# Completion Checklist (DELETE BEFORE POSTING)

* Update <MONTH> and <YEAR> in header
* Update V<X.Y.Z> in header
* Update <DEVICE NAME> in header
* Add logo to or remove the “Place Logo Here” textbox in header
* Update <YEAR> in footer
* Update <Author> in footer
* Update webpage link in footer
* Complete Overview page
* Complete Introduction
* Complete Requirements
  + List goals
  + List functional requirements
  + List non-functional requirements
  + List constraints
* Complete Research
  + Document commercially available options
  + Document DIY / maker friendly options
* Complete Ideation
  + Describe ideas created to meet the goals / requirements of the project
  + Include decisions about which ideas to continue with
* Complete Conceptual Designs
  + Describe the concepts created to meet the goal / requirements of the project
  + Include decisions about which concepts
* Complete Prototyping
  + Document prototypes developed
  + Include decisions on prototypes
* Complete Testing
  + Describe tests completed (or that would be good to complete)
  + Include results of tests
* Complete Detailed Design
  + Describe all aspects of the current version of the device to be released
* Complete Opportunities for Improvement (OFIs)
  + List OFIs for the device
* Check images have been inserted where required
  + Can search for <INSERT IMAGE OF DEVICE>
* Update Table of Contents
* Delete all help text
* Delete Completion Checklist
* For detailed instructions on completing the Design Rationale, please see the [OpenAT Documentation Guide](https://github.com/makersmakingchange/OpenAT-Template/blob/main/OpenAT_Template_Guide.pdf)

# Overview

The Design Rationale is intended to provide designers and maker information about the design process and design decisions behind the development of the <DEVICE NAME>, <INSERT ONE-LINE DESCRIPTION OF DEVICE>.

<INSERT IMAGE OF DEVICE>

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# Introduction

<DESCRIPTION OF WHERE IDEA FOR THE DEVICE ORIGINATED>

<Do NOT include identifying information on a specific end-user if they requested the device be designed (ex: name, age, gender, sex, location). >

<DESCRIPTION OF NEEDS BEING MET BY DEVICE>

<DESCRIPTION OF INTENDED END-USER. INCLUDE SPECIFIC NAMES OF CONDITIONS IF KNOWN.>

# Requirements

The goals and requirements outlined here can be used to assess if a device would meet the needs of a user, and determine when a design is sufficient for release.

## Goals

<GOALS ARE THE NEEDS THAT NEED TO BE MET BY THE DEVICE>

|  |  |
| --- | --- |
| G01 | Low force joystick |
| G02 | Optimized for low volume builds |
| G03 | Released as Open Source Hardware |
| G04 | Compatibility with existing toppers |
| G05 | Device should be ergonomic and not put strain on the user’s wrist during use |
| G06 | Device should have a physical range of motion comparable to LipSync or typical gaming thumbstick (e.g., ±10 mm) |
| G07 | Minimize device envelope. |

