Design Rationale

Assistive Switch Testing System

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Summary

The goal of our project is to build a cost-effective test system for engineers to test the assistive switch for people with disabilities at a lower cost and in a more convenient way. To achieve the goal of being cost-effective, we are modifying an affordable commercial 3D printer model. By open-sourcing the DIY components for the testing system and the simple circuit board, we are expecting anyone who wants to test their assistive switch can use and modify this platform according to their needs easily.

In this document, we have explored the feasibility of design choices for various aspects of the product. By researching and comparing between different design choices, and how they interact with our entire system, we could ensure that the right design choices have been selected and best fit our design requirements. At the same time, we have provided effective alternative choices for each subsystem to ensure the general system is not defective when our first design choice is not viable.

Background

The client of our project is Neil Squire, a not-for-profit organization that uses technology, knowledge, and passion to empower Canadians with disabilities. Their Makers Making Change program hosts an open-source library of assistive technology designs and helps connect people with disabilities who need assistive technology with volunteer makers

Assistive technologies are key in improving independence and well-being for someone with a disability. Devices such as touch screens or controllers may not be user-friendly for people with physical disabilities. Assistive switches help overcome potential difficulties by lowering the actuation force and motion required to activate certain functions on various devices. However, there are not many affordable assistive technologies available in the market. Makers Making Change hosts an open-source library of these assistive technologies at a more cost-effective price. Specifically, they compile designs from their own staff and external volunteer developers, which is why a standardized testing solution is essential to their program.

Our assistive switch testing system will help validate and optimize assistive designs submitted to Neil Squire.

Design Document

Product Functional Description

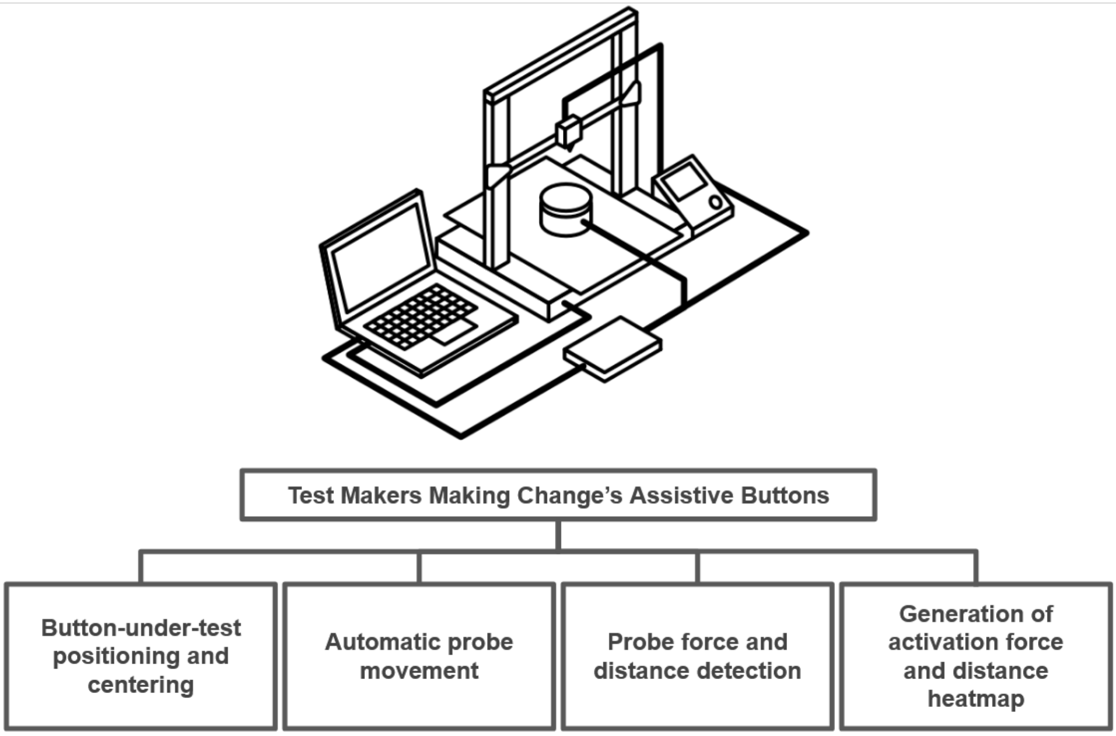


Figure 1: High-level functional decomposition of product

For this project, we will design an automatic testing system that tests assistive buttons from Maker's Making Change. The testing system would position and center the button-under-test, move the probe automatically, detect force and distance of the probe, and generate button-under-test's activation and distance heatmap. The button-under-test will focus on the Interact Switch and MMC60 Switch from Makers Making Change's Devices Selection Guide Switches [1]. These buttons will be discussed in the Button-under-Test Specification section.

Hierarchical Product Description

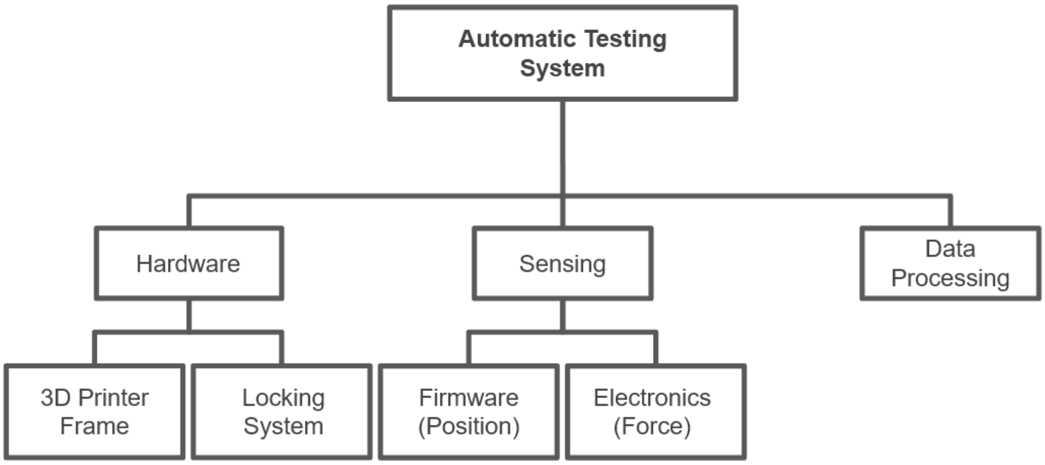


Figure 2: Hierarchical representation of product

A hierarchical representation of the automatic testing system is shown in figure 2. The testing system can be divided into hardware, sensing and data processing. The testing system uses a 3D printer frame that includes the frame, base and moving parts. A locking system is also used as the hardware to hold the button-under-test firmly on the print bed. For the sensing component, the firmware is used to control the probe whose position can be read and calculated to obtain distance. Electronics consisting of a load cell, amplifier and ESP 32 microcontroller are used to calculate force. The data processing functions by generating heatmaps using data from the sensing components.

Button-under-Test Description

For this project, we are focusing on testing two types of Assistive Switches from Makers Making Change’s Devices Selection Guide Switches [1] which are shown in Figure 3. These switches have a cylindrical shape, which enables us to concentrate our scope on all cylindrical shaped switches. This scope provides us an easy and less complex starting point to build analysis methods and designs for our testing system. The future of this project will cover more complex switch designs in Makers Making Change switches library.

a. Interact Switch   b. MMC60 Switch

Figure 3: Assistive Switches to be tested using Automatic Testing System

Product Functional Path Description

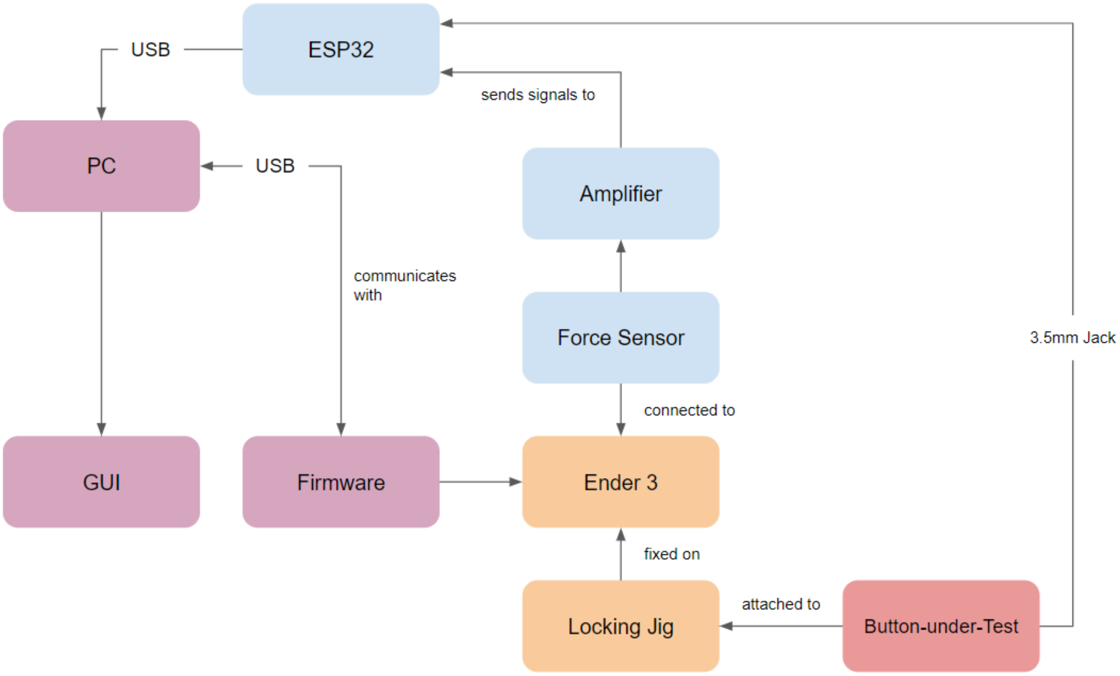


Figure 4: Design Path Diagram

A button-under-test is attached to a locking jig, which is fixed on the Ender 3's print bed. A PC is connected to the Ender 3, through a USB connection. The Ender 3 can be controlled from the PC using the GUI to choose a testing routine that is illustrated below. The testing routine uses the Ender 3's firmware to measure the distance of activation. Additionally, a force sensor that is connected, as a probe, to the Ender 3 will measure the force, which is amplified and sent to the ESP32 section for processing. The force and activation data from ESP32 and distance data from Ender 3's firmware will be sent to the PC and processed by the GUI to process outputs that include activation distance heatmap, activation force heatmap and button classification.

Testing System Use Case Description

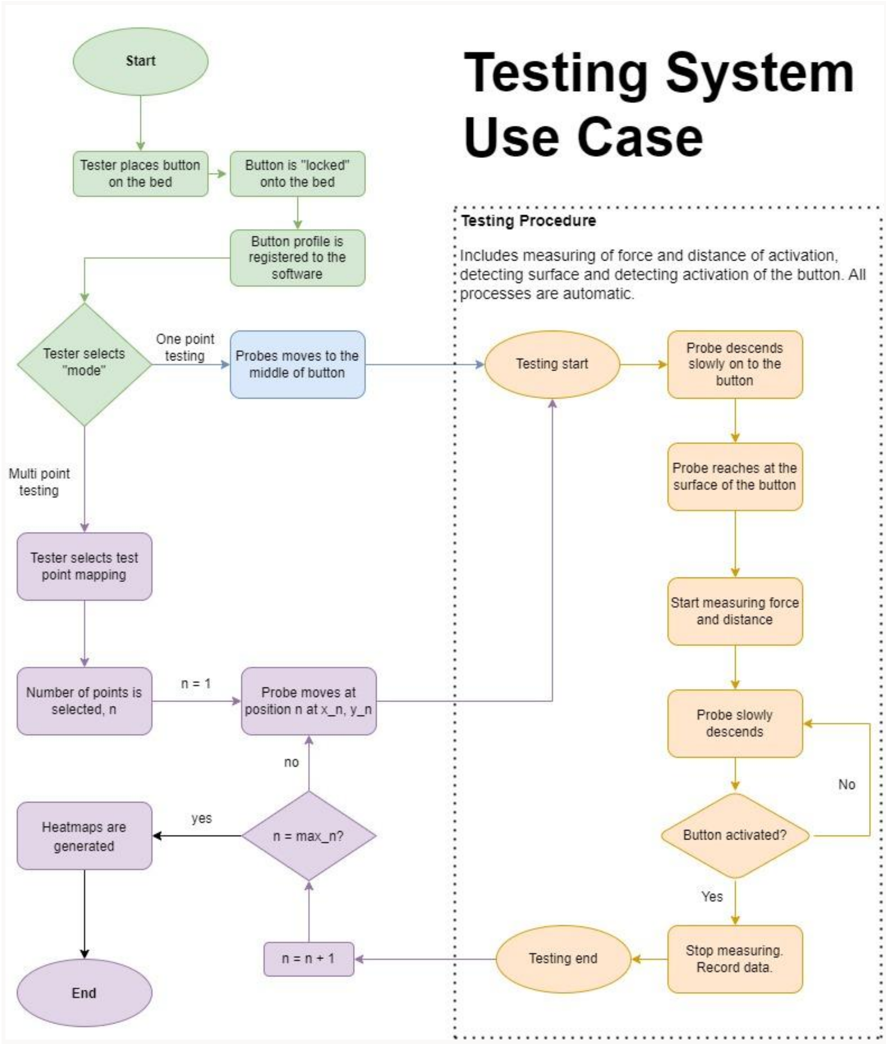


Figure 5: Complete Use Case Diagram

Figure 5 describes the use-case interaction for our testing system. It consists of three major parts (represented in 3 different colors): initialization (green), testing (orange), and processing (purple). The initialization starts as the user installs the button and chooses a testing routine. The algorithm for the testing routines is based on the number of test points, which is calculated based on the type of routine. The probe will then measure these test points to record activation force and distance. Recorded data will be sent to the microcontroller, then the computer to generate reading or heatmap.

