

Theta Beta Engineer Project Report

Foundation Color Identifier and Dispenser
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₇₇ **Chapter 1**

₇₈ **Abstract**

₇₉ The Foundation Identifier and Dispenser aims to develop a machine that is able to extract
₈₀ samples from a picture of a human to determine the shade of their skin, allowing the machine
₈₁ to dispense a corresponding foundation shade. The results produced should be both accurate
₈₂ and reproducible. Equipped with computer vision libraries and color correction algorithms,
₈₃ the system allows the user to take an picture alongside a reference color sheet, which has
₈₄ colors of known values. These captured values are processed to correct both camera bias,
₈₅ and lighting correction so that results may remain consistent regardless of lighting conditions
₈₆ during image capture. The system converts RGB values to LAB values, which are higher in
₈₇ accuracy in physical color mixing, as opposed to RGB, which is used to describe pixel colors.
₈₈ The program calculates how much of each color is needed to recreate the user's skin pigment.
₈₉ These pigments are then dispensed via a mechanical system comprised of a Raspberry Pi,
₉₀ servo motors, and syringes. This project demonstrates an application of computer vision in
₉₁ the cosmetic market to alleviate the burden of overconsumption and promote inclusivity.

₉₂ **Chapter 2**

₉₃ **Introduction**

₉₄ **2.1 Research**

₉₅ **2.1.1 Background of Problem**

₉₆ Testing foundation colors can be a frustrating experience for many, who are unable to
₉₇ find the perfect balance. At the end of the day, no line of foundation can realistically provide
₉₈ colors that cater to every possible skin tone. The seemingly unresolvable desire for a perfect
₉₉ shade leads many makeup users to spend hundreds on shades that are "close enough." This
₁₀₀ leads to lots of waste, not just in money, but in bottles thrown out after purchase because
₁₀₁ the match was ultimately unsatisfying.

₁₀₂ The beauty industry produces 120 billion packaging units per year and 95% of these units are discarded, as opposed to recycled [1]. In addition, traditionally a custom skin matched foundation can cost anywhere from \$60-100 per bottle, which leaves the consumers with the dilemma of whether they should take the gamble on the bottle that's just almost right versus breaking their wallet on a hand matched bottle. Our custom mixer machine offers the same accuracy in skin tone while also promoting cheaper makeup, sustainability, and waste-reduction.

₁₀₉ Our foundation color picker abandons the concept of creating a set of discrete skin tones to choose from, instead, opting for custom mixed shades depending on the skin color detected by a picture. It also offers the unique ability to sample a shade without having to commit to a full sized bottle.

₁₁₃ **2.1.2 Existing Solutions**

₁₁₄ BoldHue provides an option for an AI powered foundation mixer. It matches skin tone through a smart wand that detects color. What they promised was millions of shades and the ability to store user's shades in profiles. However, their color detection methods provide room for lots of error because color isn't perceived the same depending on the lighting of the room, as well as the high cost of their machine.

₁₁₉ Our product will have built in lighting correction that removes biases from the camera and uses the Macbeth Color Reference sheet as a set of control colors. The reference sheet

₁₂₁ is what will allow the machine to recalibrate it's understanding of what colors are being
₁₂₂ percieve.