## Functional Requirements

<FUNCTIONAL REQUIREMENTS ARE REQUIREMENTS RELATED TO HOW THE DEVICE WILL WORK TO MEET THE GOALS>

|  |  |
| --- | --- |
| F01 | With the default topper, the joystick must require 30 g or less of force to fully displace the joystick |
| F02 | Linear range of the joystick must be between a minimum of ±5 mm and a maximum of ±20 mm. |
| F03 | The device is operable in two operating modes: Joystick HID and Mouse HID. |
| F04 | A secondary user must be able to switch between operating modes |
| F05 | A Primary User should be able to switch between operating modes |
| F06 | Device must give the user visual or auditory feedback on the current operating mode. |
| F07 | A secondary user must be able to perform a neutral calibration of the joystick |
| F08 | The primary user should be able to perform a neutral calibration of the joystick |
| F09 | Device should have swappable toppers. |
| F10 | Devices should have toppers that are swappable by a Secondary User. |
| F11 | Device should utilize the Oak modular topper interface. |
| F12 | Device must be mountable, either compatible with the OpenAT Joystick mounting adaptor or have a built in ¼”-20 UNC thread |
| F13 | Device must output USB HID directly OR be compatible with an existing interface (e.g., LipSync Hub, Forest Hub) |
| F14 | Design must be smooth with no sharp edges |
| F15 | When passively resting on a desk or flat surface, the device must not slide when a horizontally applied force equal to the operating force is applied to the joystick. |
| F16 | When passively resting on a flat surface, the device should not tip over when a horizontally applied force equal to the operating force is applied to the joystick in any direction. |
| F17 | Device should function when mounted vertically or upside down |
| F18 | Device produced a proportional output through the range of motion. |
| F19 | Device should be able to withstand a drop of 3 feet onto a hard surface |
| F20 | Device provides two axes of output. |
| F21 | Device has an input deadzone. |
| F22 | Device should have an input deadzone that is adjustable by a Secondary User. |
| F23 | Device should have a sensitivity that is adjustable by a Secondary User. |
| F24 | Device should have a way to invert the axes by a Secondary User. |
| F25 | Device should be compatible with the XAC |

## Non-functional Requirement

<NON-FUNCTIONAL REQUIREMENTS DO NOT RELATE TO HOW THE DEVICE WORKS, BUT ARE RELATED TO THE GOALS OF THE PROJECT>

|  |  |
| --- | --- |
| NF01 | If device is bumped, it should not send an input to the connected device |
| NF04 | Design must adhere to intuitive operations |
| NF05 | Hysteresis (how well the device returns to center) |

## Constraints

<CONSTRAINTS ARE LIMITS ON THE DESIGN, SUCH AS COST, SIZE/WEIGHT, OR MATERIAL TYPES>

|  |  |
| --- | --- |
| C01 | Design must use off the shelf or 3D printed parts |
| C02 | Design must use 3D printed plastic for gimbal and enclosure |
| C03 | Device must not use batteries |
| C04 | Commercial components should be available from multiple sources |
| C05 | The parts should be sourced from as few suppliers as possible to lower shipping costs |
| C06 | Parts must be available in low quantities |
| C07 | Parts must not be region specific |
| C08 | Device must be safe for the user and disclaim any potential hazards such as magnets |
| C09 | Device should be assembled with commonly available tools |
| C10 | Only use hardware found in the LipSync gimbal in the Willow gimbal |
| C11 | The number of fastener types in the device should be minimized |
| C12 | The Willow joystick must work on the same magnetic gimbal principal as the LipSync |
| C13 | Assembly should not require high strength or torque |
| C14 | Device should be shippable within a Canada Post flat rate shipping box. |
| C15 | Device should cost less than the BoM cost for the LipSync 4 |

# Research

<DESCRIBE HOW AND WHEN RESEARCH WAS CONDUCTED>

## Commercially Available Options

Options that can be purchased but not made by a maker.

### <COMMERCIALLY AVAILABLE DEVICE NAME>

<COPY AND PASTE THIS SECTION, AND COMPLETE IT FOR EACH COMMERCIALLY AVAILABLE DEVICE>

|  |  |
| --- | --- |
| **Title / Name of device** | <TITLE / NAME OF DEVICE> |
| **Link** | <LINK TO WEBSITE, IF AVAILABLE> |
| **Author** | <DESIGNER / MANUFACTURER / DISTRIBUTOR> |
| **License** | <DISTRIBUTION LICENSE, IF APPLICABLE> |
| **Cost** | <COST (INCLUDE TYPE OF CURRENCY: CAD, USD< ETC.)> |

<INSERT IMAGE OF DEVICE>

<SHORT DESCRIPTION OF THE DEVICE AND HOW IT WORKS>

|  |  |
| --- | --- |
| **Requirements Met** | **Requirements Unmet** |
| <LIST REQUIREMENTS FROM PREVIOUS SECTION THIS DEVICE MEETS> | <LIST REQUIREMENTS FROM PREVIOUS SECTION THE DEVICE DOES NOT MEET> |

#### Useful Design Features

<INCLUDE ANY DESIGN FEATURES OF THE DEVICE THAT COULD / SHOULD BE CONSIDERED IN THE DESIGN OF ANOTHER DEVICE>

## DIY / Maker-Friendly Options

Options that can be made by a maker.