1 Hardware

1.1 Alternatives

The table below describes the alternatives considered for the hardware solution:

Table 1.1: Comparison between modified 3D printers and DIY CNC machine

Alternatives	Modified 3D Printer	Building from scratch
Advantages	• Most parts already provided • No need to write the build documentation. The machine is already built. Sensor installation needed • Most 3D printers use Marlin firmware which is modifiable and programmable • Consultation with manufacturing company available	• Higher freedom in personalization • Less risk in scope change • Components can be hand-picked suited for application • Higher modifiability • Lower building cost can be achieved
Disadvantages	• Higher risk in an event where we need to change scope. • Reverse engineering 3D printers will take skill and time • Higher cost	• Lower availability of technological support • Requires higher iterations of design component decisions • Harder to document.

1.2 Hardware Components

The designed hardware components consist of

1. Controller Board
    a. BigTreeTech SKR Mini E3 V1.2 [2]
2. Frame
3. Stepper Motors
    a. NEMA-17(20-25, 40-45, and 50-56 N-cm) [2]
4. Belts
5. Threaded rods
6. End Stops
    a. Indicator for the printer to determine its location and keep it from exceeding its allowed limits
7. Power Supply Unit (PSU)
    a. 12V or 24V DC output voltage
8. Bed
9. Sensor Holder (Only thing we need to make, designed after the sensor)
10. User Interface and Connectivity
11. File Transfer Options
    a. SD Card
    b. USB Cable serial connection

1.3 Consideration

Key functional requirements in choosing a solution:

1. Able to move in a 3D workspace, larger than the dimensions of Interact Switch and MMC60 in the Makers Making Change library (area > 18cm*10cm*8cm) *F6*

Key quality attribute in choosing a solution:

1. Ease-of-use for user *NF5*
2. Documentability *NF3*

Key constraint to be satisfied for a solution:

1. Approved safety certification *C5*

1.4 Alternative Decision

Based on hardware design considerations discussed in 1.3, the alternative **modified 3D printer is chosen** over building from scratch. This design choice will allow us to:

1. Have a 3D testing workspace of larger than 18cm*10cm*8cm (size of Interact Switch and MMC60 switch)
2. Have a quality that satisfies our replicability requirement due to the nature of the product components (eg. motors, belts, controller board) being commercially available. Building from scratch requires more research and cost to find specific product components that are suitable for the same function.
3. Have a quality that satisfies our documentability requirement due to the product being produced by experts in the RepRap industry. Additional documentation will be discussed in Firmware, Sensor, and Software components. Building from scratch requires more thorough documentation to build, maintain and troubleshoot.
4. Using a commercial 3D printer that is already safety certified is easier than finding individual hardware components that are safety certified

1.5 Equipment Safety

In order to use the electrical equipment inside public buildings, they are required to have an approved certification mark [3] (e.g. CSA, ETL, FSA etc.). It would also be beneficial for Makers Making Change to have a safety certified testing system.

In order to acquire a safety certified 3D printer, the equipment would be ordered from a local 3D printer vendor. The details of a safety certified 3D printer model that has been explored is as shown in table 1.2.

Table 1.2: Safety Certified 3D Printer Model

3D Printer	Info
	**Model:** Creality Ender 3 V2 **Certification:** Intertek Testing Services - ETL / Warnock Hersey *(Approved)* **Price:** *$388.22 CAD* **Vendor:** 3D Printing Canada Online Store [4]

1.6 Hardware Discussion

Since it is necessary to have safety certified equipment, only the Creality Ender 3 V2 model shown in Table 1.2 is suitable for this project. It has a workspace of 220x220x250mm and costs cheaper (less than $500) than other safety certified 3D printers that are commercially available. This model is manufactured by Creality, a well-known RepRap manufacturer that provides a lot of resources and technical support. Thus, it will be used as this product's base hardware.

2 Firmware

2.1 Alternatives

The two firmware choices we were considering were Marlin firmware and GRBL firmware. They can both take G-code as input and control the stepper motor to provide certain 3D printers/ CNC control features.

Marlin is an open source firmware for the RepRap family of 3D printers first created in 2011 Erik van der Zalm et. al. The firmware runs on the 3D printer's main board, managing all the real-time activities of the machine. It coordinates the heaters, steppers, sensors, lights, LCD display, buttons, and everything else involved in the 3D printing process with officially provided functions.

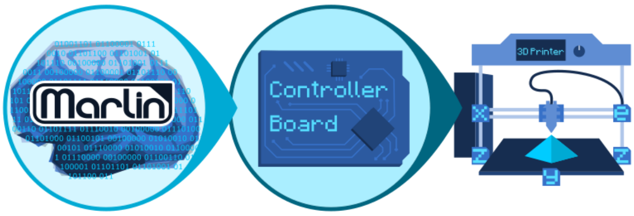


Figure 2.1: Marlin Firmware[1]

GRBL is an open-source firmware that controls the movement of CNC machines and can run on any boards that have an ATmega328-based microcontroller, uses G-code as input, and outputs motion control via the Arduino. It has a two-way real-time channel over the serial link that bypasses the GCode buffer in the Arduino for instant feed, spindle and emergency stop control and to send status updates (current coordinates, switch triggers) back to the controller.

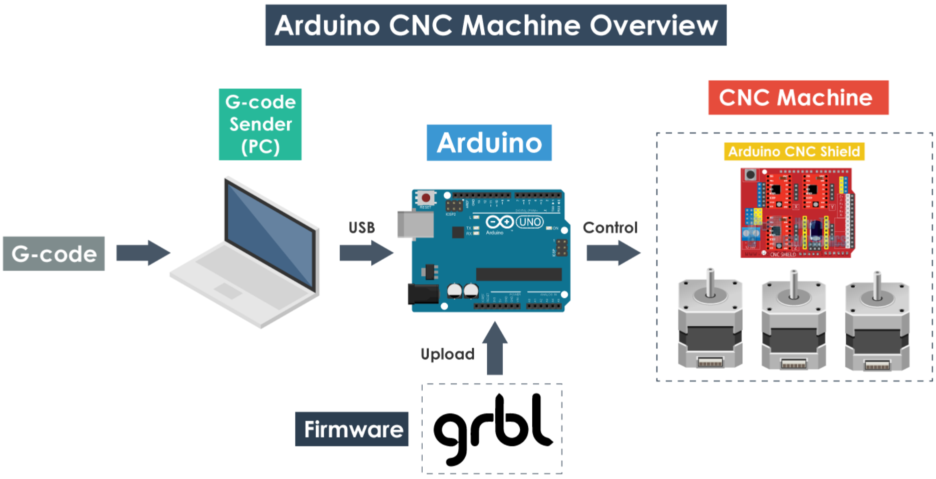


Figure 2.2: GRBL Firmware[2]

2.2 Comparison

1. 99% of 3D printers in the market are using Marlin firmware
2. Lots of features are similar, such as positioning & autonomous printing.
3. Grbl is more specific, and therefore is simpler for some things, and has more advanced features for milling.
4. Marlin coordinates are just workspace coordinates, while it can’t support MCS (machine coordinate system).

[1] https://marlinfw.org/docs/basics/introduction.html
[2] https://howtomechatronics.com/tutorials/how-to-setup-grbl-control-cnc-machine-with-arduino/
The figure listed here is an Arduino CNC Machine interaction example for illustration purposes. Actual microcontroller design choice in our project would be ESP32.

2.3 Considerations & Decision

Lots of features between these two firmware are similar, such as positioning & autonomous printing. GRBL is more specific and has more advanced features for milling. While 99% of commercial 3D printers already have the Marlin firmware set-up on their microcontrollers, its original function support provides more ease of use, accessibility and modifiability of its source code. Ultimately, we will use Marlin as the testing system's firmware.

If there are exceptions in our future designs such as not being able to accomplish required control accuracy with Marlin, not being able to transfer data, etc. the alternative would be GRBL firmware.

3 Centering and Locking System

The locking system will help fix the button-under-test on the system's 'bed' to prevent movement of the button-under-test that will contribute to errors during testing. Specifically, as a probe is lowered down over different points of the button-under-test, it is crucial to have the button-under-test fixed so that measurements would remain accurate. The locking systems that will be compared are simple rubber band clamps, a self-centering chuck and modular button jigs. In this paper, we will study different types of locking systems, compare their performances through preliminary functional and non-functional evaluation and assess the cost of 3D printed manufacturing of parts through recommended 3D printing services.

3.1 Design Options

3.1.1 Twistlock Clamp

Figure 3.1: Twistlock Clamp by JakeJake on Cults [5]

This design allows two jaws to fix onto an object by turning a nut around a shaft to close it. This design can be applied as a locking system by increasing the size of the jaws' opening and the depth of the jaws. The clamp can be fixed onto the bedframe and measured to ensure the closing would always be in the middle.

The design can be improved by having a rubber surface to the grips to ensure enough friction so that the button-under-test would not slip. The design can also be made stronger by having a 100% infill when printing the parts.

3.1.2 Self-centering Chuck Jaw

Figure 3.2: Three Jaw Lathe Chuck by bobwomble on [Thingiverse] [6]

Another design for the Locking system would be the self-centering chuck jaw. As shown in Figure 3.2, this design would allow three jaws to meet in the middle by turning a gear.

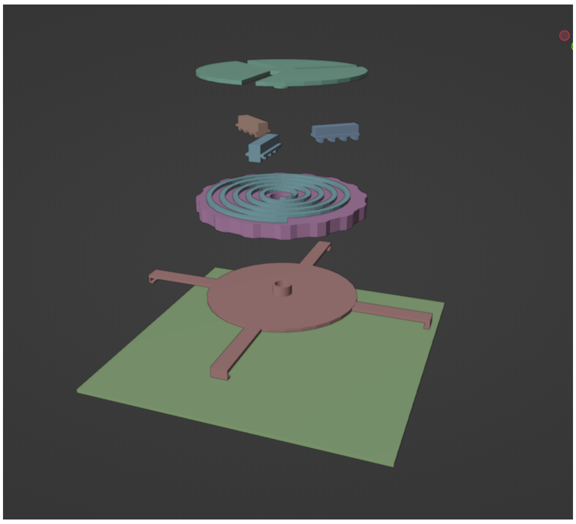


Figure 3.3: Remixed Lathe Chuck designed by team member

Figure 3.3 shows an initial chuck design that is more compatible with a 3D printer print bed. It has a fixture that is locked on the print bed. Parts are attached on top of it, including the jaws.

3.1.3 Modular Design (Print Bed Adapter + Switch-specific Jig)

This design includes a print bed adapter and multiple switch-specific jigs. Compared to the previous two designs which only consider cylindrical-shaped switches, this design allows every type of switch to have its own locking jig.

Figure 3.4 illustrates the application of the print bed adapter, switch-specific jig and switches.

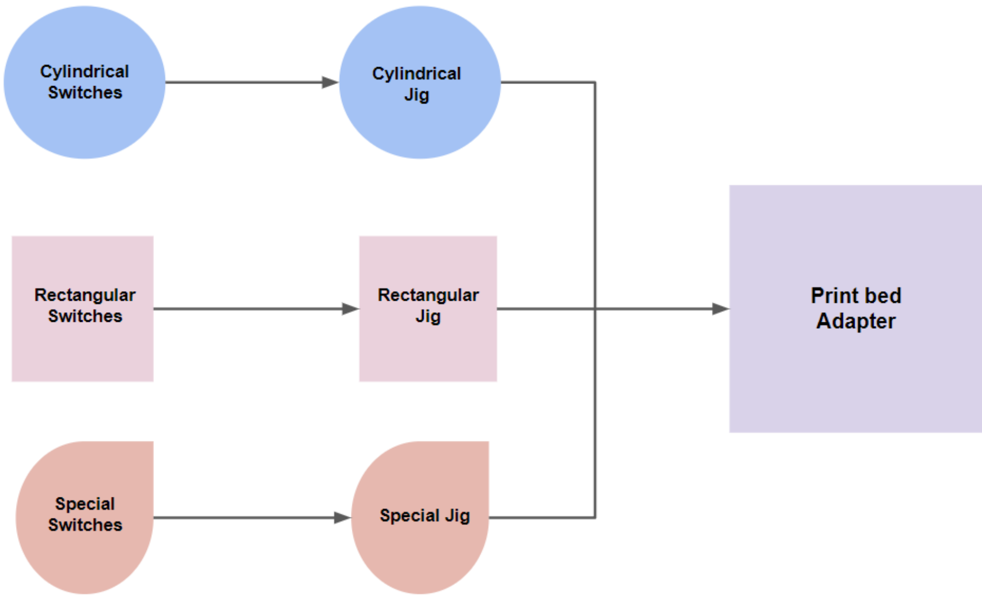


Figure 3.4: Modular approach illustration

To ensure the adaptability of this design, a variety of jigs need to be carefully and accurately designed for each type of switch. A few examples of initial specialized switch jigs designs are shown in Figure 3.5.

