

# Theta Beta Engineer Project Report

Foundation Color Identifier and Dispenser  
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<sup>75</sup> **Chapter 1**

<sup>76</sup> **Abstract**

<sup>77</sup> The Foundation Identifier and Dispenser aims to develop a machine that is able to extract  
<sup>78</sup> samples from a picture of a human to determine the shade of their skin, allowing the machine  
<sup>79</sup> to dispense a corresponding foundation shade. The results produced should be both accurate  
<sup>80</sup> and reproducible. Equipped with computer vision libraries and color correction algorithms,  
<sup>81</sup> the system allows the user to take an picture alongside a reference color sheet, which has  
<sup>82</sup> colors of known values. These captured values are processed to correct both camera bias,  
<sup>83</sup> and lighting correction so that results may remain consistent regardless of lighting conditions  
<sup>84</sup> during image capture. The system converts RGB values to LAB values, which are higher in  
<sup>85</sup> accuracy in physical color mixing, as opposed to RGB, which is used to describe pixel colors.  
<sup>86</sup> The program calculates how much of each color is needed to recreate the user's skin pigment.  
<sup>87</sup> These pigments are then dispensed via a mechanical system comprised of a Raspberry Pi,  
<sup>88</sup> servo motors, and syringes. This project demonstrates an application of computer vision in  
<sup>89</sup> the cosmetic market to alleviate the burden of overconsumption and promote inclusivity.

<sub>90</sub> **Chapter 2**

<sub>91</sub> **Introduction**

<sub>92</sub> **2.1 Research**

<sub>93</sub> **2.1.1 Background of Problem**

<sub>94</sub> Testing foundation colors can be a frustrating experience for many, who are unable to  
<sub>95</sub> find the perfect balance. At the end of the day, no line of foundation can realistically provide  
<sub>96</sub> colors that cater to every possible skin tone. The seemingly unresolvable desire for a perfect  
<sub>97</sub> shade leads many makeup users to spend hundreds on shades that are "close enough." This  
<sub>98</sub> leads to lots of waste, not just in money, but in bottles thrown out after purchase because  
<sub>99</sub> the match was ultimately unsatisfying.

<sub>100</sub> 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.

<sub>107</sub> 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.

<sub>111</sub> **2.1.2 Existing Solutions**

<sub>112</sub> 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.

<sub>117</sub> 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

<sub>119</sub> is what will allow the machine to recalibrate it's understanding of what colors are being  
<sub>120</sub> percieve.