### <DIY / MAKER-FRIENDLY DEVICE NAME>

<COPY AND PASTE THIS SECTION, AND COMPLETE IT FOR EACH COMMERCIALLY AVAILABLE DEVICE>

|  |  |
| --- | --- |
| **Title** | <TITLE / NAME OF DEVICE> |
| **Link** | <LINK TO WEBSITE, IF AVAILABLE> |
| **Author** | <CREATOR OF THE DEVICE> |
| **License** | <DISTRIBUTION LICENSE, IF AVAILABLE> |
| **Cost** | <COST (INCLUDE TYPE OF CURRENCY: CAD, USD< ETC.)> |
| **Test Build (Y/N)** | <HAVE YOU BUILT THIS DEVICE?> |
| **Add to Library (Y/N)** | <SHOULD THIS DEVICE BE ADDED TO THE MMC LIBRARY?> |

<INSERT IMAGE OF DEVICE>

<SHORT DESCRIPTION OF THE DEVICE AND HOW IT WORKS>

|  |  |
| --- | --- |
| **Requirements Met** | **Requirements Unmet** |
| <LIST REQUIREMENTS FROM PREVIOUS SECTION THIS DEVICE MEETS> | <LIST REQUIREMENTS FROM PREVIOUS SECTION THE DEVICE DOES NOT MEET> |

#### Useful Design Features

<INCLUDE ANY DESIGN FEATURES OF THE DEVICE THAT COULD / SHOULD BE CONSIDERED IN THE DESIGN OF ANOTHER DEVICE>

## Joystick Force and Range of Motion Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| **Joystick** | **Operational Force** | **Range of Motion** |  |
| Celtic Magic Feather | 5, 10, 15, 20 g | Up to +/- 6 Degrees |  |
| Celtic Magic J1, J2, J3 | 60 or 20 g | Unknown |  |
| Celtic Magic Dangle Joystick | 10 g | +/-35 degrees |  |
| Mo-Vis Micro Joystick | 8 or 5 g | 3 mm movement |  |
| LINX 400 Compact Remote | 81 g | Unknown |  |
| ASL Micro Extremity Control | 18 g | Unknown |  |
| LipSync | 50 g | +/-10 degrees | 10 mm |
| Oak Joystick | 525 g | +/- 25 degrees |  |
| Spruce Joystick | 75 g | +/-30 degrees |  |
| Birch Joystick | 115 g | +/- 2mm | +/- 2 mm |
| Xbox One controller | 57-86 g | +/- 23 degrees |  |

## Research Summary

<Summary of findings; potentially viable solutions; any gaps in existing options>

Existing low force joysticks are in the 20g or less range, with a wide range of angles. Most of the extreme low force joysticks are in the ~+/-6 degrees range, while the rest of the joysticks do not go past +/-35 degrees.

# Ideation

<DESCRIBE THE INITIAL IDEAS GENERATED TO MEET THE GOALS OF THE PROJECT. THESE ARE BROAD CONCEPTS, NOT SPECIFIC IDEAS FOR PROTOTYPES, SPECIFIC COMPONENTS BEING USED, OR EXACT SOLUTIONS>

<INCLUDE SKETCHES, DESCRIPTION OF DESIRED FUCTION, AND HOW IT WOULD WORK>

<GIVE IDEAS NAMES / NUMBERS TO REFERENCE LATER>

## Key Features

### Output Architecture: Microcontroller vs Hub

#### Microcontroller Options

Criteria for microcontrollers:

Requirements

* Connect to the magnetic sensor via Stemma cable

Bonuses

* Minimize cost
* Minimize footprint
* Bluetooth
* Analog output for TRRS

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Microcontroller** | **Cost** | **Footprint (mmxmm)** | **Stemma** | **Bluetooth** | **Analog Out** | **Other** | **Link** |
| SAMD21 QT PY | $7.50 USD | 22x18 | Yes | No | Yes |  | [Link](https://www.adafruit.com/product/4600) |
| RP2040 QT PY | $9.95 USD | 22x18 | Yes | No | Yes | Dual core microcontroller | [Link](https://www.adafruit.com/product/4900) |
| CH552 QT PY | $4.95 USD | 22x18 | Yes | No | Yes | Almost no Arduino support, compiles in C not C++ so most libraries don’t work | [Link](https://www.adafruit.com/product/5960) |
| Seeed XIAO nrf52 | $9.90 USD | 22x18 | No | Yes | Yes |  | [Link](https://www.seeedstudio.com/Seeed-XIAO-BLE-nRF52840-p-5201.html) |
| CH32V203 QT PY | $4.95 USD | 22x18 | Yes | No | Unknown | Almost no Arduino support | [Link](https://www.adafruit.com/product/5996) |
| nRF52840 ItsyBitsy | $19.95  USD | 36x18mm | No | Yes | Yes |  | [Link](https://www.adafruit.com/product/4481) |
| nRF52840 glasses driver | $24.95 USD | 58x19 | Yes | Yes | No | Has lots of unneeded sensors | [Link](https://www.adafruit.com/product/5217) |
| Metro Mini 328 V2 | $14.95 USD | 44x18 | Yes | No | Yes |  | [Link](https://www.adafruit.com/product/2590) |
| ESP32 Pico QT Py | $14.95 USD | 22x18 | Yes | Yes | Yes | Also has Wi-Fi | [Link](https://www.adafruit.com/product/5395) |

**Microcontroller recommendation**

If Bluetooth is not a requirement, the SAMD21 QT PY is the best choice for its low cost, small footprint, stemma and analog capabilities while not having any unneeded features such as extra sensors.

If Bluetooth is a requirement, the ESP32 Pico QT PY is the best choice for its small footprint, Bluetooth capabilities, analog output, stemma port while minimizing unnecessary features.

**Microcontroller Pros**

* Able to function as a standalone device
* Low cost

**Microcontroller Cons**

* To add capabilities beyond what is included with the microcontroller (More sensors or button inputs) either a stemma module or a protoboard and wires are required.
* Limited feedback abilities

#### Hub Options

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Hub** | **Price** | **Inputs** | **Feedback** | **Adjustability** | **Output Modes** |
| LipSync Hub | $107.48 | * 3x 3.5mm switch Jacks * RJ11 i2c connector * 2x onboard push buttons | * Audio buzzer * 3x LEDs * Text display | * Neutral reset * Extent calibration * Cursor speed adjustment | * HID Gamepad * HID Mouse * Bluetooth * USB |
| Forest Hub | $78.54 | * 5x 3.5mm switch Jacks * RJ11 i2c connector * 2x onboard push buttons * 3.5mm TRRS jack | * Audio buzzer * 5x LEDs | * Neutral reset * Cursor speed adjustment | * HID Gamepad * HID Mouse * USB |

To make the willow joystick work with the hubs, the hubs themselves would need a firmware update. The hubs would need the basic programming added to allow them to translate the readings from the magnetic sensor into the HID output. They would also need to have an addition that allows them to recognize when a willow joystick is connected. The forest hub would just need to check if the magnetic sensor is attached, but the LipSync hub would need to be able to tell the difference between a willow joystick and a LipSync joystick. The LipSync hub already has the firmware required to convert magnetic sensor readings into HID, although if the order of magnet and sensor is reversed a slightly different version would have to be used for the Willow.