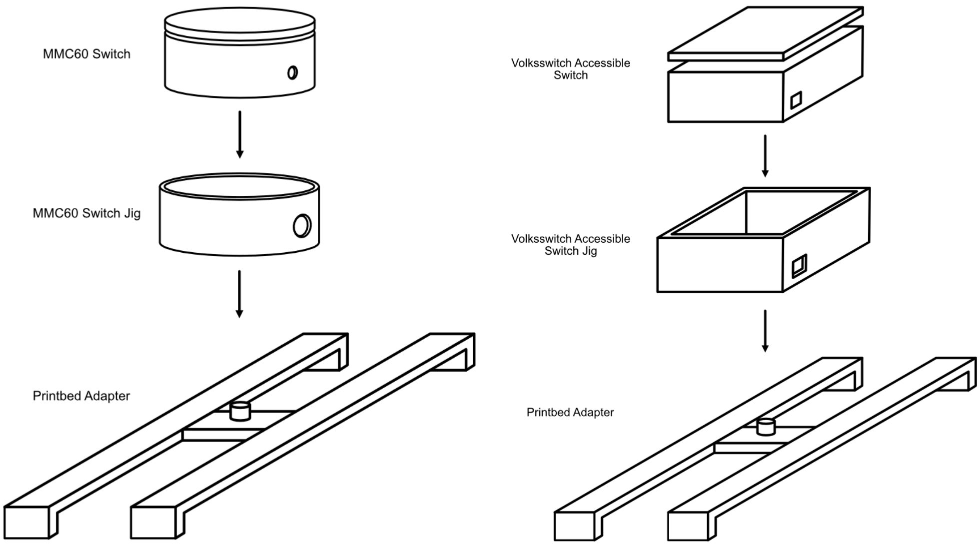


Figure 3.5: Modular approach initial designs for MMC60 and Volksswitch

3.2 Requirements Consideration

Key functional requirements in choosing a solution:

1. Switch position lock *F4*
2. Switch centre detection *F5*
3. Non-obstructive design *F16*

Key quality attribute in choosing a solution:

1. Replicability *NF3*

Key constraint to be satisfied for a solution:

1. Print Bed structure C4

3.3 Evaluation

3.3.1 Switch position lock

Ratings are evaluated by how secure the locking is by the design and the probability of the button to move or rotate. Table 3.1 shows the rating and comments for each alternative.

Table 3.1: Position Lockability Rating

Clamp	**Chuck Jaw**	**Modular**
5/10	7/10	8/10
The clamp design has good locking on the button since the locking force of the jaws can be varied by the shaft's rotation. However, only two points are in contact with the button.	Compared to the clamp design, the chuck jaw has a three-point locking which will negate any axis of rotation. However, the design must be accurate to secure the button-under-test by limiting the movement of the chucks by the gears. The design is also only limited to cylindrical-shaped buttons.	The modular design has more adaptability in securing different shapes of buttons due to the different designs of jigs.

3.3.2 Center Detection

For this requirement, there will be no routing from the firmware to determine the center of the button-under-test. Rather, the locking system provides a center that the firmware can initialize. The switch center detection can be evaluated by how easy it is to keep the button-under-test onto the print beds center. Table 3.2 shows the rating and comments for each alternative.

Table 3.2: Center Detection Ratings

Clamp	**Chuck Jaw**	**Modular**
7/10	5/10	8/10
The clamp design jaws	The chuck jaw design has	The modular design has

move inwards simultaneously as the nut turns. This ensures that the button-under-test is always at the center	a platform that can be designed to have the upper body fixed on to the center of the printbed. However, since the jaws are susceptible to moving simultaneously, inaccuracies might be introduced	no moving parts which allow the switch to be fixed on the printbed adapter

3.3.3 Non-obstructive Design

Since different shapes and sizes of buttons are being tested, it is important for the locking system to not obstruct the testing routine. The designs are evaluated by the ability for it to lock the button-under-test while still not interfering with the testing routine. Table 3.3 shows the rating and comments for each alternative.

Table 3.3: Center Detection Ratings

Clamp	**Chuck Jaw**	**Modular**
5/10	5/10	8/10
The clamp design works poorly with smaller buttons.	The clamp design works poorly with smaller buttons. Testing with larger buttons will decrease its grip.	The modular design has adaptability in its design.

3.3.4 Replicability

Each of the designs will be 3D printed and available as an open-source. The rating for each design will be based on the complexity of the design and its assembly. Table 3.4 shows the rating and comments for each alternative.

Table 3.4: Center Detection Ratings

Clamp	Chuck Jaw	Modular
7/10	5/10	8/10
The clamp uses a familiar and simple clamp concept for its design. Small parts are involved	The design involves small moving parts. Its designs are detailed and complex to assemble	The design has a simple pick-and-place concept with many main parts to choose from.

3.3.5 Cost

Since each of the designs will be 3D printed, there will be costs in producing the designs. The rating for each design will be based on the approximate volume of the overall design and the maintenance costs. Table 3.5 shows the rating and comments for each alternative.

Table 3.5: Center Detection Ratings

Clamp	Chuck Jaw	Modular
8/10	7/10	5/10
The design requires medium-sized parts with adequate infill percentage for its rigidity. Some parts might be broken (e.g. jaws) and might require regular replacement.	The design makes use of parts that has a large surface area which increases the material used for printing. Jaws and gears might require regular replacement	Due to the design having multiple parts for multiple switches, a lot of materials are needed for printing.

3.3.5 Print Bed structure

Since the design of the print bed is already fixed, the designs of the locking systems are limited. In particular, the print bed adapter needs to be designed carefully so that it does not block the movement underneath the print bed.

3.4 Decision Matrix

A decision matrix is shown in Table 3.6 to compare the overall criteria based on their ratings:

Table 3.6: Decision Matrix for Locking and Centering System options

	Clamp	**Chuck Jaw**	**Modular**
Position Lock	5	7	8
Center Lock	7	5	8
Non-obstructive Design	5	5	8
Replicability	7	5	8
Cost	8	7	5
Total:	32	29	37

Based on the ratings, the modular approach is chosen for the Locking and centering System. Although it scores lower in cost compared to the other two options, its ability to perform well in other criteria, ensuring accurate measurement recorded, is favorable.

3.5 Design Approach

In this section, we will compare the costs of printing the parts for the modular design and discuss the 3D design workflow.

3.5.1 Cost by Vendor

3D printing services that are considered are UBC ECE services, UBC Rapid, 3DSmith and JLC3D. The two most common types of 3D printing methods are FDM (Fused Deposition Modeling) and Stereolithography (SLA). SLA printing works best for producing parts with high accuracy with fine features and smooth surfaces. FDM printing method is best for basic proof-of-concept models and low-cost prototyping of simple parts. Additional costs cover setup fees, delivery fees or consultation fees.

Table 3.7: 3D printing services comparison

	FDM	**SLA**	**Additional Costs**
UBC ECE Services [7]	CAD0.10 per gram	CAD1.00 per gram	CAD15 per build plate
UBC Rapid [8]	CAD0.15 per gram	NA	CAD5 per build plate. CAD3 per hour applies for a print resolution of 0.10 mm or less
3DSmith **(Vancouver)** [9]	CAD0.50 per gram	CAD1.00 per gram	CAD20 per build plate (CAD 10 onwards)
JLC3D **(China)*** [10]	CAD0.50 per cm^3 (ABS)	~CAD0.10 per cm^3 (9000R Resin)	CAD25++ (DHL Worldwide Express)

* JLC3D does not provide rates for 3D printings. The rates shown in the table are obtained and calculated from personal experience with JLC3D printing costs.

Based on Table 3.7, JLC3D has the lowest rates for SLA printing parts but has a higher cost in delivery and a longer delivery time (1.5 weeks). The service works best for end-product parts manufacturing. UBC ECE Services and UBC Rapid work best for initial designs and prototyping due to them having cheaper rates in FDM printing and lower setup fee, compared to 3DSmith.

3.5.2 Optional Printing Approach

The testing system uses an Ender 3 3D printer which we could make use of its 3D printing ability. This approach can lower the cost of setup and rapid availability of parts. This approach requires the Ender 3 to be in its “3D printing setup” and 1.75mm filament to be purchased. Table 3.8 shows the price of filaments by different providers.

Table 3.8: Filament prices comparison

	Filament Prices	**Additional Costs**
Amazon [11]	CAD22	NA
Lee’s Electronics [12]	CAD38	NA
Filaments.CA [13]	CAD19.95	CAD18 (UPS Delivery)

3.5.3 3D Design Workflow

The 3D printed parts of the locking system will be designed in Solidworks with a license provided by the UBC ECE Department. The 3D design workflow will be taken in steps.

1. The print bed adapter will be designed first, considering the printbed’s movement and structure.
2. Each of the open-source switches will have its jig designed. We will consider its ability to lock the button and attach it to the print bed adapter as well as make sure that the jig does not block the activation function.
3. After a design is made, a 3D printed prototype will be made along with its specific button
4. The locking system prototype will be tested

3.6 Modular Approach Component Design

This section discusses the goals, design and usage of each component of the modular approach design for the button locking and centering.

3.6.1 Adapters

The adapters create a space in which the jig can be placed on. Its design must be able to align with the edges of the printbed to ensure that the jig is centered. This can be achieved by a number of ways.

“W” Design

The figure below shows how four edge aligners can create a centered space using its edges to align with the printbed. A section can be seen on the edges’ end where a small clip can help hold the adapter in place.

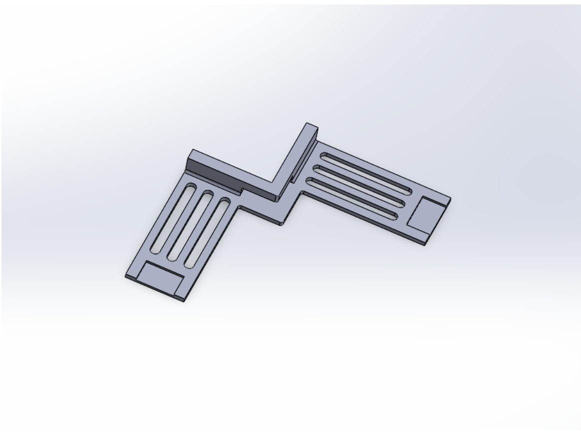
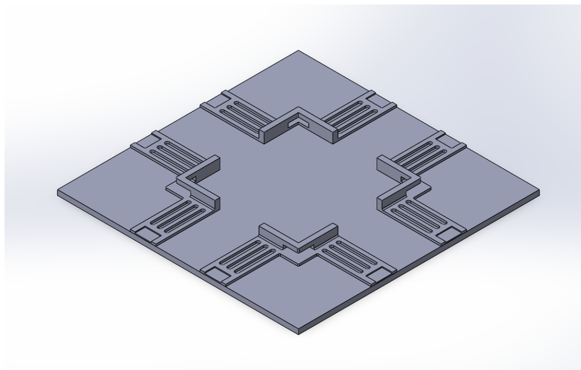
	
Individual adapter design	**Combination of adapters**

Figure 3.6: Adapter bend example

The design can also be 3D printed and built inexpensively as it is small and only uses eight extra clips to create a centered space. However, the design has lower rigidity as it is only being held at two points. This would allow the adapter to bend and would lead to potential part damage.

Adapter Bending

The bending issue of the “W” design is due to several reasons.

1. Less clamp points. Parts further from the points where it is clamped with the clip are prone to movement.
2. Thin and flexible structure. The ‘legs’ of the adapter are 2mm thick and 90mm long. A way to solve this problem is to reinforce the specific parts by making it thicker and rigid.

Reinforced “W” Design

This design is an improvement for the original “W” design. The individual adapter is designed to have a more rigid structure. This reduces the flexibility of the structure.

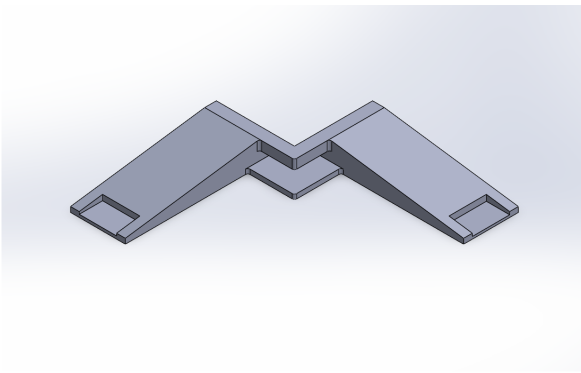
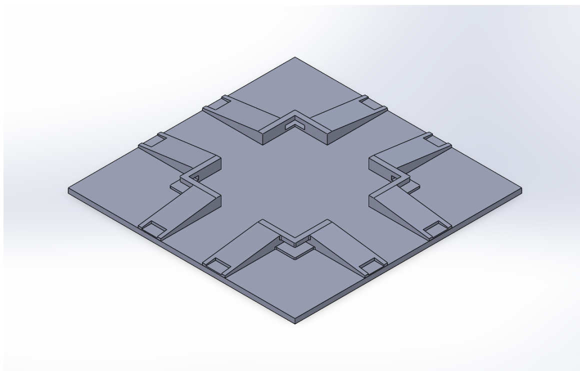
	
Individual adapter design	**Combination of adapters**

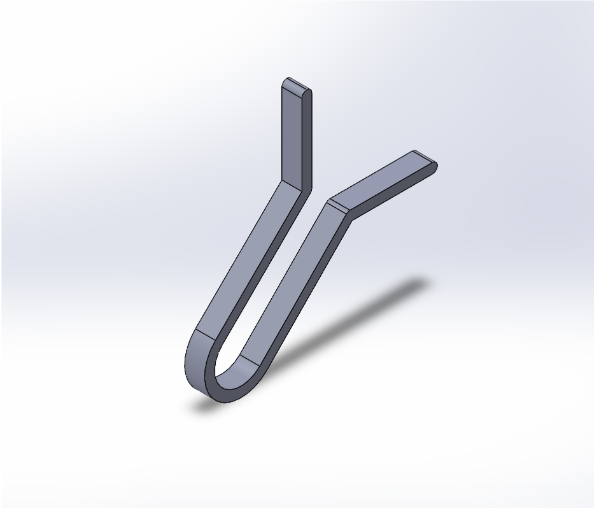
Figure 3.7: Modified “W” design with reinforced structure and using reinforced structure

3.6.2 Connectors

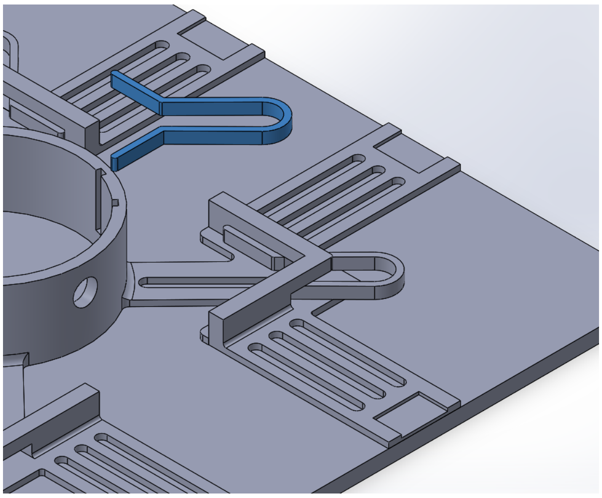
A connector is used to fix the jig on to the centered space created by the adapters. The connector prevents the jig to wiggle and move vertically at the centered space.