₁₂₃ 2.2 Design Choices

₁₂₄ 2.2.1 Past Considerations and Scrapped Plans

¹²⁵ Chapter 3

¹²⁶ Hardware Design and Specifications

¹²⁷ 3.1 First Iteration

¹²⁸ 3.1.1 Initial CAD Model and Hand Sketches

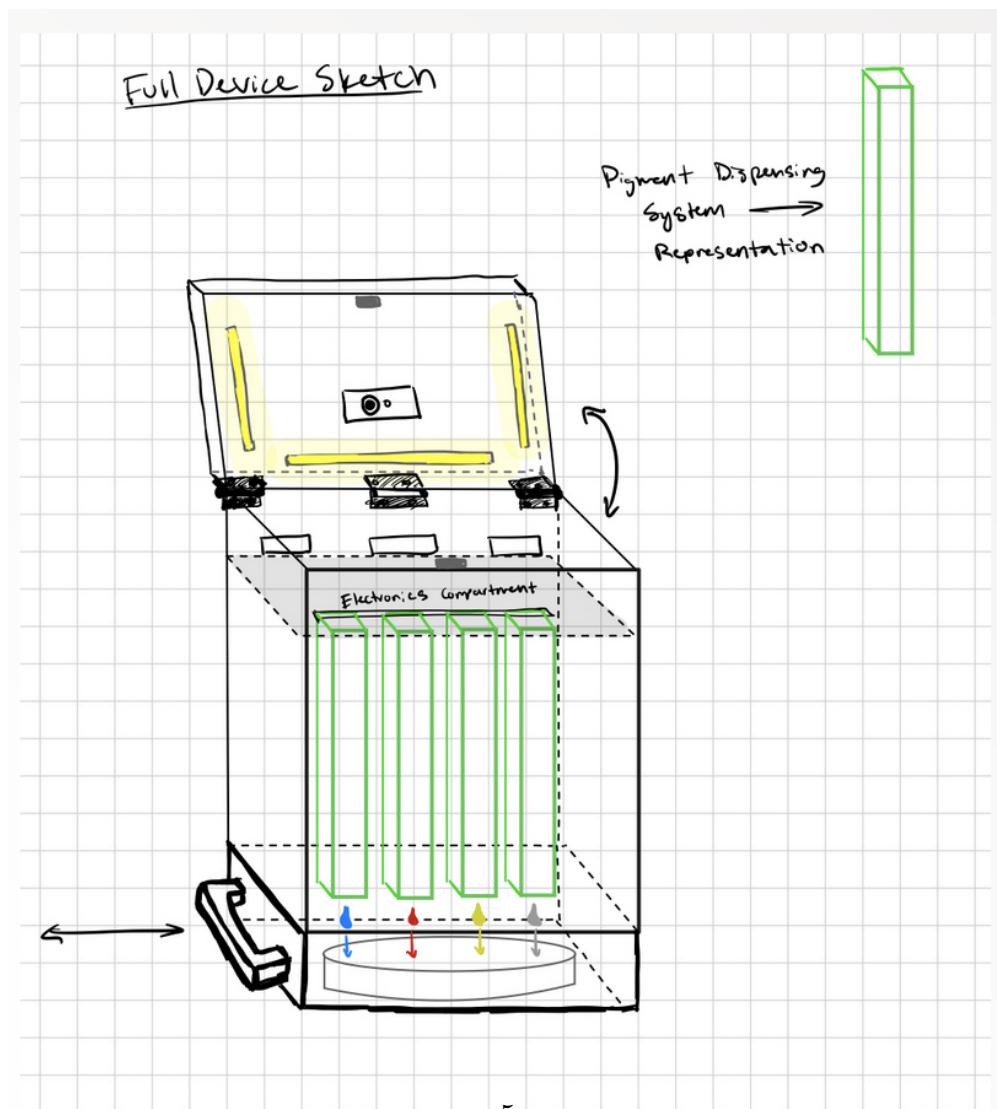


Figure 3.1: First Sketch: Housing

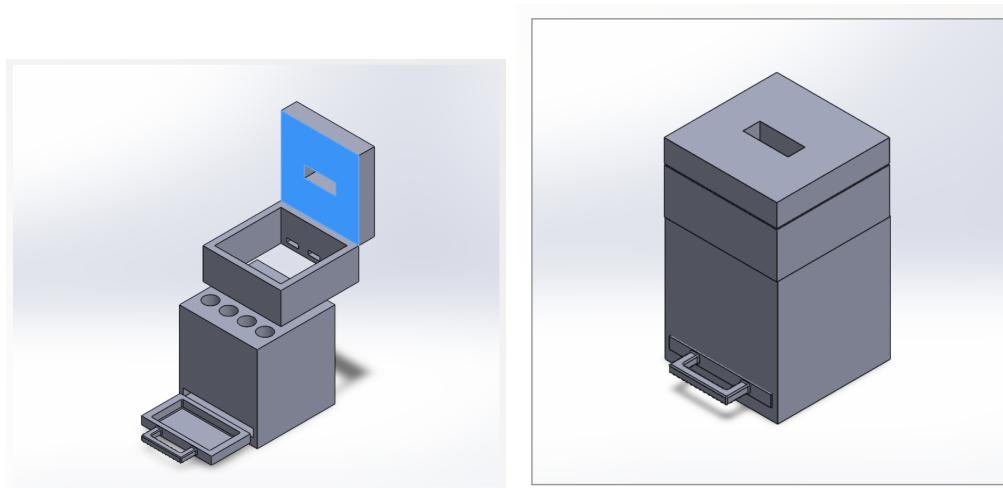


Figure 3.2: First CAD Models: Housing

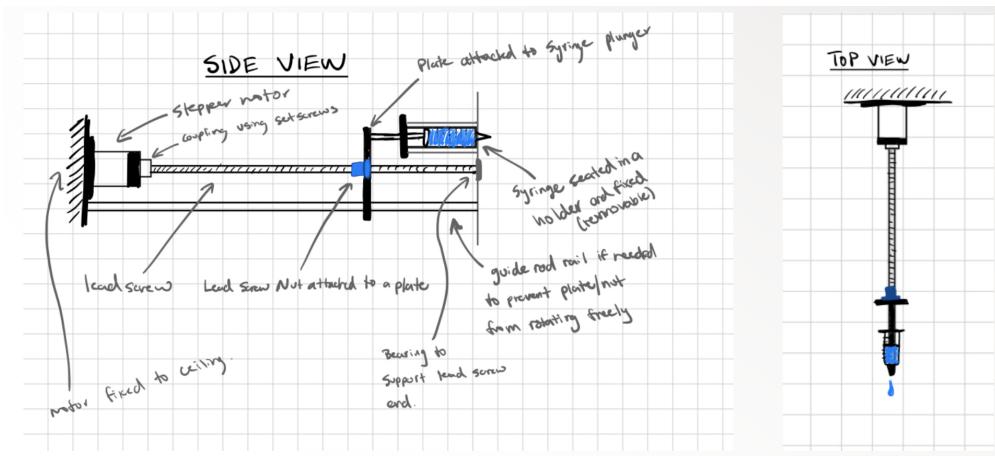


Figure 3.3: First Sketch: Dispenser Systems



Figure 3.4: First CAD Models: Dispenser Systems

¹²⁹ 3.1.2 Commentary

¹³⁰ Our first CAD Models were very simple and provide the most general idea we had at
¹³¹ our projects conception. We made large changes to the design of the housing because the
¹³² dimensions would have been much wider if we lined the syringes up, as shown in Figures 3.1
¹³³ and 3.2.

¹³⁴ The preliminary sketch we have of the dispenser system has stayed consistent throughout
¹³⁵ development.

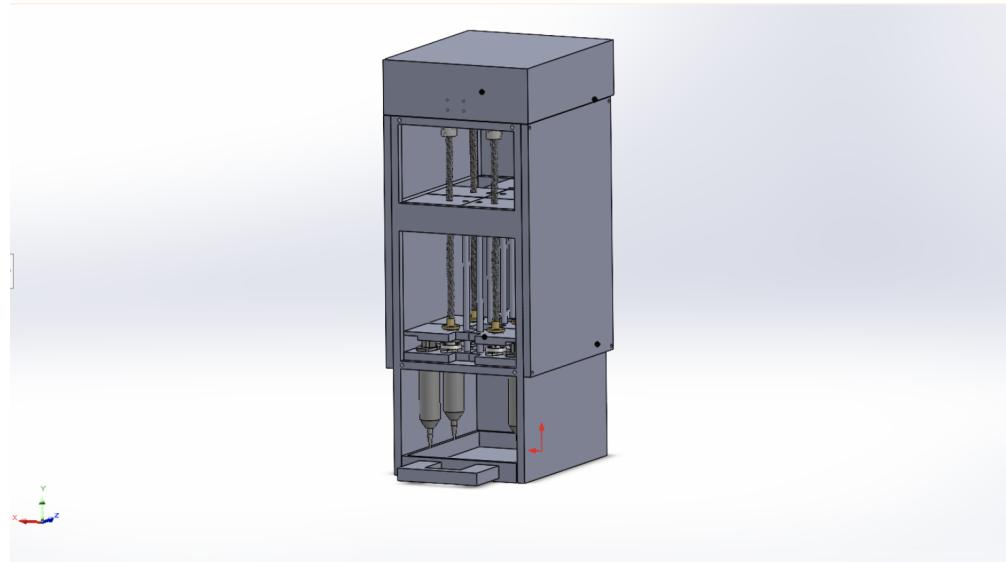
136 3.2 Second Iteration**137 3.2.1 Updated CAD Models****138 Assembly**

