN bus output from arduino closed enclosure

Figure 11. Arduino wired

and secured in enclosure

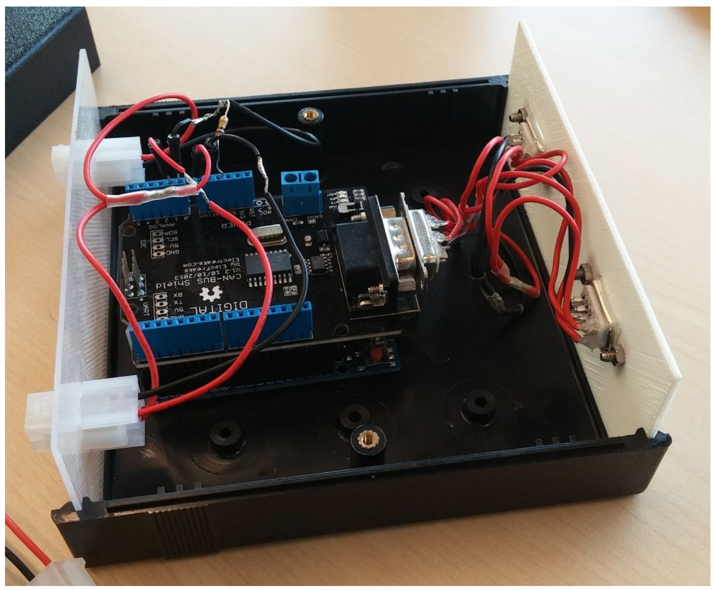


Figure 12. 3D printed analog input enclosure side

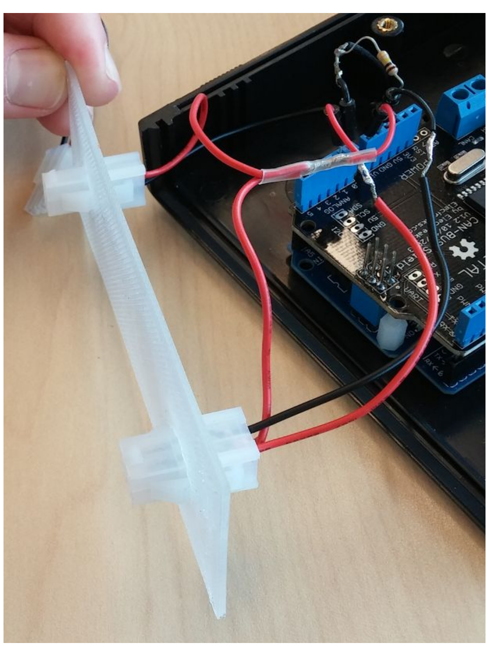
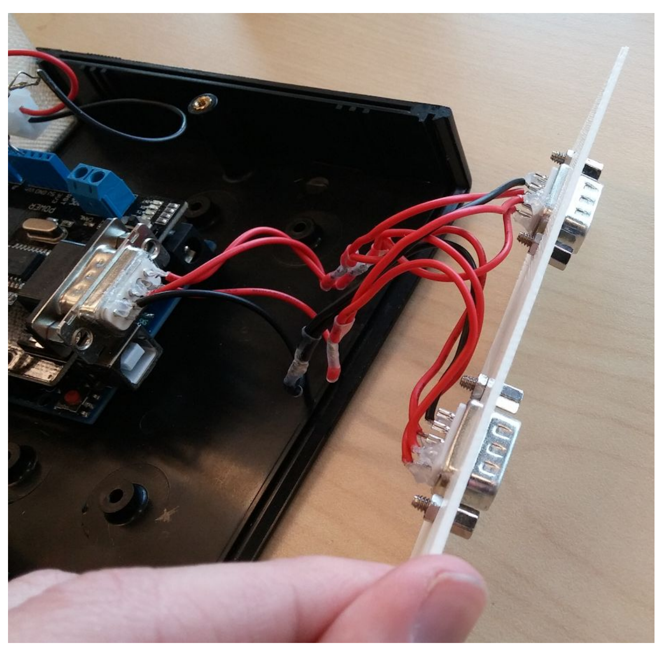


Figure 13. 3D printed CAN bus enclosure side



3.0 SOFTWARE AND SIGNAL

The Throttle Lockout system's code is written in Arduino language and transmitted via CAN bus. In this section the detection and transmission of the signal are further explained.

3.1 OVERVIEW

The Arduino microcontroller in the enclosure has three main purposes: to read the data obtained by the pressure and rotation sensor, to use that data to determine whether the brake pedal is being pressed, and to send an appropriate throttle lockout message through the car's CAN bus system.

3.2 DETECTION

The first part of the process is detection: obtaining data from the pressure and rotation sensor. Both sensors function as variable resistors, taking an input voltage from the Arduino, which then reads the output voltage as an integer value. The code is set up such that it reads both sensors roughly 10 times per second (slower if the code that it needs to execute takes longer than 100 milliseconds to finish), which is fast enough to satisfy our safety concerns. If the code finishes a loop in under 100 milliseconds, it does NOT delay until it is time for the next check; instead, it restarts the loop immediately, and only executes the main body of the code (in an if statement) if enough time has passed. Because there are many microcontroller nodes in the car's CAN bus system that are all connected to each other, unnecessary delay statements can slow the transmission of messages from node to node and hamper the function of the car, which is why they were avoided.