**Hub Pros**

* Increased user feedback
* Integrated switch inputs
* Integrated neutral or extent calibration
* Integrated cursor speed adjustment

**Hub Cons**

* Increased cost
* Joystick cannot be used as a standalone
* Chosen hub will need a software update to include the software needed for the Willow
* No possibility of TRRS output

### Neutral Calibration Options

* Microcontroller reboot/calibration on startup
* Externally triggered calibration

The two primary methods of neutral calibration are performing a calibration on microcontroller startup, and calibrating while the microcontroller is already powered on.

Calibration of the joystick during operation can be done by rebooting the microcontroller and taking advantage of the startup calibration. Most microcontrollers include a reboot button on the board itself, and the enclosure can be designed to allow a primary or secondary user to press the button to reboot the microcontroller and calibrate the neutral position. However, this would cause the loss of any data, such as cursor speed that was set since the last reboot.

Triggering the neutral calibration without rebooting the joystick would require an input to the microcontroller such as a button or switch jack. If the microcontroller does not have an onboard button that is not connected to the reset pin, then an external button or jack would be needed to allow the user to trigger the reset. This button can either be directly wired to the microcontroller pins, or it can be connected a stemma button breakout board. This requires more parts, but works with accessible switches and preserves information between calibrations.

### Extent Calibration Options

When performing an extent calibration on the LipSync, the user follows the directions on the screen, holding the mouthpiece in the four corners until the LipSync beeps.

To perform this type of extent calibration, the LipSync needs an input to initiate the calibration, and feedback to inform the user when to move to each corner. The text display also allows the instructions to be displayed to the user in real time, instead of having to refer to a user guide. This is not necessary for an extents calibration, but it does greatly simplify the process.

If using a hub, the extent calibration requirements are largely already met. The hubs have enough inputs that the user can use one to initiate an extents calibration, and both hubs have user feedback to time the different steps of the process. The LipSync Hub also has the text based display to show the steps in real time

When using a microcontroller, the user feedback and input need to be provided. The options for providing input are the same as the options for a non reboot neutral calibration. If the microcontroller does not have an onboard input button, and external button or switch jack would be required. These can either be soldered directly to the microcontroller pads or connected via the stemma port. To provide user feedback, most microcontrollers from Adafruit have an LED, and some come with a NeoPixel LED that can be used to give feedback in any colour. Additional audio or visual feedback can be added by wiring to the microcontroller pins or added via stemma port.

### Centering Strength Adjustment

There are two general methods available to change the centering force of the Willow gimbal

* Change the distance between the gimbal and sled magnet
* Change the strength of the sled magnet

For the sake of keeping the strength adjustment user friendly, making changes to the magnet in the gimbal itself will be disregarded, focusing on making changes to the magnet in the sled which is more accessible to the user.

Changing the distance between the sled and gimbal allows for the strength to be changed without changing the magnet used. This can be done by using a screw to advance or retract the magnet, as well as having a variety of locations in the sled that the magnet can be mounted in. Mounting the magnet in different locations in the sled would require the sled to be opened and the magnet moved. Changing the position of the magnet using a screw allows for a secondary user to change the strength without opening the enclosure while allowing the strength to be adjusted anywhere between the two extremes.

Changing the strength of the sled magnet can be done in two ways. The first way that it can be done is changing the magnet used in the sled for a different magnet with a stronger field. The second method is to add more magnets. This does have diminishing returns as the number of magnets increases. The following is an excerpt from the LipSync Design rationale when exploring this option for the LipSync Gimbal

“When stacking magnets, the magnetic force increases until the thickness of the stack reaches the diameter of the magnets [[first4magnets.com](https://www.first4magnets.com/tech-centre-i61/frequently-asked-questions-i69)]. Since the magnets used in the LipSync are 2.5mm x 8mm, 3 to 4 can be stacked before reaching diminishing returns. This is demonstrated in a graph showing the force vs thickness of the magnet. Note the X axis does not increase linearly. [[totalelement.com](https://totalelement.com/en-ca/blogs/working-with-neodymium-magnets/will-stacking-magnets-together-make-them-stronger)]