Figure 3.5: Second Iteration: Full Assembly

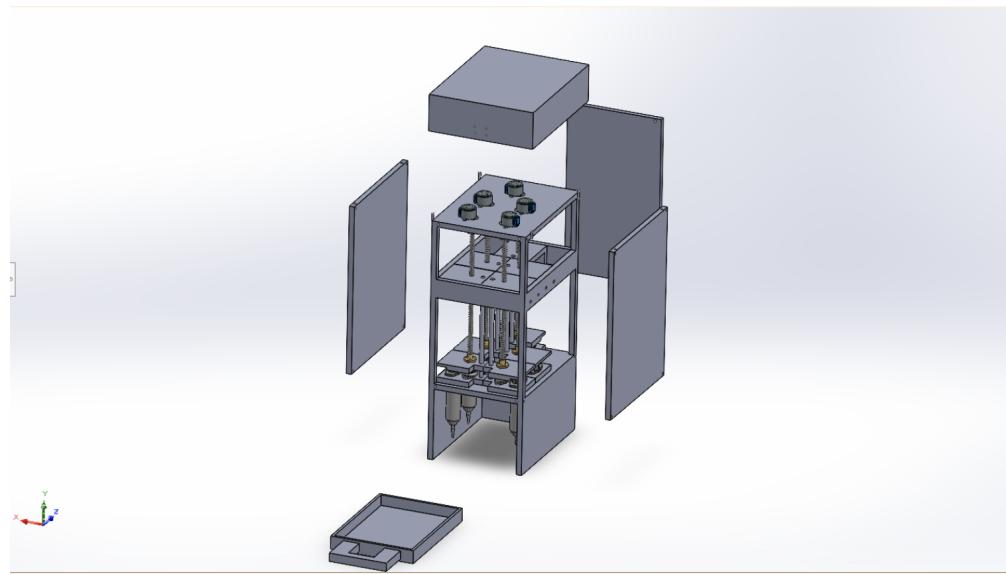


Figure 3.6: Second Iteration: Exploded View

139

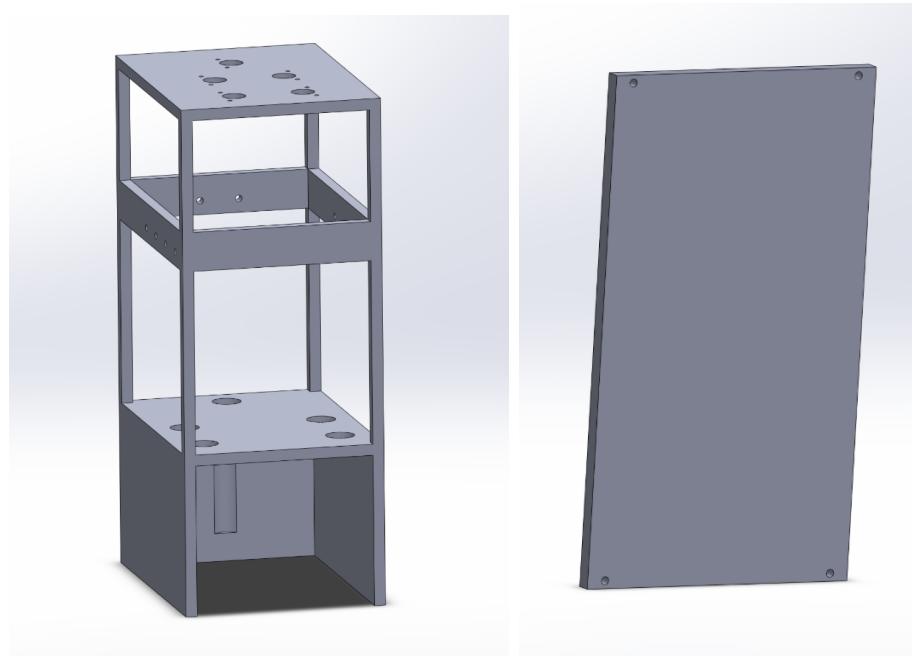
Housing

Figure 3.7: Second Iteration: Housing Skeleton and Walls

140

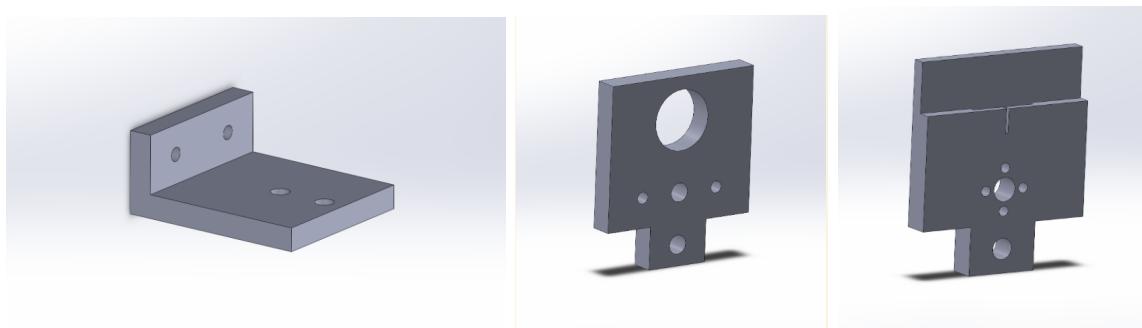
Dispenser

Figure 3.8: Second Iteration: Brackets for Dispenser System

141 3.2.2 Commentary

142

Housing

143

The housing skeleton is what holds the syringes in place while the walls create an enclosure so that the internal structure may be protected and hidden from users. The main concern with this iteration's design was with the housing skeleton's stability. Since we were 3D printing all parts for the demo, the empty spaces could be flimsy, so the final iteration includes a redesign.

148 Dispenser

149 These brackets hold and control the dispenser system. The first L-shaped Bracket holds
150 the guide shaft in place. The other two are for stabilizing and pushing the syringe plunger
151 down. This second iteration is missing one of the parts but it will be shown in the next
152 section, along with final drawings of all parts.