Slotted Key Design

This design uses the flexibility of the material to build a key so that it fits into the slot of an adapter. The head of the key goes into the slot of the “W” adapter and its legs hold down the jig.



Individual key design

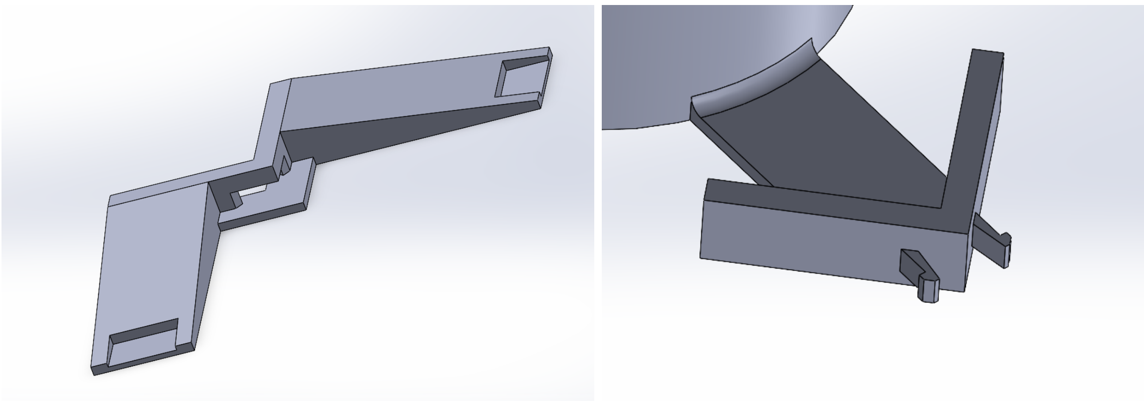


Example of use (Original “W”)

Figure 3.8: Slotted Key Design

Snap Fit Design

This design uses a snap fit mechanism to attach the jig to the adapters.



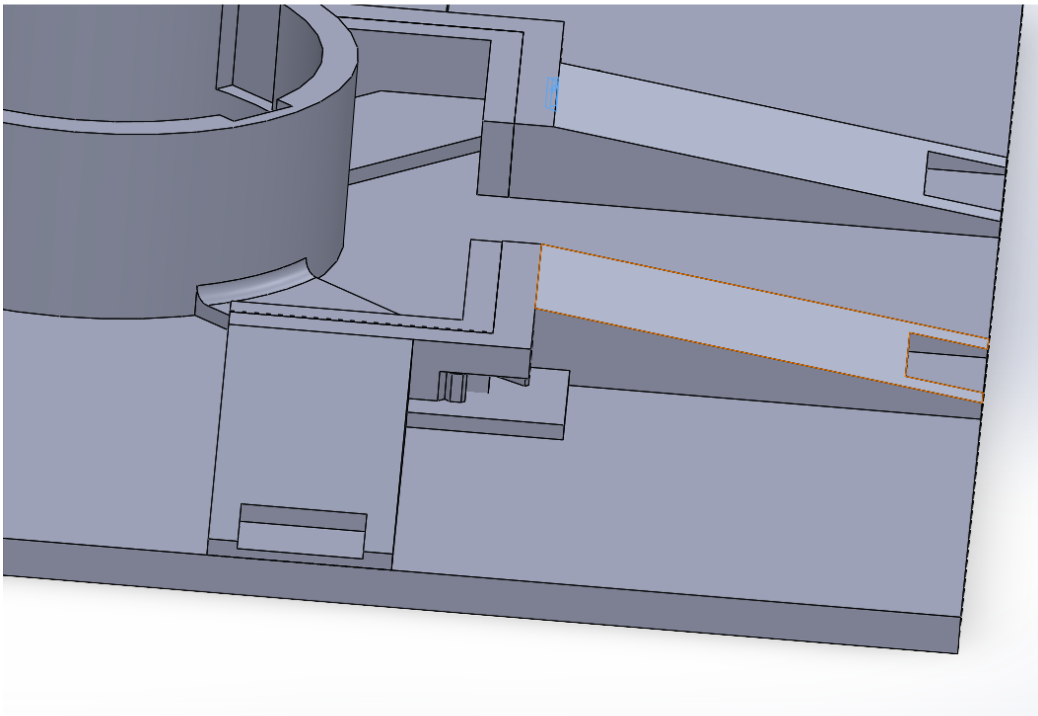
Latches

Example of use

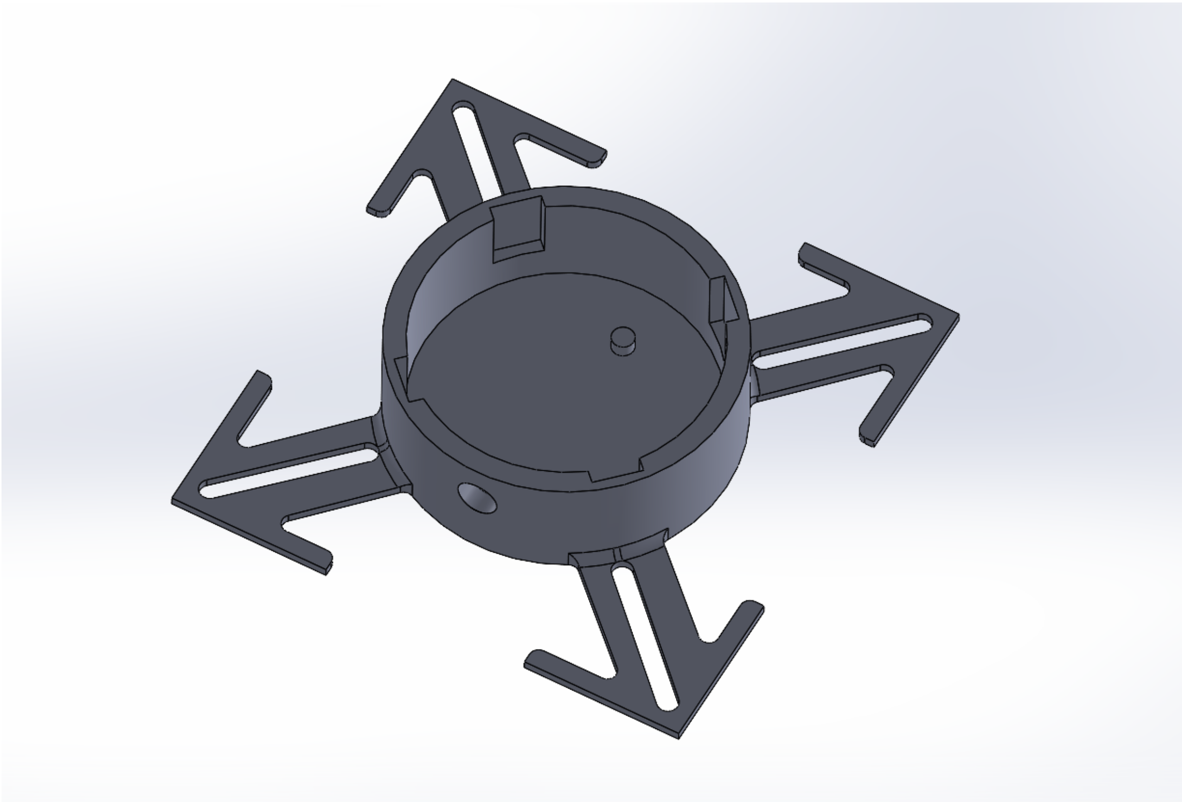
Figure 3.9: Snap Fit Design

3.6.3 Jig

A jig is used to hold the button-under-test to the center space that is provided by the adapters. The jig depends on what connector and adapter that is used. The general design of the jig consists of the “holder” and the “aligner”. The holder has fastener mechanisms that allow the jig to hold the button-under-test tightly. The aligner is used to align the “holder” to the adapters. This combination allows different approaches to design a jig for each type of button, which was discussed in the Button-under-Test Description section.

MMC60 Switch Jig

This design uses a cylindrical holder. A hole is added to ensure the 3.5mm jack can be inserted to the switch. Four rubber feet (D10x3mm) will be placed on the slots inside the holder to provide grip when inserting the button into the holder.