3.3 TRANSMISSION

The next part of the throttle lockout process is using the data obtained from the two sensors to determine whether or not the brake pedal is being pressed. The rotation sensor is very accurate, so it is very easy to interpret its data. The code specifies a threshold voltage, and if the reading from the rotation sensor is greater than or equal to the threshold, then the code knows the brake is currently being pressed.

The interpretation of the pressure sensor data is more difficult, due to the quirk of the pressure sensor where the value of its reading will slowly increase over time, even if the pressure on the pedal doesn't change. This factor means we couldn't set a simple threshold value in the code to determine whether or not the brake was being pressed, as the reading might slowly increase past the threshold value if the brake was not pressed for a long time. Instead, we use the derivative of the voltage reading from the pressure sensor to determine whether or not the brake is pressed. To do this, we record and store the last 15 values read by the pressure sensor, and compare the most recent reading to the minimum of these readings (we don't compare directly to the oldest stored reading, as the pressure sensor still fluctuates somewhat). If the difference is large enough, then we determine the brake pedal has been pressed. Originally, we planned to use the same derivative system to determine when the pedal was released, but it lead to some problems. Specifically, if the pedal was released very slowly, there would never be a sharp enough decrease in the voltages being read by the pressure sensor and the code would never register the release of the pedal. To counteract this problem, we used a simple threshold system (like the one used with the rotation sensor) to determine when the pedal is released. The voltage of the pressure sensor will slowly increase while the pressure is at rest, but it won't decrease, so there is no danger of the sensor mistakenly dipping below the threshold value after being held for a long time.

The code tests both sensors independently; if either sensor registers a press of the brake pedal, the code sends a CAN bus message telling the rest of the systems in the car that the brake is being pressed, and those systems then execute the correct response (e.g. stopping the throttle, turning on the brake lights, etc.). Both sensors must register a release of the brake pedal before the code sends the all-clear CAN bus message. This is why the derivative system for the pressure sensor works when pressing the pedal but not releasing. Hypothetically, if the driver pressed the pedal very slowly, the pressure sensor wouldn't register a fast enough change to send the braking message, but the rotation sensor would catch it and send the message anyway. Both systems have to be in agreement for the release message to be sent, though, which is why a different system was necessary for detecting the release. The CAN bus message that is sent is a simple one-digit binary code signifying whether the brake is pressed or not.

4.0 TESTING

During testing, all the parts were properly mounted to the brake and force was applied by hand to simulate the braking motion. This section specifies the methodology and observations from testing different scenarios that simulate real conditions.

4.1 METHODOLOGY

Using PuTTY, values from the rotary potentiometer was gathered every 0.1 seconds and then plotted using excel. It was chosen not to plot the pressure sensor values to maintain a cleaner graph. A plot of one test is presented below.

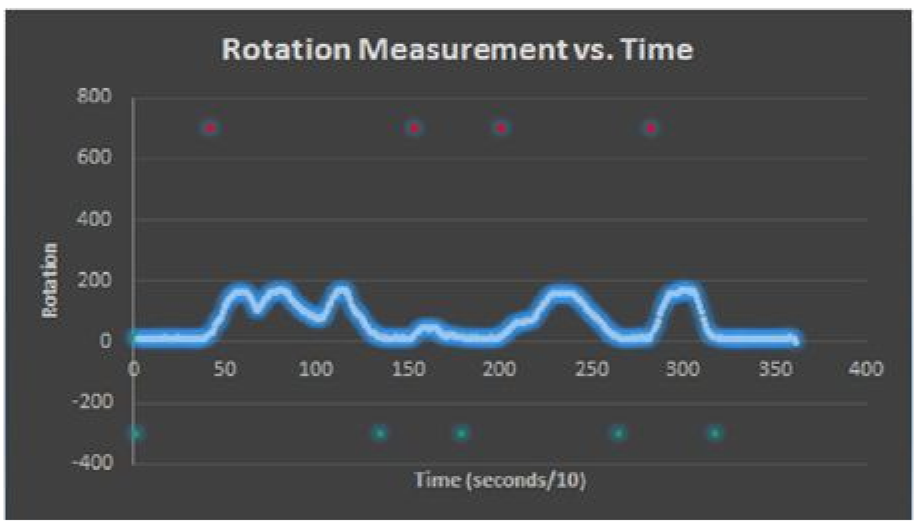


Figure 13. Graph of rotation vs. time from sensor testing

Green dot: sensors detect brake is released.

Red dot: sensors detect brake is being pressed.

Blue line: rotation measurements from rotary potentiometer.

Two important scenarios were specifically tested:

- Brakes actuated, varying pressure applied to the brakes, but not completely released. Followed by sharp a release.
- Brakes actuated and slowly released.
- Brakes lightly pushed, followed by a release.

4.2 OBSERVATIONS

After testing, it was concluded that the Throttle Lockout is very responsive to different styles of breaking. And sends out the right signals: brake pressed or released.

During the first 140 units of time in Figure 13, the brake was actuated and different amounts of pressure were applied to it, but the brake was not completely released. The Throttle Lockout reacted according to plan: it sends a message when the brakes are pressed and only sends a clear message (brakes released) when the brake is completely released.

Between units 150 and 200 the system was tested for sensitiveness. Again, it responded as expected by sending out a brake message even though the brakes were only lightly pressed.

From 200 to 250 brakes were actuated and slowly released. This scenario, its complexities and solutions were explained in section 4.3.