## <sub>121</sub> 2.2 Design Choices

### <sub>122</sub> 2.2.1 Past Considerations and Scrapped Plans



## <sup>123</sup> Chapter 3

# <sup>124</sup> Hardware Design and Specifications

### <sup>125</sup> 3.1 First Iteration

#### <sup>126</sup> 3.1.1 Initial CAD Model and Hand Sketches

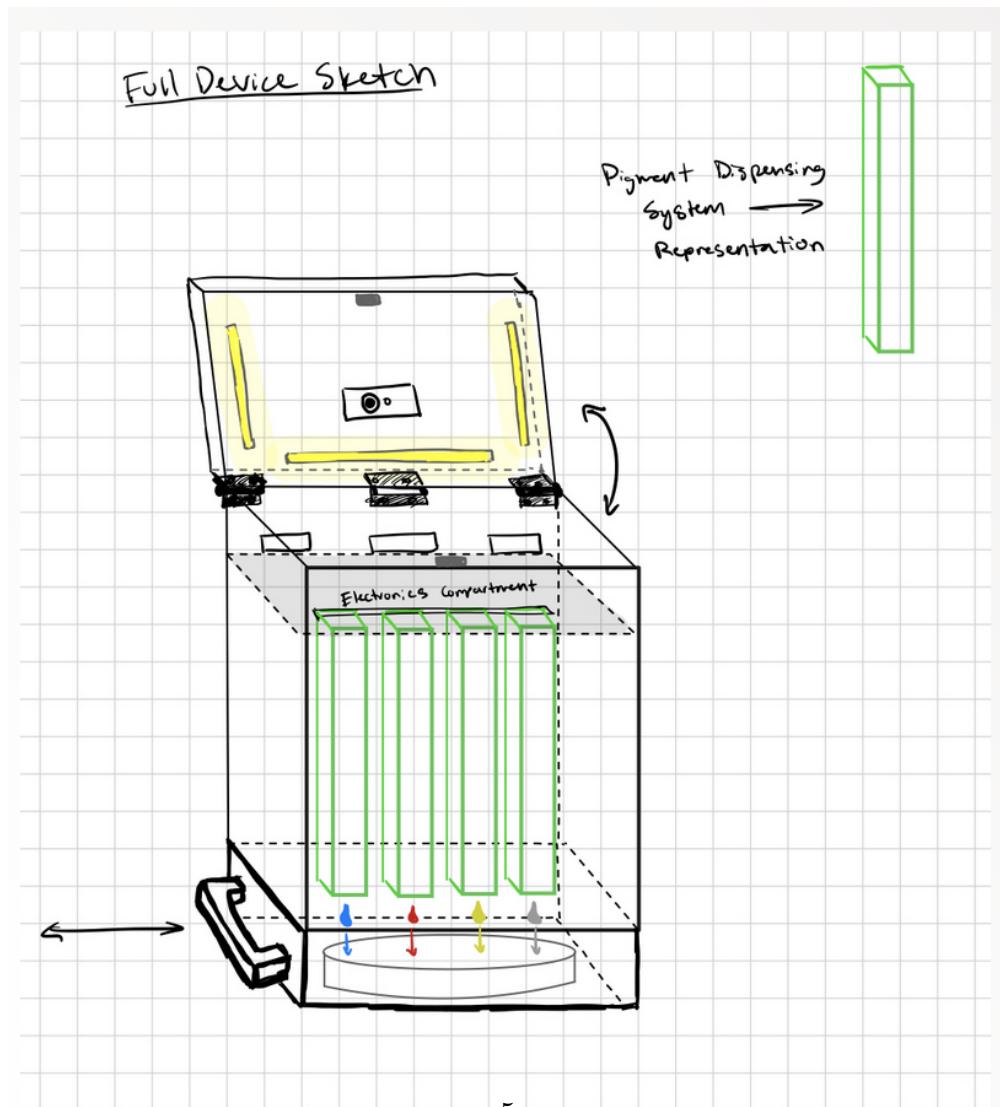


Figure 3.1: First Sketch: Housing

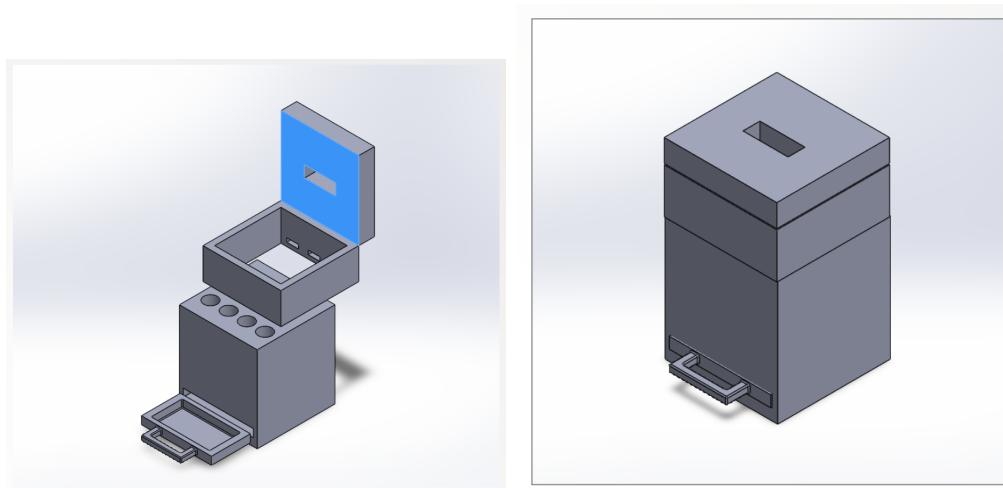


Figure 3.2: First CAD Models: Housing

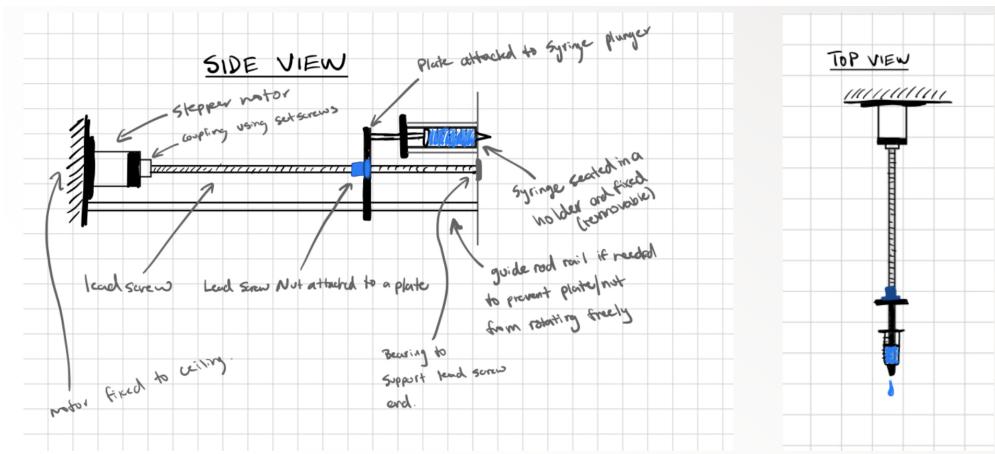


Figure 3.3: First Sketch: Dispenser Systems



Figure 3.4: First CAD Models: Dispenser Systems

<sup>127</sup> Our first CAD Models were very simple and provide the most general idea we had at  
<sup>128</sup> our projects conception. We made large changes to the design of the housing because the  
<sup>129</sup> dimensions would have been much wider if we lined the syringes up, as shown in Figures 3.1  
<sup>130</sup> and 3.2.

<sup>131</sup> The preliminary sketch we have of the dispenser system has stayed consistent throughout  
<sup>132</sup> development.