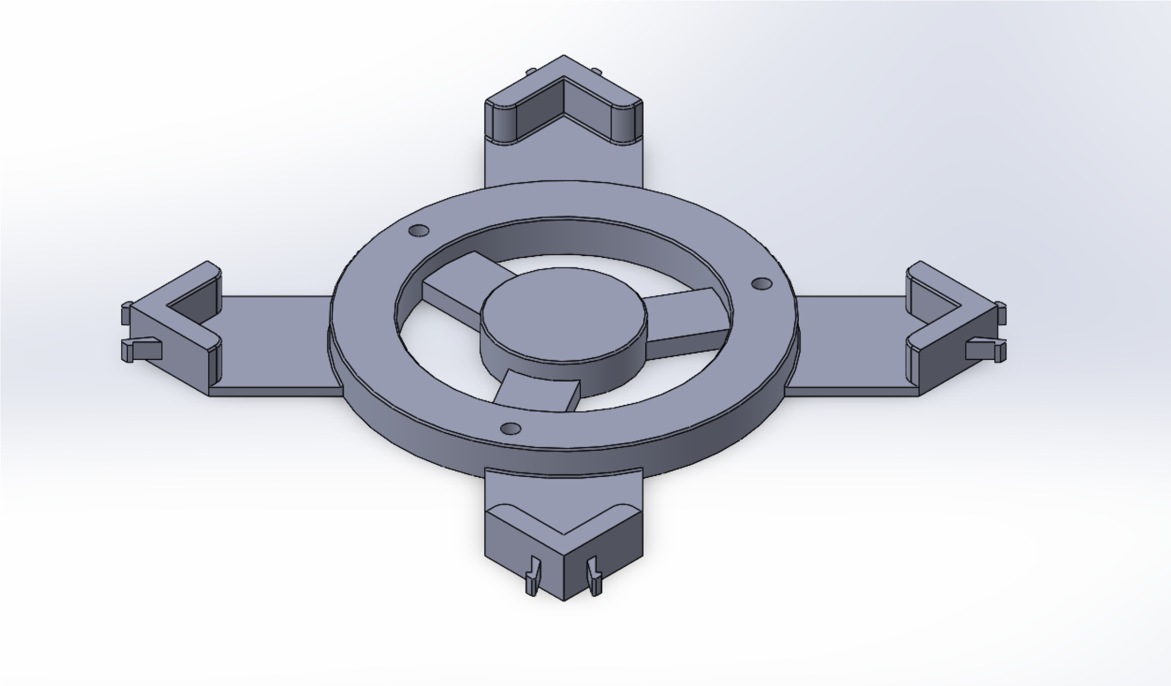


MMC60 Switch Jig Design

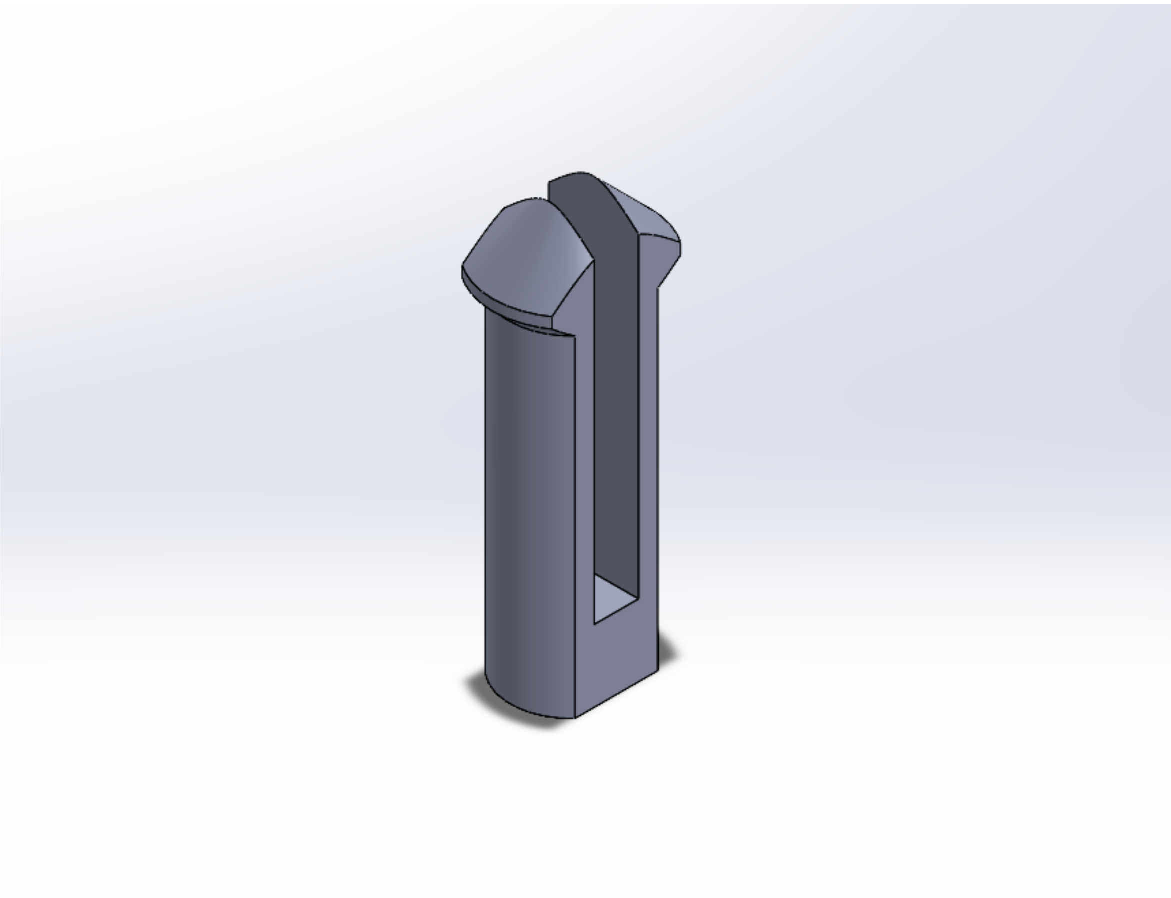
Figure 3.10: MMC60 Switch Jig Design

Interact Switch Jig

This design has two parts, the holder and the cylindrical snaps. The cylindrical snaps are inserted into the holes of the holder. These cylinders will snap to the Interact switch which already includes holes with the same radius



Interact Switch Jig Holder



Interact Switch Jig Snaps

Figure 3.11: Interact Switch Jig

4 Force Sensor

4.1 Alternatives

Alternatives considered for the design solution:

Table 4.1 Force Sensor Alternatives Consideration

Alternatives	**Resistive Force Sensors**	**Capacitive Force Sensors**	**Load Cells**
Advantages	● Cheap ● Simple circuit design	● High Accuracy: ±0.9gf[1] (*not including linearity)	● High Accuracy: ±0.25gf[1] ● High Linearity
Disadvantages	● Low Accuracy ● Can only measure sudden changes of force ● Smallest measurable force is 10-20g	● Somewhat Expensive ● Complex Electronics needed to measure the capacitance ● 2-10% Linearity Error	● Large in size ● Need to amplify voltage from load cell to a readable voltage

1. Equivalent to Max Force * Full Scale Error, see Table 4.2 for Load cell and Appendix A for Capacitive sensors

Key functional requirements in choosing a solution:

1. Must be able to register a force between 1gf to 500gf with an accuracy of ±1gf *F2*

Key quality attributes in choosing a solution:

1. Modularity *NF2*
2. Replicability *NF3*

Key constraint to be satisfied for a solution:

1. Budget *C1*

4.2 Alternative Decision

Based on the force sensor design considerations discussed in 3.2, the alternative of a **Load Cell** will be chosen due to the improved accuracy and cost over capacitive and resistive sensors. This design choice will allow us to:

1. Pick a Load cell which can measure a force between 1g and 500g, with an accuracy of ±1gf.
2. Have a quality that satisfies our modularity requirement due to the nature of off-the-shelf solutions which are easy to assemble.
3. Have a quality that satisfies our replicability requirement due to the nature of the product components being commercially available.

4.3 Load Cell Choices

Key considerations in choosing a Load Cell (Note all load cells are linear) are

1. Cost
2. Force Resolution Accuracy
3. Linearity Error
4. Max Nominal Force
5. Sensor Size

Table 4.2 Load cell choices

Option	Cost	Force Resolution Accuracy	Linearity Error	Max Force	Sensor Size
TAL221 (mouser) [14]	17CAD	0.05%[1]	0.05%[1]	500gf	47mm x 12mm
SEEED 314990000 [15]	27CAD	0.05%	0.05%[1]	500gf	45mmx9mm

1. Equivalent to 0.25gf

To accompany a load cell circuit we need to amplify the voltage to a readable level. This can be accomplished by the amplifier HX711 and can be integrated into our own custom board. For early testing, we can purchase the following test circuit from SparkFun: SEN-13879 [16], which is 17 CAD on Digikey.

4.4 Design Choice

Comparing the load cells discussed above, **TAL221 - 500g** [14] is the best design due to its cost-efficiency. This sensor option allows us to:

1. Remain in a low-cost range
2. Measure a force within ±1gf accuracy and within 1gf to 500gf

4.5 Additional Design Considerations

In order to mount the Load cell chosen to the 3D printer, a design was developed which can mount to the extruder carriage from the Ender 3. This design would need to be easy to mount and we would therefore use the built in screws the Ender 3 has. Keeping the button press location centered from the normal position for the Ender 3 nozzle, we designed 3D printed parts which could attach to the load cell, as shown below:

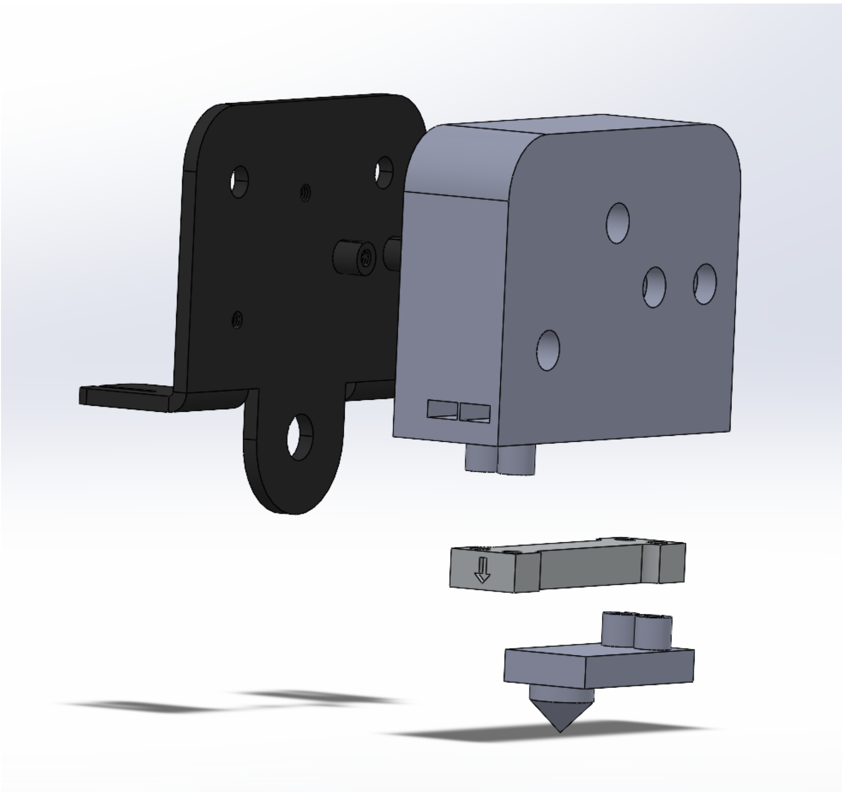


Figure 4.1: Load Cell attachment and Button Presser where the extruder from Ender 3 is shown on the left (Black), with the load cell attached in the middle.

Note, the load cell only has one set of threaded holes, which is why for one side we need nut holes in order to lock them in place. The dimensions of each of the holes is shown in the following drawing, Figure 4.2:

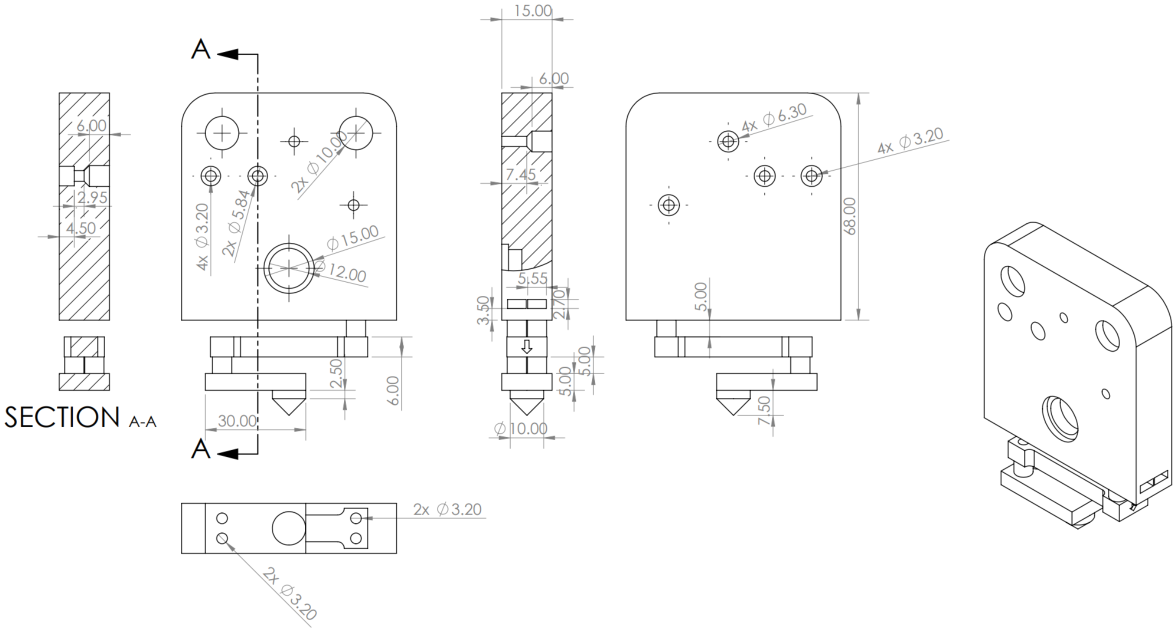


Figure 4.2: Load Cell Mount & Button Presser Dimensions for 3D printer attachment.

The design was printed and tested on the 3D printer, which can be seen in the following image for the approximate position to clear up any confusion in Figure 4.3:

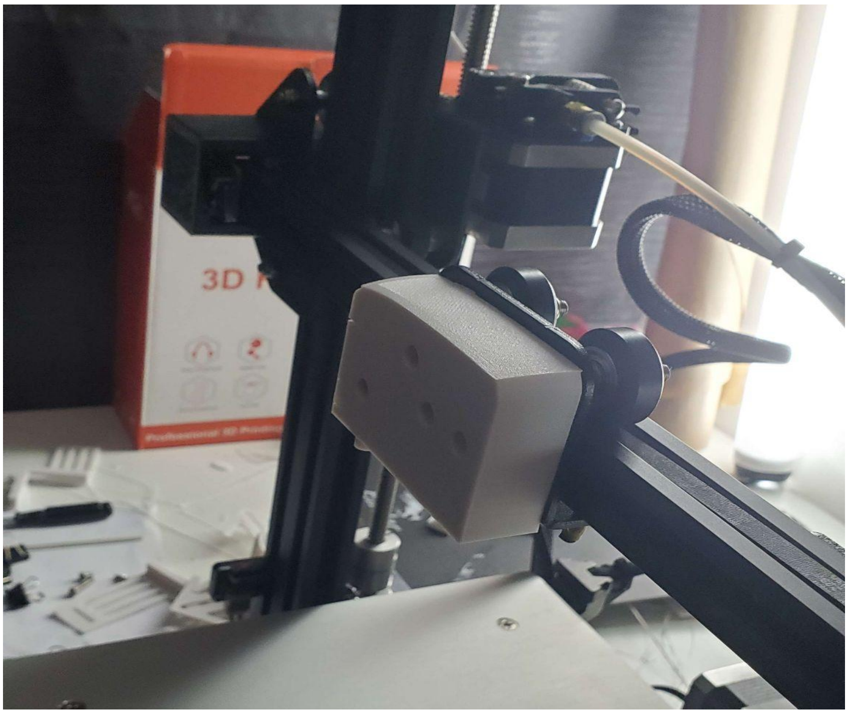


Figure 4.3: Load Cell Mount Attachment for physical placement test

5 Microcontroller

5.1 Alternatives

The microcontroller is used to communicate with the computer with the current data collected from the force sensor and the button input. Alternatives considered for the design solution:

Table 5.1 Microcontroller alternatives

Alternatives	**Arduino**	**ESP**	**PIC**
Advantages	● Simple to use ● AVR based	● Cheap ● Offers wifi Capabilities (for cheap) ● Similar to Arduino ● AVR based	● Simultaneous tasks
Disadvantages	● More Expensive	● Slightly higher complexity than arduino	● Complex Programming Environment

5.2 Consideration

Key functional requirements in choosing a solution:

1. All microcontrollers will be able to satisfy our functional requirements

Key quality attributes in choosing a solution:

1. Modularity *NF2*
2. Replicability *NF3*
3. Ease of Use *NF5*

Key constraint to be satisfied for a solution:

2. Budget *C1*

5.3 Alternative Decision

Based on the design considerations discussed in 5.2, the alternative of an **ESP** microcontroller will be chosen over the other alternatives due to the benefit of having a cheap wifi alternative if needed, with a programming environment similar to that of the Arduino. This is because we do not need a lot of concurrent tasks as we only have two inputs. This design choice will allow us to:

1. Have a quality that satisfies our modularity requirement due to the nature of off-the-shelf solutions which are easy to assemble.
2. Have a quality that satisfies our replicability requirement due to the nature of the product components being commercially available.
3. Have a quality that satisfies our ease of use requirement, where the complexity is still relatively simple

5.4 ESP Microcontroller Choices

Key considerations in choosing an ESP Microcontroller are

1. Cost
2. Ease of Use

Table 5.2 ESP Microcontroller Choices

Options	**Cost**	**Supply Voltage**	**Standalone System?**
ESP32-PICO-KIT [17]	14CAD	3.3 V, 5 V	Yes
ESP32-PICO-D4 [18]	7CAD	3.3V	No
ESP32-S3-DevKitM-1-N8 [19]	21CAD	3.3V, 5V	Yes
ESP32-C3-DevKitM-1U [20]	15CAD	3.3V, 5V	Yes
ESP8226 WiFi development board [21]	23CAD	3.3 V	Yes

5.5 Design Choice

Based on the overall cost we can see that the ESP32 PICO is the most cost effective option. Due to previous experience with ESP microcontrollers, we have decided to go with an **ESP32-PICO-KIT** [17] dev module. This allows us to get familiar with the ESP32 while allowing this to transition into a PCB solution in the end. This sensor option allows us to:

1. Remain in a low-cost range
2. Test the solution early on with off-the-shelf components

6 Interface PCB

The interface PCB combines the following: the Load Cell Amplifier, the Activation Circuit and the Microcontroller. This section will cover the schematic design for the PCB as well as the options for how the PCB will be designed. We will consider the comparison for Through Hole Technology (THT) compared to Surface Mount Technology (SMT), as well as whether to get an assembled PCB or not.

6.1 Consideration

Key functional requirements in choosing a solution:

1. The system must be able to measure the force applied on the button's surface: 10gf < Fa < 500gf, ±1gf accuracy *F2*
2. The system must be able to detect when the switch undergoing testing is activated *F3*
3. The system shall provide users with audio and visual feedback upon button activation *F8*

Key quality attributes in choosing a solution:

1. Modularity *NF2*
2. Replicability *NF3*
3. Ease of Use *NF5*

Key constraint to be satisfied for a solution:

1. Budget *C1*

6.2 Schematic Design

Breaking the schematics into three parts by the three fundamental requirements, we will discuss the choices for the schematic design. The overall schematic is shown below in figure 6.1, which will be discussed in the following sections.

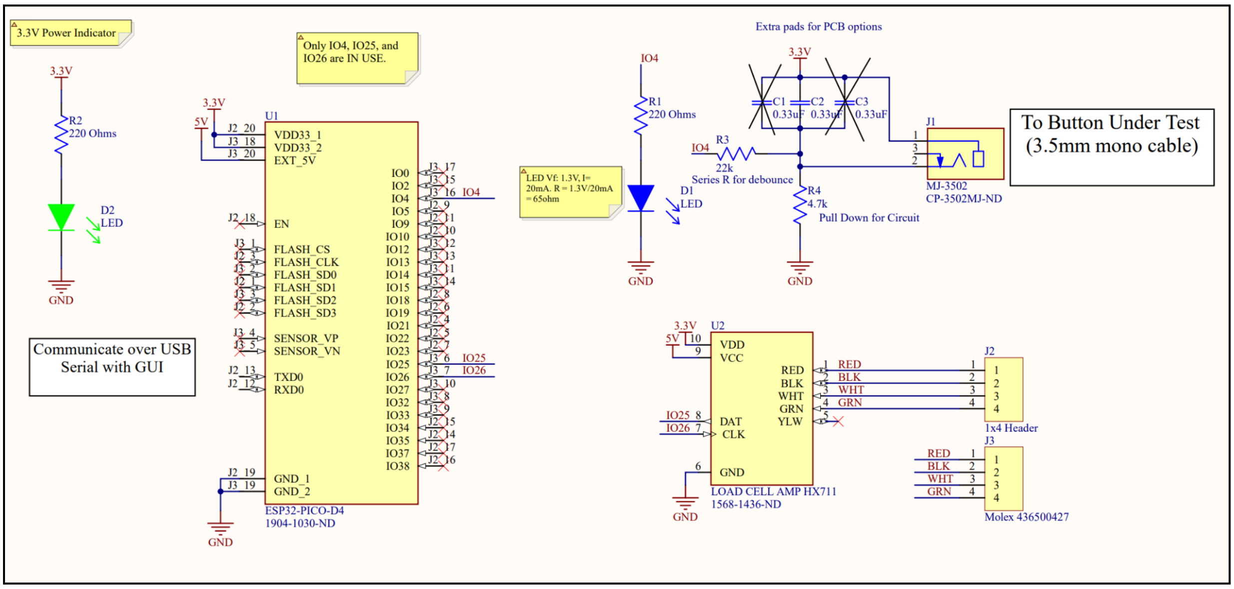


Figure 6.1: Interface PCB Schematics showing all subcomponents mentioned in this section: Microcontroller, Load Cell Amplifier and Activation Circuit

6.2.1 Force Measurement

To measure the force applied to the button, we must first attach a mounting system to the load cell in a Z formation (albeit much lighter and smaller), where the top piece shall be attached to the 3D printer and the bottom will be connected to a probe that will press against the button, shown in figure 6.2 below:

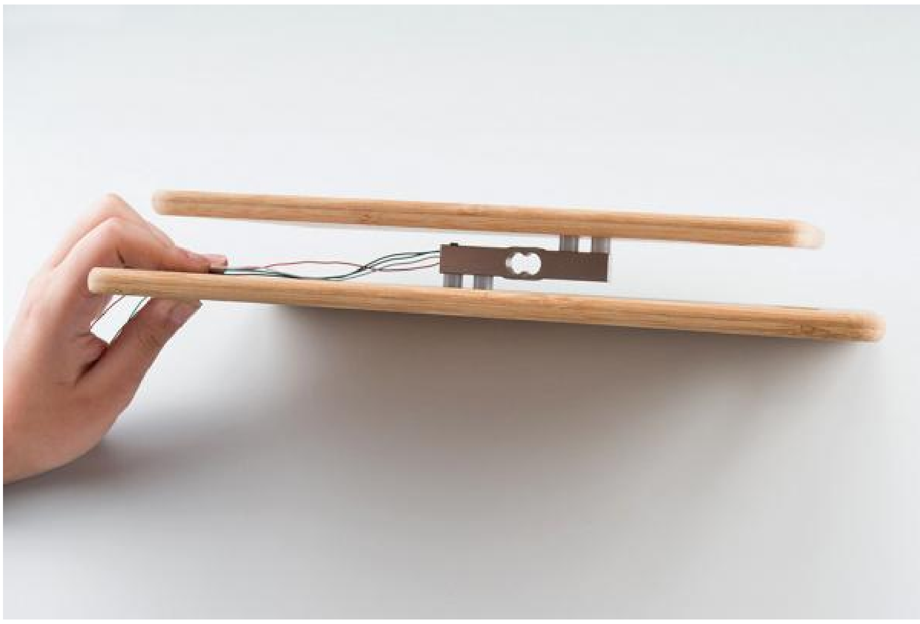


Figure 6.2: Example application of load cell in Z bar configuration [22]

This load cell shall be attached to the load cell amplifier on the circuit board with the 4 wires indicated as Red (Vin+), Black (Vin-), White (Vout-), Green (Vout+). This is the wheatstone bridge configuration from the load cell, shown in figure 6.3:

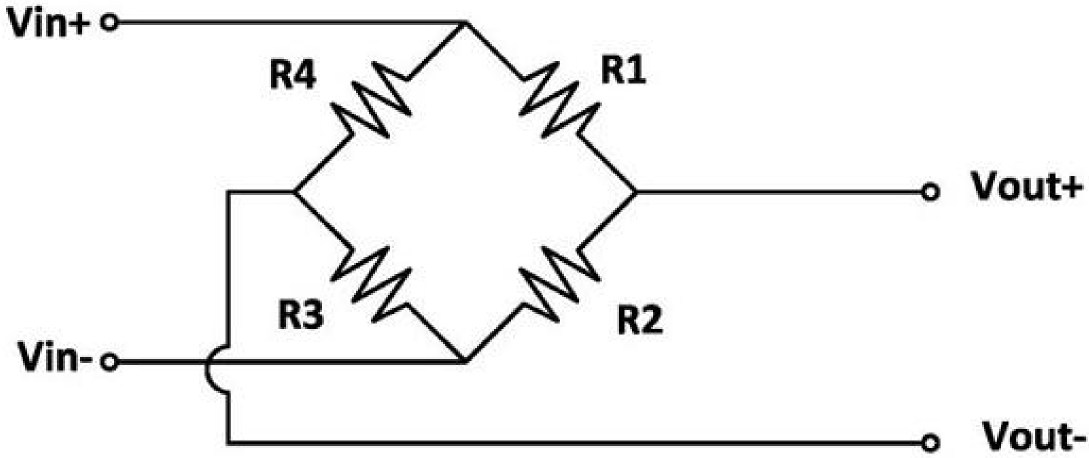


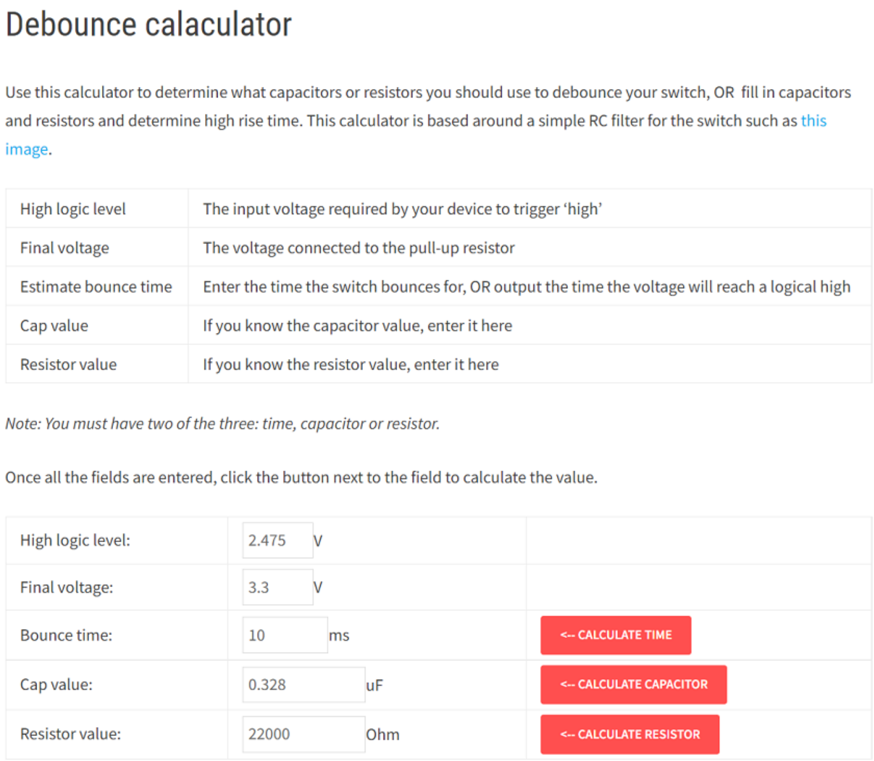
Figure 6.3: Wheatstone Bridge Configuration [23]

The load cell amplifier [24] is a data processing chip which amplifies the voltage and communicates to a master unit using a data and clock line with the information. To read the value correctly, the load cell amplifier must be calibrated using the code provided from the sparkfun guide [22], where the load cell will function using the Arduino IDE library installed using that same guide.

6.2.2 Activation Circuit

The activation circuit takes a signal from the switch undergoing testing (which has a 3.5mm mono jack) through a 3.5mm mono audio cable, to the circuit board through another 3.5mm mono jack [25].

This signal should be debounced assuming a debounce time of roughly 10ms, seeing that the average debounce time for a button is between 1.6ms and 6.2ms [26]. We used hardware debouncing rather than software debouncing so that any change of software would not affect the button operation. The calculation was performed using the following site shown in Figure 6.4 [28], using a high logic level value (VIH, the value at which the device will read high) of 0.75VDD or 2.475V [27] and an assumed resistor pull up value of 22kΩ, where the calculation is shown in Figure 7.4 below:



Debounce calaculator

Use this calculator to determine what capacitors or resistors you should use to debounce your switch, OR fill in capacitors and resistors and determine high rise time. This calculator is based around a simple RC filter for the switch such as this image.

High logic level	The input voltage required by your device to trigger 'high'
Final voltage	The voltage connected to the pull-up resistor
Estimate bounce time	Enter the time the switch bounces for, OR output the time the voltage will reach a logical high
Cap value	If you know the capacitor value, enter it here
Resistor value	If you know the resistor value, enter it here

Note: You must have two of the three: time, capacitor or resistor.

Once all the fields are entered, click the button next to the field to calculate the value.