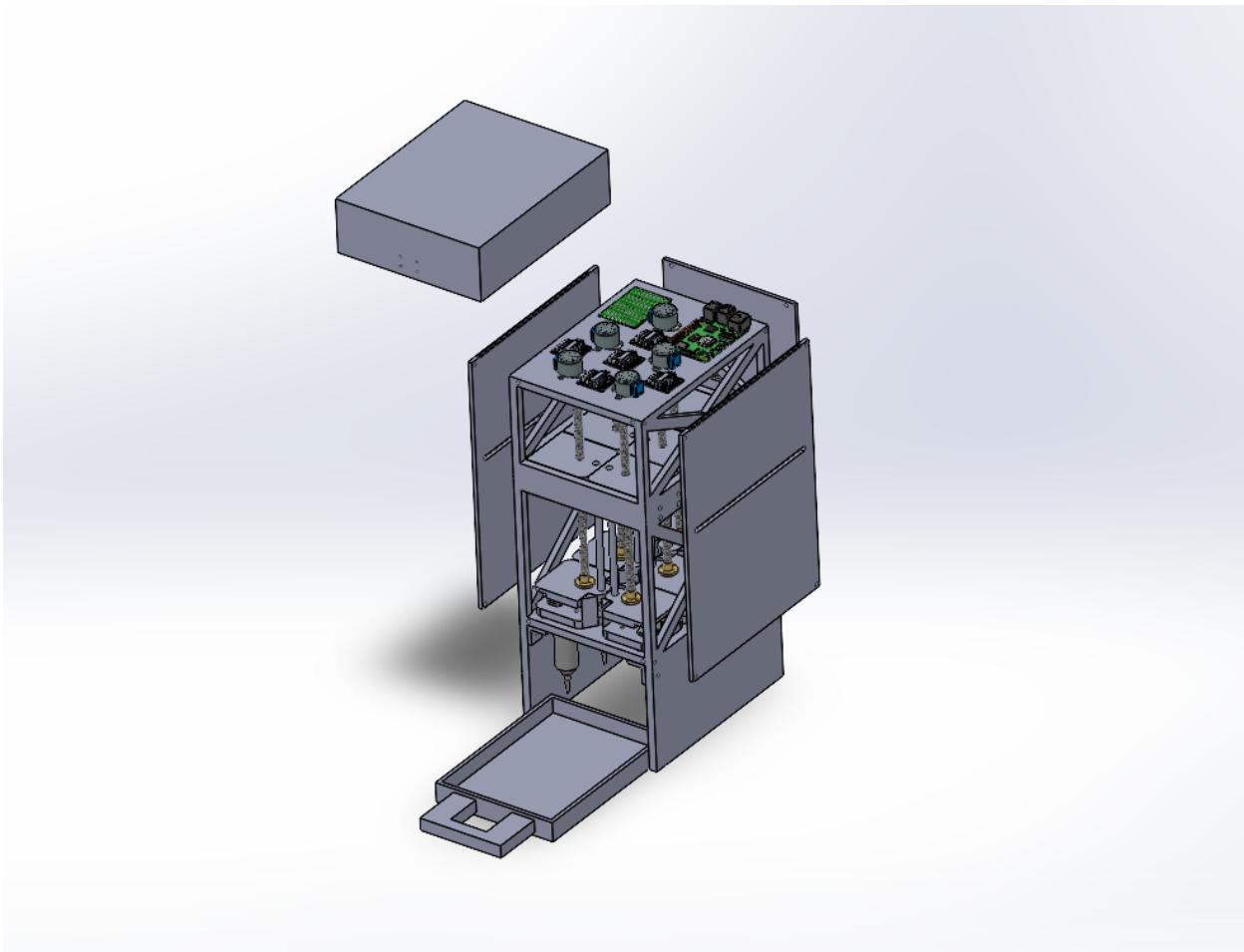
153 3.3 Third Iteration**154 3.3.1 Final CAD Models****155 Assembly**