---

<sup>133</sup> **3.2 Second Iteration**

<sup>134</sup> **3.2.1 Updated CAD Models**

<sup>135</sup> *Assembly*

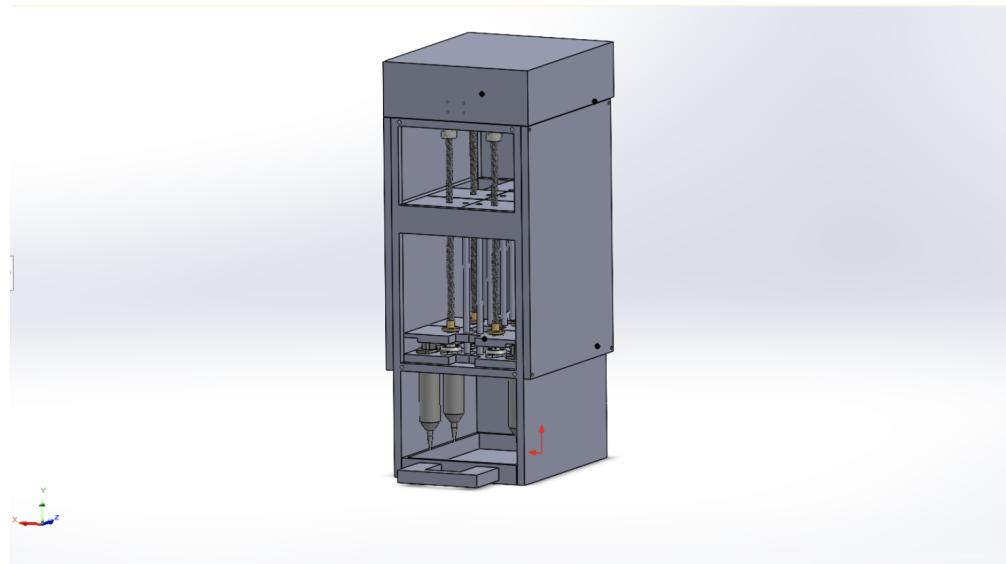


Figure 3.5: Second Iteration: Full Assembly

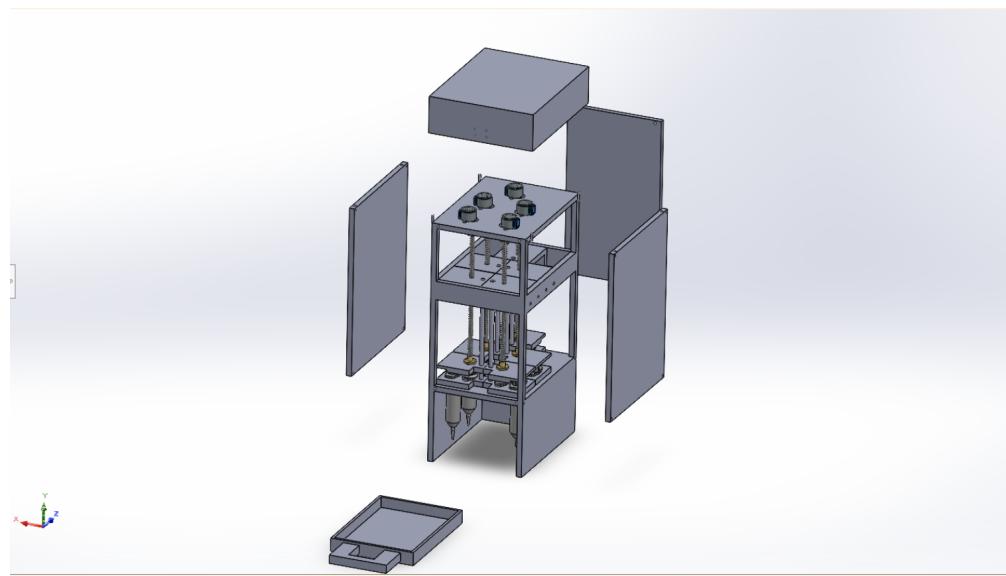


Figure 3.6: Second Iteration: Exploded View

136

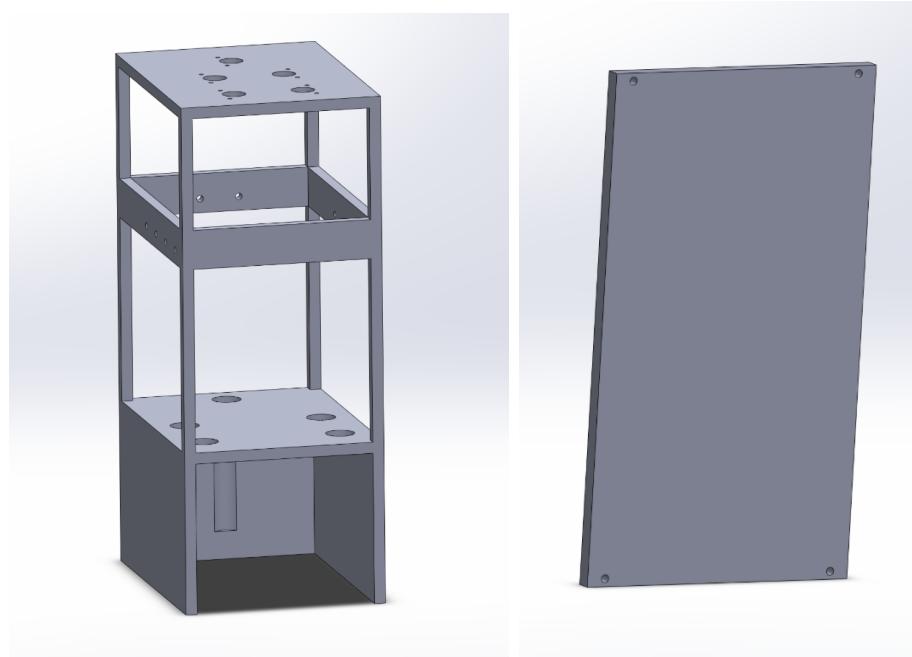