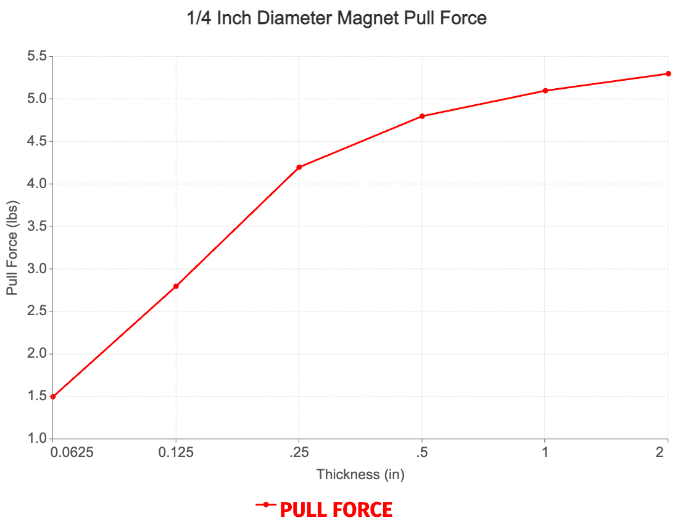


Figure 26. Magnetic Force with Greater Thickness.

“

#### Pros and Cons of Different Mounting Methods

|  |  |  |
| --- | --- | --- |
| **Method** | **Pros** | **Cons** |
| Different mounting locations | * Only uses one magnet | * Requires disassembling and reassembling the sled * The need to support the magnet makes the number of possible places very small |
| Variable mounting location (screw) | * Adjustable over the entire range with no defined stops * Only requires one magnet | * The rotation of the screw changes the location of the magnet slightly, requiring a recalibration |
| Stronger magnet | * Only uses one magnet | * Requires all the magnets of different strengths have the same dimensions * Need to take apart the sled to change magnets |
| Using more magnets | * If the first magnet is secured, more can be stacked in behind it from the exterior of the enclosure to change strength without opening the enclosure | * Different steps of strength with no in-between * Diminishing returns with more magnets, up to 3 or 4 |

### Features of the LipSync Gimbal

The following is a list of all components of the LipSync gimbal, and a judgement of if they are required in the Willow joystick

#### Sled

* Centering magnet
  + Needed
* Sensing magnet
  + Needed, but could be moved to the gimbal
* Bearing seats
  + Needed
* Cable management
  + Needed
* Angle hard stops
  + Needed
* Sliding rails
  + Needed
* Arm tabs
  + Needed

#### Outer Gimbal

* Angle hard stops
  + Needed
* Cable management
  + Needed if the sensor stays on inner gimbal
* Part identifiers
  + Needed
* Bearing seats
  + Needed
* Bearing posts
  + Needed

#### Inner Gimbal

* Shield
  + Needed
* Luer adaptor
  + Unneeded
* Air path
  + Unneeded
* Pressure sensor
  + Unneeded
* Magnetic sensor
  + Needed, but could be moved to sled
* Centering magnet
  + Needed
* Angle hard stops
  + Needed
* Part identifiers
  + Needed
* Bolt holes
  + Needed, but only if magnetic sensor stays on inner gimbal
* Cable management
  + Needed, but only if magnetic sensor stays on inner gimbal
* Bearing posts
  + Needed

#### Bare Minimum Changes

* Remove pressure sensor, air tube, and Luer lock
* Design topper base that fits in Luer compartment

#### Maximum Changes

* Move magnetic sensor to the sled
* Remove pressure sensor, air tube and Luer Lock
* Move sensor magnet to inner gimbal
* Shrink the gimbal to remove the space
* Redesign Luer lock compartment to allow swappable toppers

### Topper Compatibilities

#### Oak

The Oak toppers all come in small, medium and large, and connect to the oak joystick via a collet system that clamps onto the stick of the oak joystick module. The toppers then screw onto the collet. The oak comes with 5 styles of topper.