Figure 3.9: Final: Full Assembly *Exploded*

156

Housing

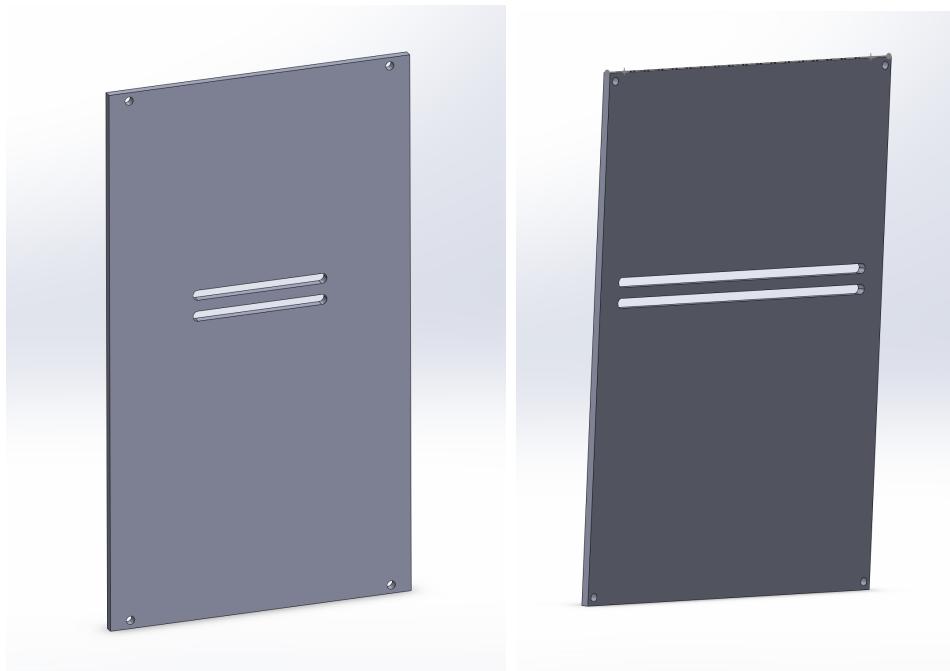


Figure 3.10: Housing: Walls

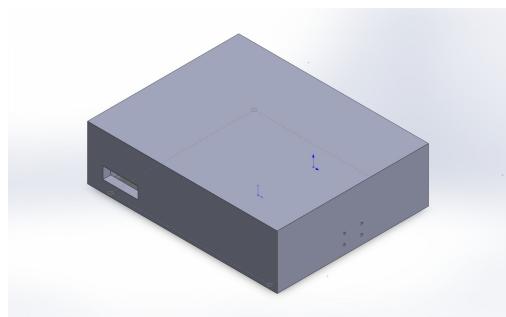


Figure 3.11: Housing: Lid

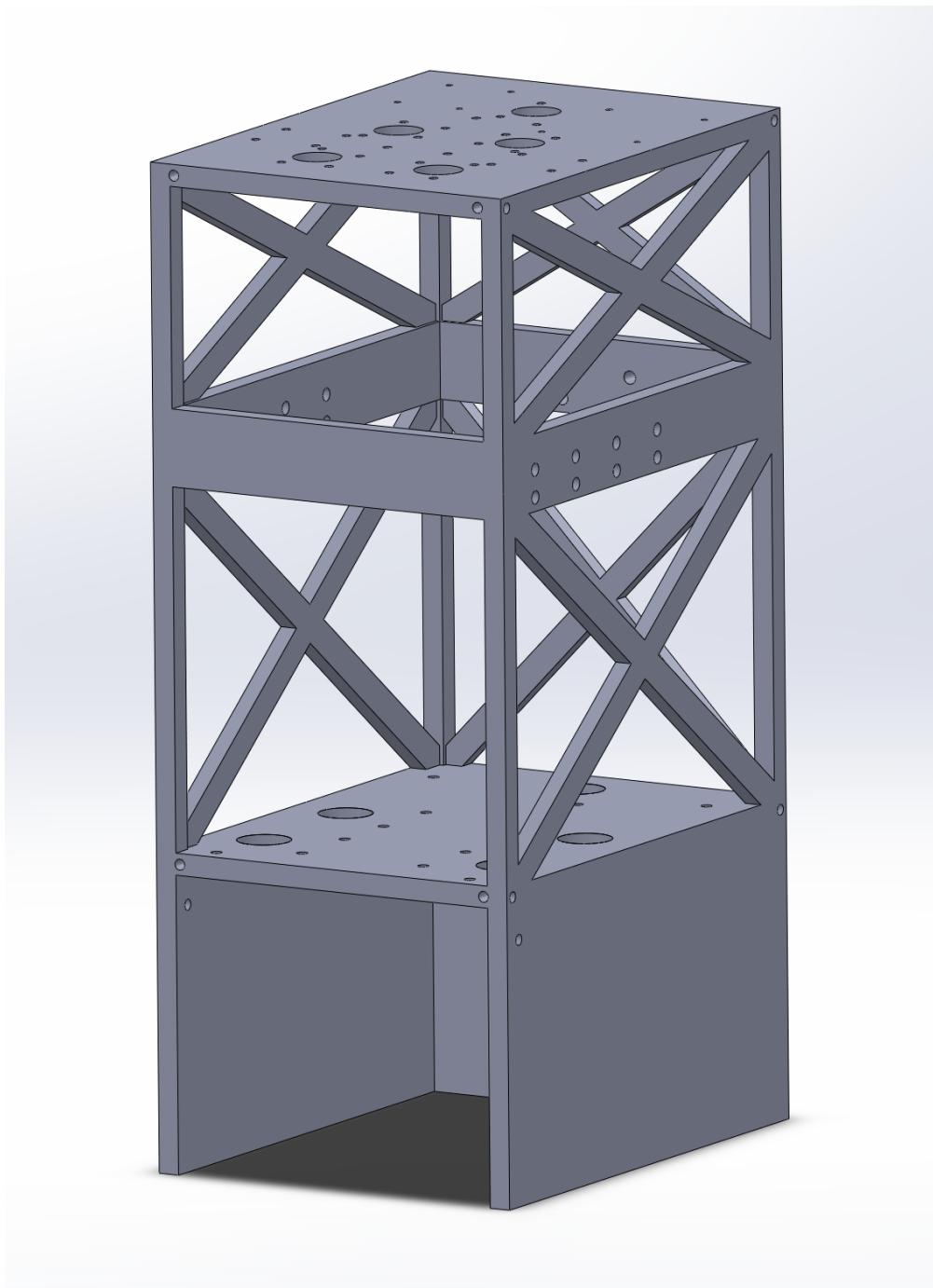


Figure 3.12: Housing: Skeleton

157

Dispenser

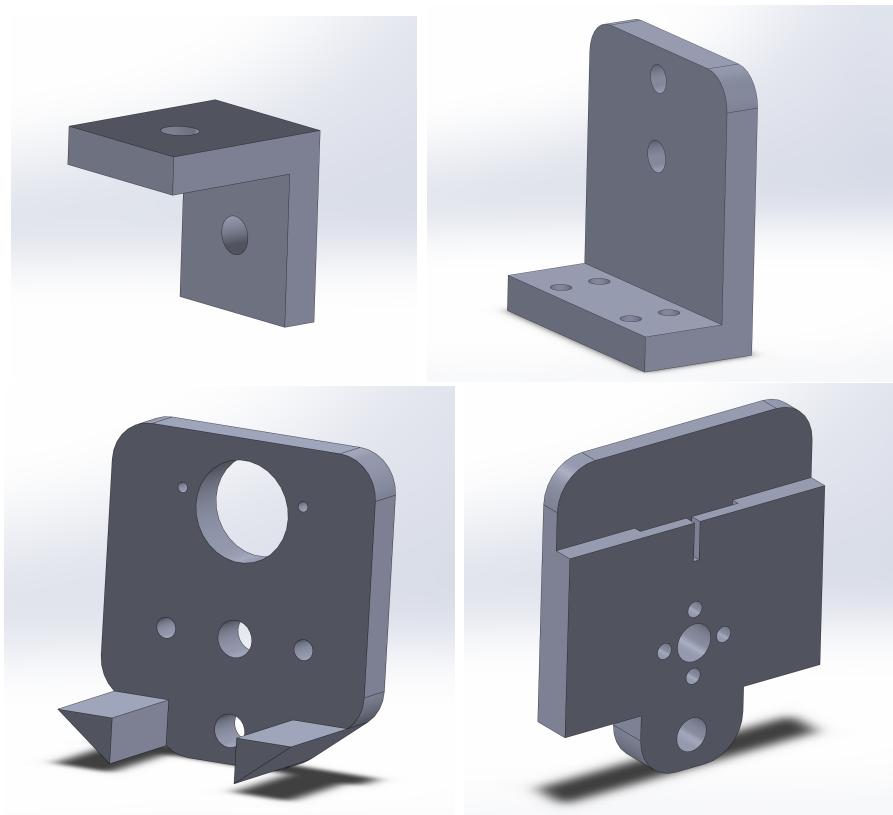


Figure 3.13: Dispenser System : Brackets - for connecting to housing, guide shaft, stabilizing syringe, and pushing down syringe plunger