**Housing**

Figure 3.7: Second Iteration: Housing Skeleton and Walls

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

142 **Dispenser**

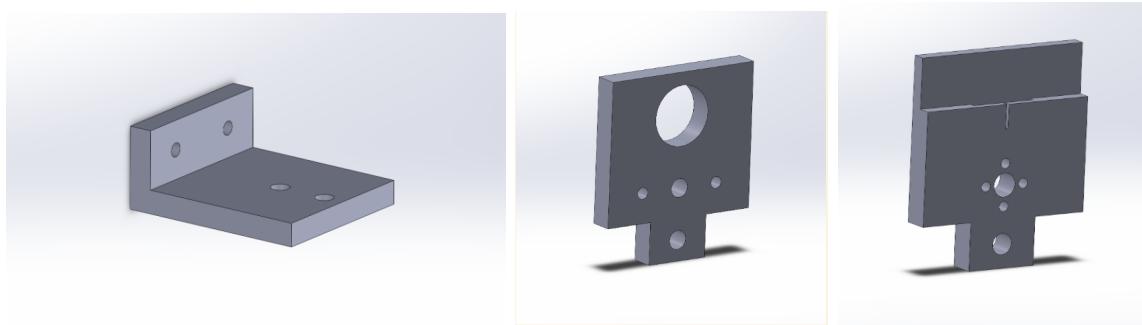


Figure 3.8: Second Iteration: Brackets for Dispenser System

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

<sup>147</sup> **3.3 Third Iteration**