* Ball
* Concave
* Convex
* Goalpost
* Stick

#### Birch

The Birch toppers connect to the joystick by a friction press fit on the joystick module. They are designed for the sliding motion of the Birch joystick, and not the rotating motion of a traditional joystick. The birch comes with 5 different styles of topper.

* Concave
* Large Dome
* Medium Dome
* Ring
* Small Dome

#### Evaluation Criteria

The primary criteria that toppers will be evaluated on are attachment and weight. Attachment is a measure of how well the topper attaches to the joystick stick. Weight is a measure of how much each topper weighs.

## Ideation Decisions

<DESCRIBE AND JUSTIFY WHY DIFFERENT IDEAS WERE ABANDONDED, MODIFIED, OR CHOSEN TO PROCEED>

|  |  |  |
| --- | --- | --- |
| **Idea** | **Decision (Abandon, Modify, Proceed)** | **Justification** |
| <IDEA 1> | <DECISION> | <JUSTIFICATION> |
| <IDEA 2> | <DECISION> | <JUSTIFICATION> |

# Conceptual Designs

<DESCRIBE DIFFERENT DESIGNS BEING WORKED ON. SHOULD INCLUDE DESIGNING PARTS, SELECTING COMPONENTS, AND OUTLINING CODE (IF APPLICABLE)>

<GIVE CONCEPTS UNIQUE NAMES / NUMBERS TO REFERENCE LATER>

<COPY THE BELOW SECTION FOR EACH CONCEPT CREATED>

<IF PARTS ARE SHARED BETWEEN CONCEPTS (EX: THE CODE FUNCTION / STRUCTURE), ONLY DESCRIBE IT ONCE AND REFER TO IT IN OTHER CONCEPT SECTIONS>

<REMOVE IRRELEVANT SECTIONS IF NOT USED IN THE DESIGN>

## <CONCEPT 1>

<INSERT ONE-LINE DESCRIPTION OF THE CONCEPT>

A diagram of a machine

Description automatically generated

### Physical Component / Enclosure

<INSERT DESCRIPTION OF THE PHYSICAL COMPONENTS / ELECTRICAL ENCLOSURE. INCLUDE IMAGES, LINKS TO PARTS, ETC.>

### Electrical Components

<INSERT DESCRIPTION OF THE ELECTRICAL COMPONENTS. INCLUDE IMAGES, LINKS TO PARTS, ETC.>

### Code Structure / Function

<INSERT DESCRIPTION OF THE CODE STRUCTURE / FUNCTION. LINK TO EXTERNAL LIBRARIES (IF USED)>

## Concept Decisions

<DESCRIBE AND JUSTIFY WHY DIFFERENT CONCEPTS WERE ABANDONDED, MODIFIED, OR CHOSEN TO PROCEED>

|  |  |  |
| --- | --- | --- |
| **Concept** | **Decision (Abandon, Modify, Proceed)** | **Justification** |
| <CONCEPT 1> | <DECISION> | <JUSTIFICATION> |
| <CONCEPT 2> | <DECISION> | <JUSTIFICATION> |

# Prototyping

<DESCRIBE DIFFERENT PROTOTYPES BEING WORKED ON. SHOULD INCLUDE DESIGNING PARTS, SELECTING COMPONENTS, AND OUTLINING CODE (IF APPLICABLE)>

<GIVE PROTOTYPES UNIQUE NAMES / NUMBERS TO REFERENCE LATER>

<COPY THE BELOW SECTION FOR EACH PROTOTYPE CREATED>

<IF PARTS ARE SHARED BETWEEN PROTOTYPES (EX: THE CODE FUNCTION / STRUCTURE), ONLY DESCRIBE IT ONCE AND REFER TO IT IN OTHER CONCEPT SECTIONS>