158 **3.3.2 Final Manufacturing Drawings for Custom Parts**

159 **3.3.3 Commentary**

₁₆₀ Chapter 4

₁₆₁ Software Design

₁₆₂ 4.1 First Iteration

₁₆₃ 4.1.1 Preliminary Diagrams

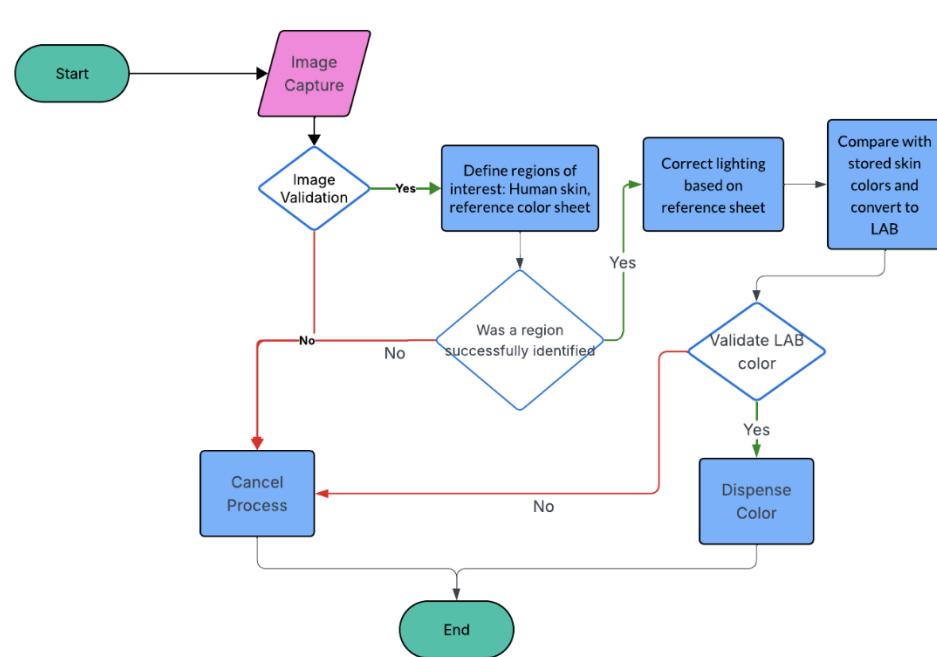


Figure 4.1: Initial Flowchart for Control Logic

```

# 1: Color Bias Adjustment and Sampling
```python
def IMAGE_PROCESSING(SAMPLE_PICTURE) :
 #INPUT: SAMPLE_PICTURE - image captured by camera
 #OUTPUT: LAB_values - color values compatible with paint mixing

 ### Get/Validate image containing skin region
 ### & reference colors/control sheet

 if SAMPLE_PICTURE is EMPTY/NOT_DETECTED :
 RAISE_ERROR "Image captured failed or canceled"
 return NULL

 # initial samples contain gamma-corrected RGB values
 # use OpenCV region of interest rectangle

 SKIN_SAMPLE = list of pixel RGB values that constitute a skin region from SAMPLE_PICTURE
 CONTROL_SAMPLE = list of pixel RGB values that encompass the reference color sheet SAMPLE_PICTURE

 # check whether the reference sheet is present or the image is too dark/light

 if CONTROL_SAMPLE is EMPTY/NOT_DETECTED :
 RAISE_ERROR "Control sheet not detected. Take picture with color reference sheet in a well-lit room."
 return NULL

 # get average gamma-corrected RGB codes for the skin region and control

 SKIN_RGB_AVG = calculate average of SKIN_SAMPLE
 CONTROL_MEASURED_VALUES = list of averages of CONTROL_SAMPLE

 # get linear RGB codes from gamma-corrected RGB codes
 # allows linear operations to be performed on the codes

 SKIN_LINEAR_RGB = apply reverse gamma-correction to SKIN_RGB_AVG
 CONTROL_LINEAR_RGB = list of linearized RGB codes from CONTROL_MEASURED_VALUES

 # find difference in the control input RGB codes and stored RGB codes

 CONTROL_KNOWN_VALUES = load("CONTROL_DATABASE.csv") and linearize the codes
 CONTROL_TRANSFORM = find transformation matrix that makes CONTROL_LINEAR_RGB = CONTROL_KNOWN_VALUES * CONTROL_TRANSFORM

 # apply difference to the values found in the skin region for lighting correction

 XYZ = apply CONTROL_TRANSFORM to SKIN_LINEAR_RGB

 # convert rgb value to lab for later processing

 LAB_VALUES = convert XYZ color space to LAB(XYZ)

 for element in LAB_VALUES :
 if element is OUT_OF_RANGE :
 RAISE_ERROR "color conversion error. take a new picture."
 return NULL

 return LAB_VALUES
```

```

Figure 4.2: Pseudocode: Image Processing Algorithms.

```
# 2: Raspberry Pi Code

```python
def EVENT_HANDLER():
 #extract lab values
 SAMPLE_PICTURE = CAMERA_CAPTURE initiated by BUTTON_PRESS
 LAB_VALUES = IMAGE_PROCESSING(SAMPLE_PICTURE)

 #calculate servo turns for desired recipe
 PAINT_QUANTITIES = assign paint quantities indicating how many
 | | | | | times the servo should turn with TARGET_SHADE

 DEPLOY_TO_RASPBERRY_PI(PAINT_QUANTITIES)
 #servo motors move syringes
```

```

Figure 4.3: Pseudocode: Embedded System.