High logic level:	2.475 V	
Final voltage:	3.3 V	
Bounce time:	10 ms	<-- CALCULATE TIME
Cap value:	0.328 uF	<-- CALCULATE CAPACITOR
Resistor value:	22000 Ohm	<-- CALCULATE RESISTOR

Figure 6.4: Debounce Calculation [44]

Note, these values can be adjusted later if they are deemed incorrect (for example, the pull up value is too large of a resistance or the debounce time is incorrect) for our prototype.

The signal from the button will then be read by the microcontroller as well as the LED which will light up indicating a button press, with no debounce. Note there is also an LED on the 3.3V rail.

6.2.3: Microcontroller functions and feedback

With the button signal read by the microcontroller, we can send a PWM pulse using the microcontroller to the piezo buzzer indicating a press. As well, we will communicate with the PC over USB, using the serial communication library in Arduino IDE. The data that will be transmitted over USB is two numbers: the button state will be high if pressed and low otherwise, and the force measurement (in grams) from the load cell amplifier using the command “`scale.get_units()`[22]”.

6.3 PCB Design Technology Alternatives

Key considerations to compare the technology and method to develop the PCB are:

1. Cost
2. Size
3. Ease of Use

Table 6.1: PCB Design Technology Options

Alternatives	**THT**	**SMT**
Advantages	● Durability ● Ease of assembly	● Small size ● Lower cost ● Faster assembly
Disadvantages	● Large size ● Higher cost	● Difficult to assemble ● High Accuracy assembly

When it comes to designing printed circuit boards (PCBs), choosing the right technology can make a significant impact on the function of the whole board. We considered Through-Hole Technology (THT) and Surface-Mount Technology (SMT).

According to the requirement from the client, we need to make the whole system user friendly and easy to assemble. We chose to use the **THT technology** to make the PCB. Its durability makes it less likely to break off or become damaged during handling and assembly. What is more, its ease of assembly and repair makes it a good choice for meeting the requirement. Furthermore, THT components offer improved heat dissipation compared to SMT components. All the components are physically connected to the PCB, they can easily dissipate heat. Although it is not a high power application, this characteristic can still make the design more durable.

The PCB developed for the M3 presentation is shown below (a 2 Layer PCB from JLCPCB) in figure 6.5:

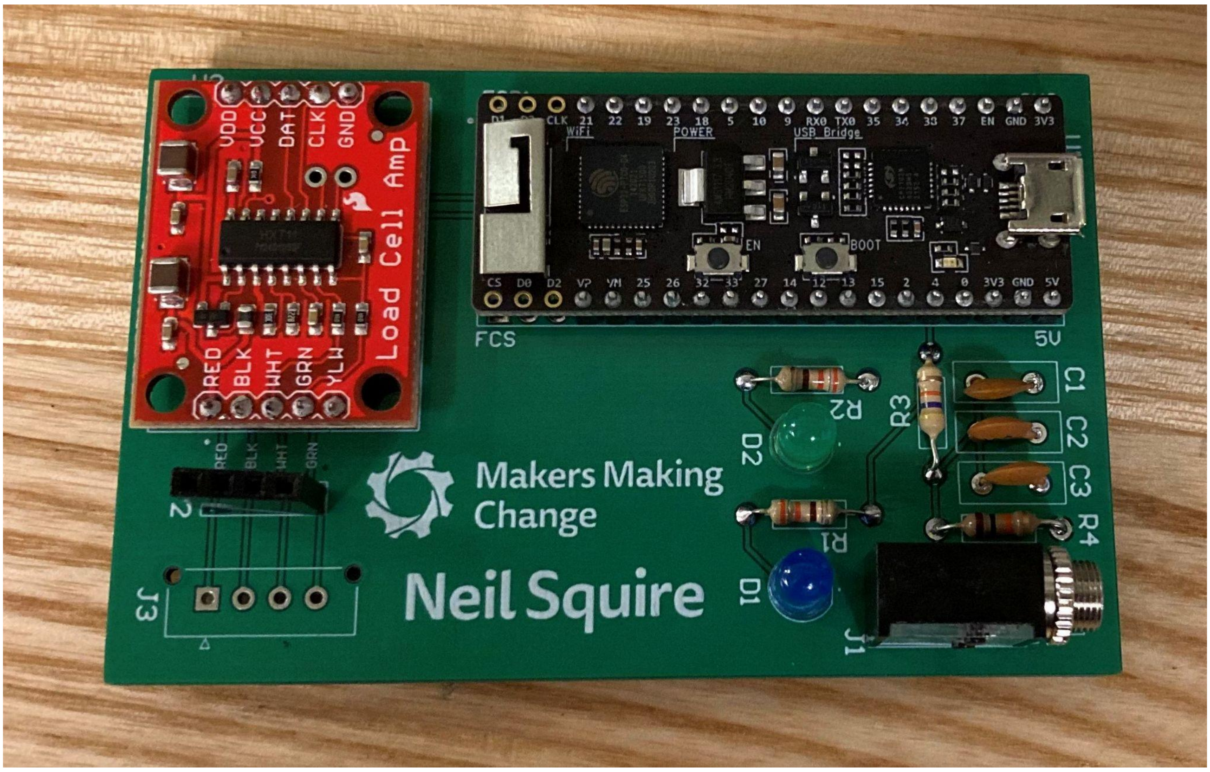


Figure 6.5: Breakout PCB developed based on schematics shown above, using Through hole components for ease of assembly.

7 Data Processing Software

7.1 Programming Language Alternatives

Related requirements and goals to the data processing software aspect:
(see Requirements Document for detailed version)

- F9: temporarily store and display the raw data (spreadsheet of button position, force activation, and distance activation) for the current round of testing, and generate that data if requested in a machine-readable format after testing is finished for:
    a. Button heatmap force activation.
    b. Button heatmap distance activation.
    c. Button characterization
- F12: has a reasonable operating time (displays data within ~0.8s of the switch being activated or heatmaps being requested)
- F13: conduct tests and store the actuation distance and peak force automatically in the “area” test mode
- F14: measure and display the actuation distance and peak force at an arbitrary point in the “single test point” mode
- NF3: replicable and open-source
- NF5: easy to use
- G4: familiar to Neil Squire team

The purpose of having data processing software for this project is to store and display data, as well as generate and display heat maps from the stored data. The software will get 3 data inputs when the switch undergoing testing is activated: the current force being applied, the travel distance of the switch, and the position of the switch tested. In the “single test point” mode, the software should display the 3 data on the computer (F14). In the “area” mode, the software should store the 3 data repeatedly until the user ends the test (F13). Then, if the user requests, the software should generate a heat map of force activation and distance activation from the stored data (F9).

The software chosen must be capable of performing the above scenario as well as fulfill F12, NF3, and NF5. Because of NF3, all closed-source software such as Matlab cannot be considered. We will consider two open-source programming languages, Java and Python, which are both capable of fulfilling F9, F13, F14, and NF3. Both of these have a broad and active user base. There are many example code and help available online.

F12 and NF5 are more subjective, depending on how strictly we define a reasonable operating time and ease of use. We can compare the two options by using these two requirements as the criteria, meaning the software with a quicker runtime and higher readability is more suitable for this project.

Python is an interpreted language and uses verbose language, so it is simpler to understand and debug. Java is more time-efficient at runtime because it is a compiled language unlike Python and does not require time to reprocess and convert code from human-readable to machine-readable. Overall, the time performance depends on the code more than the platform used, so the time difference should not be high. Both Java and Python can fulfill the requirements, so this design decision depends on preferences/goals. After discussing with our client, we found that using Python would be easier to maintain and modify internally (G4). Because of this reason, we decided to choose Python.

The software component of this project is developed using open-source tools and is available on the product GitHub page. The GitHub page includes detailed documentation on the software development process, as well as user instructions on how to install and use the software.

Reference

[1] “Device selection guide: Switches,” Makers Making Change, 19-Oct-2022. [Online]. Available: https://makersmakingchange.com/resource/device-selection-guide-switches/. [Accessed: 27-Nov-2022].

[2] “3D printers components - how 3D Printers work,” VLC Components s.l. [Online]. Available: https://solectroshop.com/en/blog/3d-printers-components-how-3d-printers-work-n40. [Accessed: 27-Nov-2022].

[3] Safety Authority, "APPROVED CERTIFICATION MARKS FOR ELECTRICAL PRODUCTS", accessed Feb. 13, 2023. [Online]. Available: https://drive.google.com/file/d/1DkFi_HOcekOpocnc85cRan2cuswp66j2/view.

[4] 3D Printing Canada. "Creality Ender 3 V2." Accessed Feb. 13, 2023. [Online]. Available: https://3dprintingcanada.com/products/creality-ender-3-v2?_pos=2&_sid=ed07f2276&_ss=r.

[5] JakeJake, “Twistlock clamp,” Cults 3D, 05-Jun-2019. [Online]. Available: https://cults3d.com/en/3d-model/tool/twistlock-clamp-jakejake. [Accessed: 27-Nov-2022].

[6] Thingiverse.com, “3 jaw lathe Chuck by Bobwomble,” Thingiverse. [Online]. Available: https://www.thingiverse.com/thing:624625. [Accessed: 27-Nov-2022].

[7] ECE Engineering Services. [Online]. Available: https://eng-services.ece.ubc.ca/forms/3d-printing-forms/undergraduate/. [Accessed: 27-Nov-2022].

[8] UBC Rapid. [Online]. Available: https://ubc-rapid.com/#/printing. [Accessed: 27-Nov-2022].

[9] 3DSMITH. [Online]. Available: https://www.3dsmith.ca/. [Accessed: 27-Nov-2022].

[10] “JLC3D - online 3D printing service: Custom Electronics Enclosures,” JLCPCB. [Online]. Available: https://jlcpcb.com/3d-printing. [Accessed: 27-Nov-2022].

[11] “Overture PLA filament 1.75mm 3D printer filament, 1kg spool (2.2lbs), Dimensional Accuracy +/- 0.03 mm, fit most FDM printer, orange,” Amazon.ca: Industrial & Scientific. [Online]. Available: https://www.amazon.ca/OVERTURE-Filament-Consumables-Dimensional-Accuracy/dp/B07VJ13BHY/ref=sr_1_5?crid=3ASU04C3RXIDI&keywords=filament%2Bpla&qid=1669402806&qu=eyJxc2MiOiI3LjM5IiwicXNhIjoiNy4xNCIsInFzcCI6IjYuNjMifQ%3D%3D&sprefix=filament%2Bpla%2Caps%2C177&sr=8-5&th=1. [Accessed: 27-Nov-2022].

[12] “ANET3D printer filament ABS 1.75mm 1KG/spool black,” Lee's Electronic Components. [Online]. Available: https://leeselectronic.com/en/product/15227-3d-printer-filament-abs-175mm-1kg-spool-black.html. [Accessed: 27-Nov-2022].

[13] “Standard ABS filament - dark orange - 1.75mm - 1 kg,” Filaments.ca. [Online]. Available: https://filaments.ca/collections/3d-filaments/products/abs-filament-dark-orange-1-75mm?variant=1252336336904. [Accessed: 27-Nov-2022].

[14] “Mini load cell - 500G, straight bar (TAL221),” SEN-14728 - SparkFun Electronics. [Online]. Available: https://www.sparkfun.com/products/14728. [Accessed: 27-Nov-2022].

[15] “314990000: Digi-Key Electronics,” Digi. [Online]. Available: https://www.digikey.ca/en/products/detail/seeed-technology-co-ltd/314990000/5488115. [Accessed: 27-Nov-2022].

[16] “Sen-13879: Digi-Key Electronics,” Digi. [Online]. Available: https://www.digikey.ca/en/products/detail/sparkfun-electronics/SEN-13879/6202732. [Accessed: 27-Nov-2022].

[17] “Esp32-Pico-Kit espressif systems: Mouser,” Mouser Electronics. [Online]. Available:

https://www.mouser.ca/ProductDetail/Espressif-Systems/ESP32-PICO-KIT?qs=MLItCLRbWsyoLrlknFRqcQ%3D%3D. [Accessed: 27-Nov-2022].

[18] "Esp32-Pico-D4: Digi-Key Electronics," Digi. [Online]. Available: https://www.digikey.ca/en/products/detail/espressif-systems/ESP32-PICO-D4/9381722. [Accessed: 27-Nov-2022].

[19] "ESP32-S3-DEVKITM-1-N8: Digi-Key Electronics," Digi. [Online]. Available: https://www.digikey.ca/en/products/detail/espressif-systems/ESP32-S3-DEVKITM-1-N8/15295895?s=N4IgTCBcDaIKIGUAKBmMBaBL0BECmAbgNICWALgLLoCM6AcgBwgC6AvkA. [Accessed: 27-Nov-2022].

[20] "ESP32-C3-DEVKITM-1U: Digi-Key Electronics," Digi. [Online]. Available: https://www.digikey.ca/en/products/detail/espressif-systems/ESP32-C3-DEVKITM-1U/15198974?s=N4IgTCBcDaIKIGUAKBmMBaAwi9ARApgG4DSAlgC4Cy6AjAKogC6AvkA. [Accessed: 27-Nov-2022].

[21] "2821 Adafruit: Mouser," Mouser Electronics. [Online]. Available: https://www.mouser.ca/ProductDetail/Adafruit/2821?qs=xE9dPqTLfL5V1q3xfEeZFw%3D%3D. [Accessed: 27-Nov-2022].