<REMOVE IRRELEVANT SECTIONS IF NOT USED IN THE DESIGN>

## <PROTOTYPE 1>

<INSERT ONE-LINE DESCRIPTION OF THE PROTOTYPE>

### Physical Component / Enclosure

<INSERT DESCRIPTION OF THE PHYSICAL COMPONENTS / ELECTRICAL ENCLOSURE. INCLUDE IMAGES, LINKS TO PARTS, ETC.>

### Electrical Components

<INSERT DESCRIPTION OF THE ELECTRICAL COMPONENTS. INCLUDE IMAGES, LINKS TO PARTS, ETC.>

### Code Structure / Function

<INSERT DESCRIPTION OF THE CODE STRUCTURE / FUNCTION. LINK TO EXTERNAL LIBRARIES (IF USED)>

## Prototype Decisions

<DESCRIBE AND JUSTIFY WHY DIFFERENT PROTOTYPES WERE ABANDONDED, MODIFIED, OR CHOSEN TO PROCEED>

|  |  |  |
| --- | --- | --- |
| **Prototype** | **Decision (Abandon, Modify, Proceed)** | **Justification** |
| <PROTOTYPE 1> | <DECISION> | <JUSTIFICATION> |
| <PROTOTYPE 2> | <DECISION> | <JUSTIFICATION> |

# Testing

<DESCRIBE THE TESTING COMPLETED, OR THAT SHOULD BE COMPLETED ON THE DEVICE>

<DESCRIBE THE GOAL OF EACH TEST COMPLETED>

<INCLUDE LINKS TO TEST CODE, IF APPLICABLE>

<INCLUDE IMAGES, IF APPLICABLE>

## Test Methods

<DESCRIBE HOW THE TESTS WERE COMPLETED, WITH ENOUGH DETAIL FOR SOMEONE ELSE TO REPEAT THE TEST>

<GIVE TESTS DESCRIPTIVE NAMES / NUMBERS TO REFER TO LATER>

### <TEST 1>

<DESCRIBE THE FIRST TEST, AS EXPLAINED ABOVE>

## Test Results

<DESCRIBE THE RESULTS OF EACH TEST. INCLUDE RELEVANT IMAGES, DATA, AND FIGURES.>

# Detailed Design

<DESCRIBE THE CURRENT VERSION OF THE DEVICE TO BE PUBLISHED>

<INSERT IMAGE OF DEVICE>

<INCLUDE GOALS AND REQUIREMENTS THAT WERE MET AND NOT MET>

### Physical Component / Enclosure

<INSERT DESCRIPTION OF THE PHYSICAL COMPONENTS / ELECTRICAL ENCLOSURE. INCLUDE IMAGES, LINKS TO PARTS, ETC.>

### Electrical Components

<INSERT DESCRIPTION OF THE ELECTRICAL COMPONENTS. INCLUDE IMAGES, LINKS TO PARTS, ETC.>

### Code Structure / Function

<INSERT DESCRIPTION OF THE CODE STRUCTURE / FUNCTION. LINK TO EXTERNAL LIBRARIES (IF USED)>

# Opportunities for Improvement

<DESCRIBE HOW THE DEVICE COULD BE IMPROVED IN FUTURE VERSIONS>

### Physical Component / Enclosure

<INSERT DESCRIPTION OF IMPROVEMENTS TO THE PHYSICAL COMPONENTS / ELECTRICAL ENCLOSURE. INCLUDE IMAGES, LINKS TO PARTS, ETC.>

### Electrical Components

<INSERT DESCRIPTION OF IMPROVEMENTS TO THE ELECTRICAL COMPONENTS. INCLUDE IMAGES, LINKS TO PARTS, ETC.>

### Code Structure / Function

<INSERT DESCRIPTION OF IMPROVEMENTS TO THE CODE STRUCTURE / FUNCTION. LINK TO EXTERNAL LIBRARIES (IF USED)>