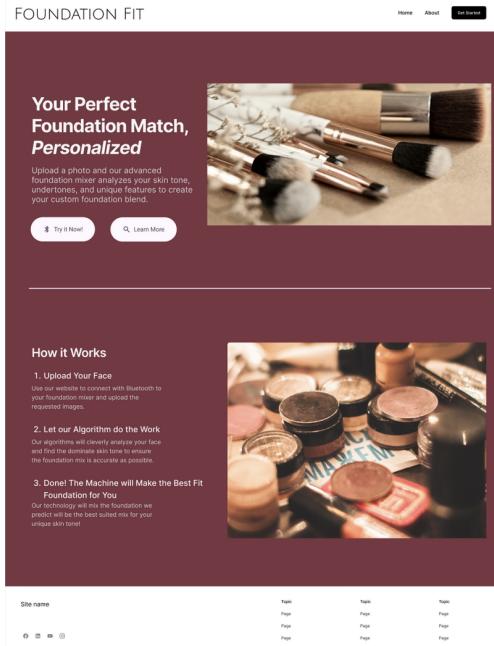


Figure 4.4: Initial Figma Mockup: UI/UX - Landing page.

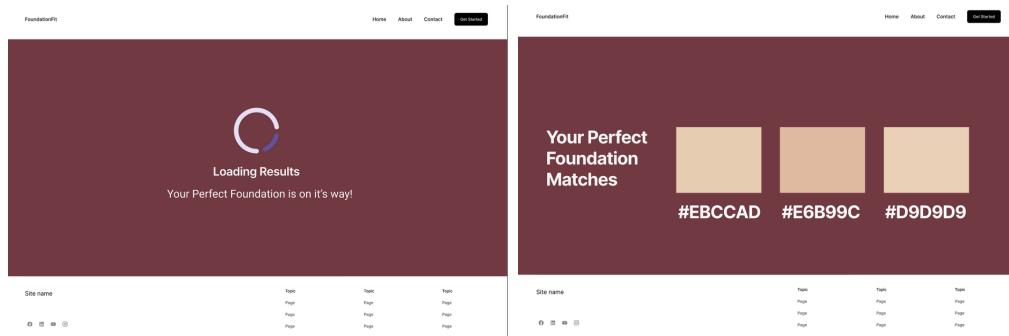


Figure 4.5: Initial Figma Mockup: UI/UX - Loading the foundation shades.