[22] "Load Cell amplifier HX711 breakout hookup guide," Load Cell Amplifier HX711 Breakout Hookup Guide - SparkFun Learn. [Online]. Available: https://learn.sparkfun.com/tutorials/load-cell-amplifier-hx711-breakout-hookup-guide?_ga=2.6464886.596726431.1669574994-353345243.1665696030. [Accessed: 27-Nov-2022].

[23] "Load cell electrical circuit.," Utilcell. [Online]. Available: https://www.utilcell.com/en/load-cell-electrical-circuit-/. [Accessed: 27-Nov-2022].

[24] "Sen-13879: Digi-Key Electronics," Digi. [Online]. Available: https://www.digikey.ca/en/products/detail/sparkfun-electronics/SEN-13879/6202732. [Accessed: 27-Nov-2022].

[25] "MJ-3502: Digi-key electronics," Digi. [Online]. Available: https://www.digikey.ca/en/products/detail/cui-devices/MJ-3502/281321. [Accessed: 27-Nov-2022].

[26] M. Maxfield, A. Says: M. M. says: J. D. says: E. S. D. says: R. C. says: S. K. says: A. H. says: A. Says: and E. Says: “Ultimate Guide to Switch Debounce (part 4),” EEJournal, 21-Feb-2020. [Online]. Available: https://www.eejournal.com/article/ultimate-guide-to-switch-debounce-part-4/#:~:text= As Jack Ganssle reported in,microseconds (or 6.2 ms). [Accessed: 27-Nov-2022].

[27] “Esp32-Pico-D4 - Mouser Electronics.”, Page 15, [Online]. Available: https://www.mouser.com/datasheet/2/891/esp32-pico-d4_datasheet_en-1365829.pdf . [Accessed: 28-Nov-2022].

[28] “Debounce Calaculator,” Protological. [Online]. Available: https://protological.com/debounce-calaculator/. [Accessed: 27-Nov-2022].

[29] “FSR 400 Series Data Sheet” [Online]. Available: https://cdn2.hubspot.net/hubfs/3899023/Interlinkelectronics November2017/Docs/Datasheet_FSR.pdf. [Accessed: 28-Nov-2022].

[30] “SingleTact Datasheet” [Online]. Available: https://www.singletact.com/SingleTact_Datasheet.pdf. [Accessed: 28-Nov-2022].

[31] “SingleTact User Manual” [Online]. Available: https://www.singletact.com/wp-content/uploads/SingleTactST-manual-V2_7.pdf. [Accessed: 28-Nov-2022].

[32] “Force sensor - singletact,” PPS. [Online]. Available: https://pressureprofile.com/sensors/singletact. [Accessed: 27-Nov-2022].

Appendix A

8 Resistive Force Sensor Information

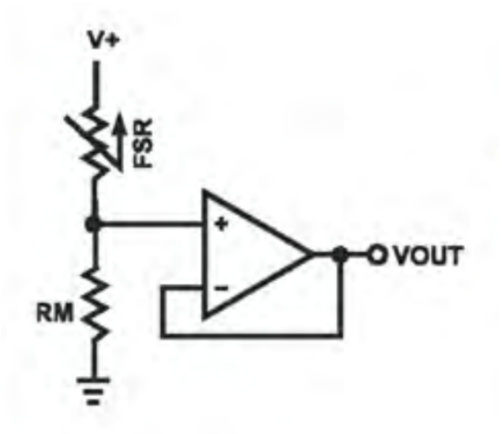
Principle: Force applied to the sensor will change the resistance. An example of such a sensor is the FSR402 [29].

8.1 Design note

- Manufacturer: Interlink Electronics
- Price: $12.78
- Response Time: 8us
- Output Type: Analog
- Minimum Detect Force: 0.2N
- Sensitivity Range: 20N
- Size: 14mm diameter

8.1.1 Measure Option 1

Simple Force to Voltage conversion, the force sensing resistor is tied to a measure resistor in a voltage divider, using simple circuit calculation.



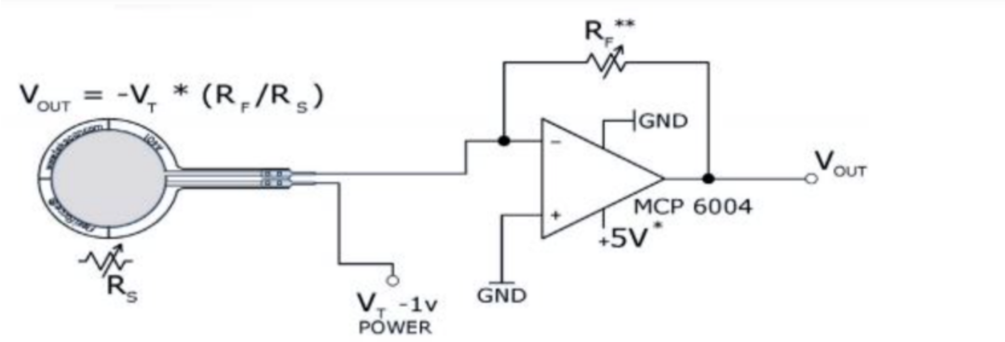
$$V_{OUT} = \frac{R_M V+}{(R_M + R_{FSR})}$$

Figure 9.1 Circuit Illustration and Calculation Formula

8.1.2 Measure Option 2

Due the characteristic of the resistance changing with force, combine it with an OpAmp to create a simple circuit. The source will provide a -1V power, based on the characteristic of the OpAmp, we can apply another resistor Rf to the circuit and the ratio between the Rf and the resistance of the sensor is the ratio between the Vout and the power source which is -1V.

Then using the relationship between the resistance of the sensor and the force applied can provide us with the data of the force we applied.



- * Supply Voltages should be constant
- ** Reference Resistance R_F is 1kΩ to 100kΩ
- Sensor Resistance R_S at no load is >5MΩ
- Max recommended current is 2.5mA

Figure 9.2: Resistive Force Sensor Circuit

The downside of the resistive force sensor is the relationship between the force applied to the sensor and the change of resistance is not linear. This means it is not easy to find an equation for the conversion from input output which will create errors.

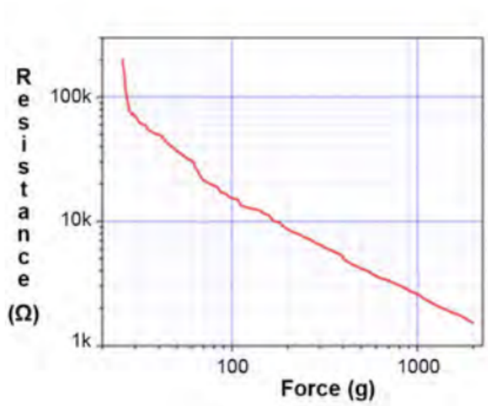


Figure 9.3: Force Sensor Performance

8.2 Capacitive Force Sensor Information

For capacitive sensors, we are considering force sensors from PressureProfile, called SingleTact.

Table 9.1: Capacitive Force Sensor Specs

Option	**Cost (incl. shipping)**	**Force Resolution Accuracy**	**Linearity Error**	**Force Range**	**Voltage to Force Relationship**	**Sensor Size**
S15-4.5N [30]	81CAD[1]	<0.2%[2]	10%[3]	0.9gf - 450gf	Non-Linear	15mm dia
S15-4.5N (incl. electronics) [30]	130CAD	<0.2%	10%[3]	0.9gf - 450gf	Non-Linear	15mm dia
CS15-4.5N (incl. electronics) [21]	213CAD	<0.2%	<2%	0.9gf - 450gf	Linear	15mm dia

1. Since we need to develop custom electronics this will add roughly another 30-40 CAD to the cost
2. Likely worse accuracy than shown due to unknown accuracy of capacitance measurement from custom electronics
3. Linearity error can be improved to similar 2% range if sensor is calibrated correctly by us

Note, all sensors have a max force rating (without damage) of 300% of the full-scale force range (upper limit). This corresponds to an output analog voltage of 2V, where above this range the sensor voltage will saturate. To avoid damage to the sensors, pressure should be limited to less than 3x the Full-Scale Range. If the output voltage is less than 0.5V, this indicates a negative pressure and tension on the sensor which should be avoided.

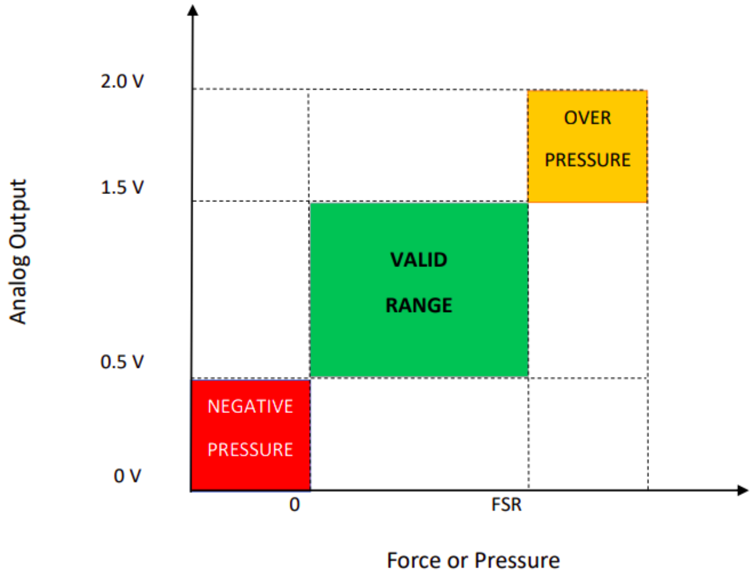


Figure 9.4: Pressure Range

We will need to calibrate the non-linear sensor to the applied force since the relationship is curved. Can do this by using a known sensor or weights and determine the best fit curve for the force measurement.

8.3 Uncalibrated Sensor

Principle: Force applied to the sensor will change the capacitance, which can be measured using a 555 timer circuit or their custom electronics.

Sensor Design Notes [30][31][32]:

- Manufacturer: SingleTact
- Model Number: **S8-1N**
- 10% Accuracy
- Non-Linear Relationship to Force
- Cost: 25$ USD
- 8mm diameter
- Full scale Range: 100g (0.22lbs)
- Minimal Detectable Force: 0.2g

- The relationship is not calibrated, so we would have to do that calibration ourselves in software

8.3.1 Calculation of Capacitance

- **Option 1:** Electronics : $35 USD (

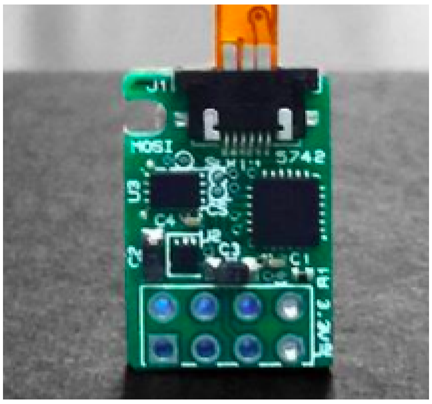
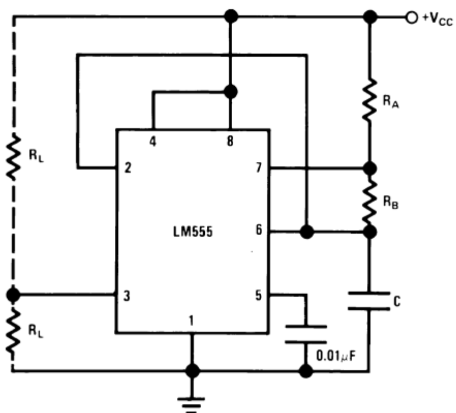


Figure 9.5: Capacitance Measure Board

  - Output is analog voltage from 0.5 to 1.5V which corresponds to the capacitance measurement

- **Option 2:** Custom Electronics using 555 timer to measure the capacitance, integrated into our MCU



$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2R_B)C}$$

Figure 9.6: 555 Timer

  - For 75pF nominal, a value of RA = 976kΩ and RB = 475kΩ are selected for a frequency of 10kHz (9.99KHz to be exact), as 555 timers are more accurate in the 5-10kHz range
  - The idea is to use a timer and count the pulses for a specified time. This may not work adequately for low capacitance values we will be using.

- There is still a possibility of doing timer based if we include passive compensation and active shielding of the measured capacitance, where there is an induced capacitance from the pins of the 555 timer.

8.3.2 Conversion to Force

If we are using SingleTact Electronics, the following equation for force (N) can be used as an estimate, however to get better accuracy we need to calibrate the sensor.

$$\boldsymbol{Load\ (N) = \frac{Analog\ Output\ (V) - Baseline\ Output(V)}{1\ (V)} * Sensor\ Rating\ (N)}$$

Therefore, for our 8mm 1N sensor the equation becomes:

$$F = \frac{V_{out} - 0.5V}{1V} \times 1N$$

8.4 Calibrated Sensor

Principle: Force applied to the sensor will change the capacitance, which can be measured using their custom electronics with an analog output.

Design Notes [30]:

- SingleTact is the only manufacturer that makes force sensitive capacitors
- Model Number: **CS8-1N**
- Cost: $120, in retrospect, this is only 60$ more than uncalibrated with electronics)
- 2% Accuracy
- Linear Relationship to Force
- 8mm diameter
- The relationship is calibrated, so the analog data output is linear compared to force (easier to measure).
- Everything else is the same, except we get given a linear scale from output to force

8.4.1 Conversion to Force

The conversion of the analog output voltage to N is a linear scale using the same equation as the uncalibrated sensor, except this time it is accurate.

Therefore, for our 8mm 1N sensor the equation becomes:

$$F = \frac{V_{out} - 0.5V}{1V} \times 1N$$