¹⁶⁴ 4.1.2 User Flow Diagram

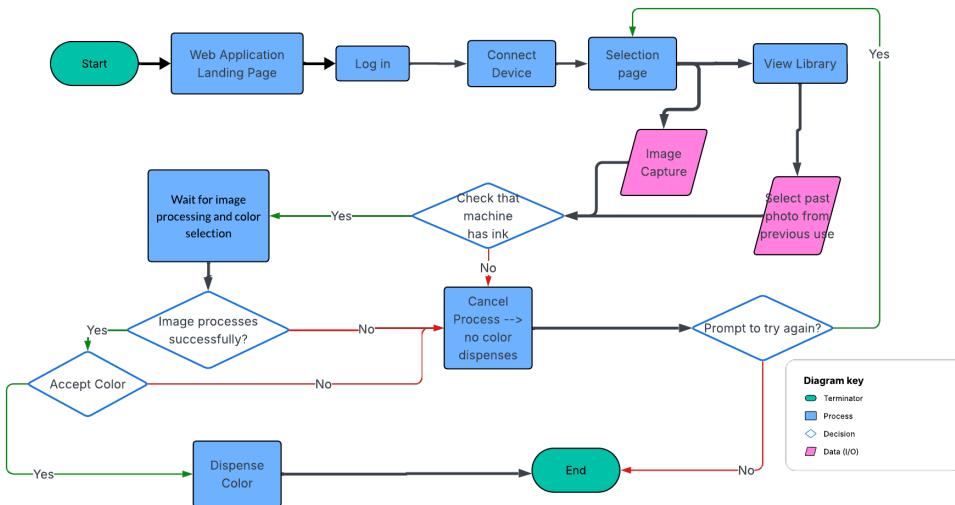


Figure 4.6: User Flow Diagram

¹⁶⁵ 4.1.3 Techstack

¹⁶⁶ Operating systems: Linux on Raspberry Pi

¹⁶⁷ Libraries: OpenCV, NumPy, Pandas

¹⁶⁸ Frameworks: React, Flask

¹⁶⁹ Languages: Python

¹⁷⁰ **4.2 Second Iteration**

¹⁷¹ **4.2.1 Lo-fi/Mid-fi Designs**

¹⁷² **4.2.2 Basic Logic and Functionality**

¹⁷³ **4.2.3 Core Features of Algorithm**

¹⁷⁴ **4.3 Third Iteration**

¹⁷⁵ **4.3.1 Final Product**

¹⁷⁶ Chapter 5

¹⁷⁷ Electrical Systems Design

¹⁷⁸ 5.1 First Iteration

¹⁷⁹ 5.1.1 Initial Wiring Diagrams

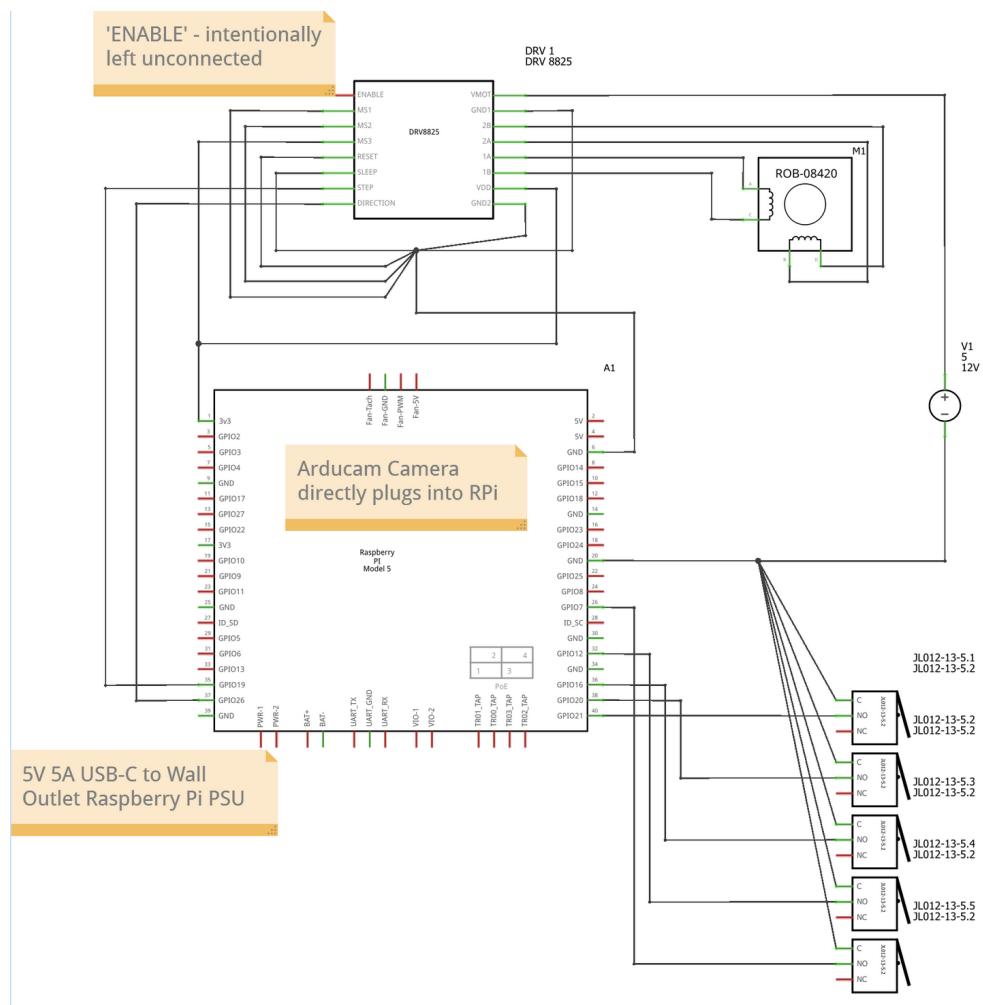


Figure 5.1: Preliminary Wiring Diagram

180 **5.1.2 Initial Power Calculations**

| Parameter | Symbol | Value |
|------------------|--------|-------|
| Phase Current | I | 0.7 |
| Phase Resistance | R | 4.0 |
| Phases | — | 2 |

Table 5.1: Power Calculations

$$P_{motor} = 2 * I^2 * R$$

$$P_{motor} = 2 * (0.7)^2 * 4.0 = 3.92 * 5 = 19.6W$$

$$P_{RaspberryPi} = 10W$$

$$P_{total} = 10 + 19.6 = 30W$$

184 **5.2 Second Iteration**

185 **5.2.1 Circuit Building**

186 **5.3 Third Iteration**

187 **5.3.1 Final Wiring Diagrams**

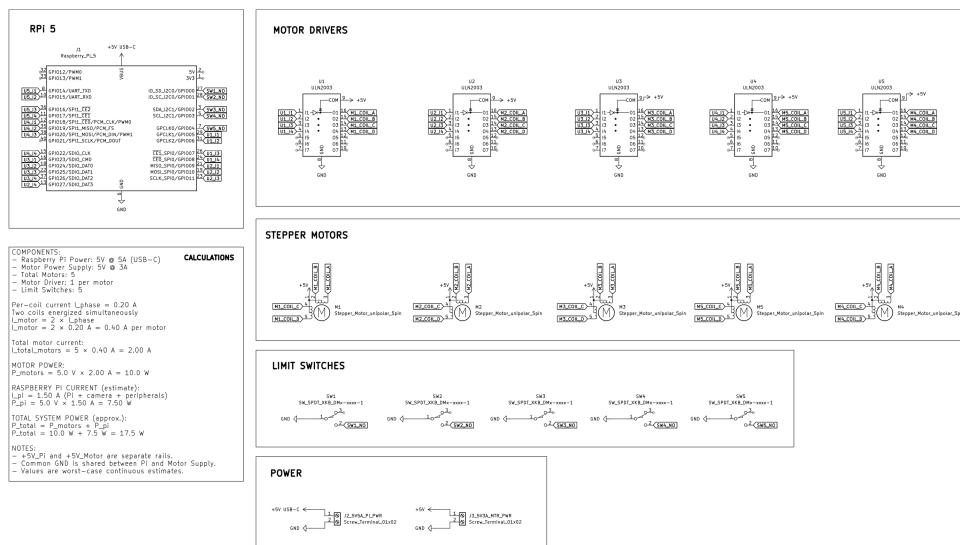


Figure 5.2: Final Wiring Diagrams

¹⁸⁸ 5.3.2 Final Power Calculations

¹⁸⁹ 5.3.3 Circuitry

₁₉₀ Chapter 6

₁₉₁ Final Product

₁₉₂ 6.1 Testing Protocol

₁₉₃ 6.2 Integration

₁₉₄ 6.3 System Performance

₁₉₅ Chapter 7

₁₉₆ Discussion

₁₉₇ 7.1 Limitations

₁₉₈ 7.2 Future Work

¹⁹⁹ **Chapter 8**

²⁰⁰ **Conclusion**

²⁰¹ **8.1 Bill of Materials**

| Component | Purpose | Quantity | Price |
|--|------------------------------|----------|-----------------|
| 2PC T8x8 Lead Screw with Brass Nut | Linear motion conversion | 3 | \$13.99 |
| 5-8mm Lead Screw Coupler 5 pack | Connect motor to screw | 3 | \$8.69 |
| 8x200mm Shaft Guide | Linear guidance | 3 | \$8.69 |
| 8mm Flange Mounted Pillow Block Bearing | Support rotating shaft | 3 | \$8.99 |
| Raspberry Pi 5 (4GB RAM) | Primary controller | 1 | \$66.00 |
| Plastic 30mL Syringes (Pack of 5) | Fluid handling prototype | 1 | \$6.99 |
| Raspberry Pi 5 Power Supply | Power for controller | 1 | \$15.99 |
| Assorted Metric Fasteners (M2–M5) | Mechanical assembly | 1 | \$20.00 |
| Limit Switch (10 pack) | Motion limit detection | 1 | \$5.99 |
| Arducam V3 Camera | Vision and monitoring | 1 | \$25.00 |
| Wiring Kit | Electrical connections | 1 | \$5.00 |
| Breadboard / Perfboard | Circuit prototyping | 1 | \$10.00 |
| 5V 3A DC Power Supply | General power source | 1 | \$7.47 |
| 5 Sets 28BYJ-48 Stepper + ULN2003 Driver | Secondary actuation system | 5 | \$14.99 |
| 1.75mm ABS Filament Reel (Black) | Structural printing material | 1 | \$16.99 |
| Total Estimated Cost | | | \$346.49 |

Table 8.1: Key Hardware Elements.

202 References

²⁰³ Bibliography

²⁰⁴ [1] Sophie Smith. Billions of beauty packaging goes unrecycled every year – theindustry.beauty. 2024. Accessed 2024.
²⁰⁵