<sup>148</sup> **3.3.1 Final CAD Models**

<sup>149</sup> *Assembly*

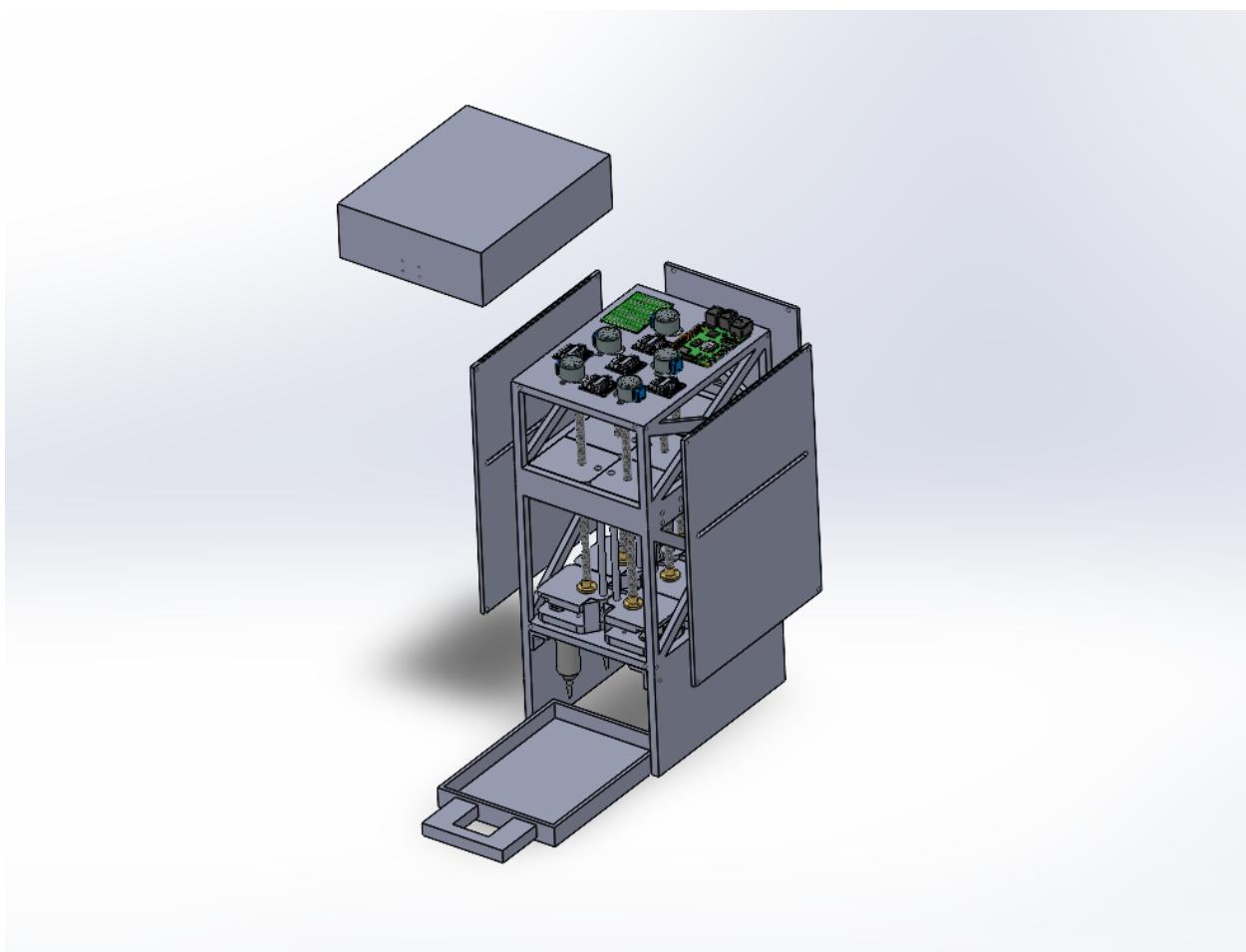


Figure 3.9: Final: Full Assembly *Exploded*

150

### **Housing**

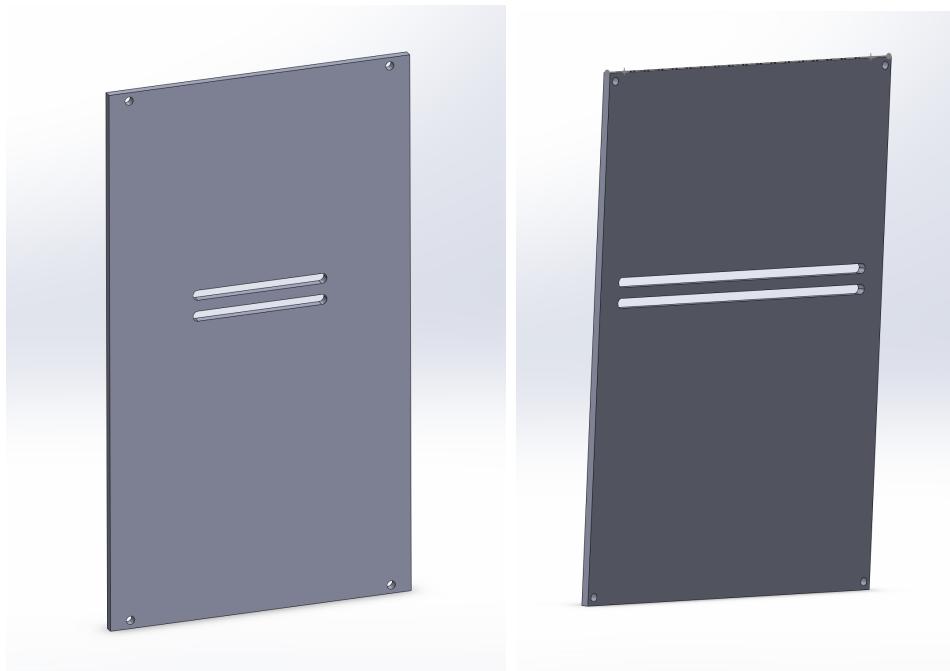


Figure 3.10: Housing: Walls

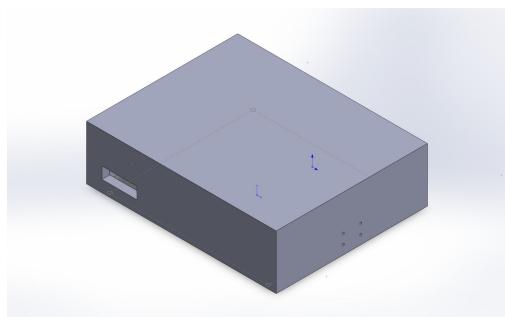


Figure 3.11: Housing: Lid

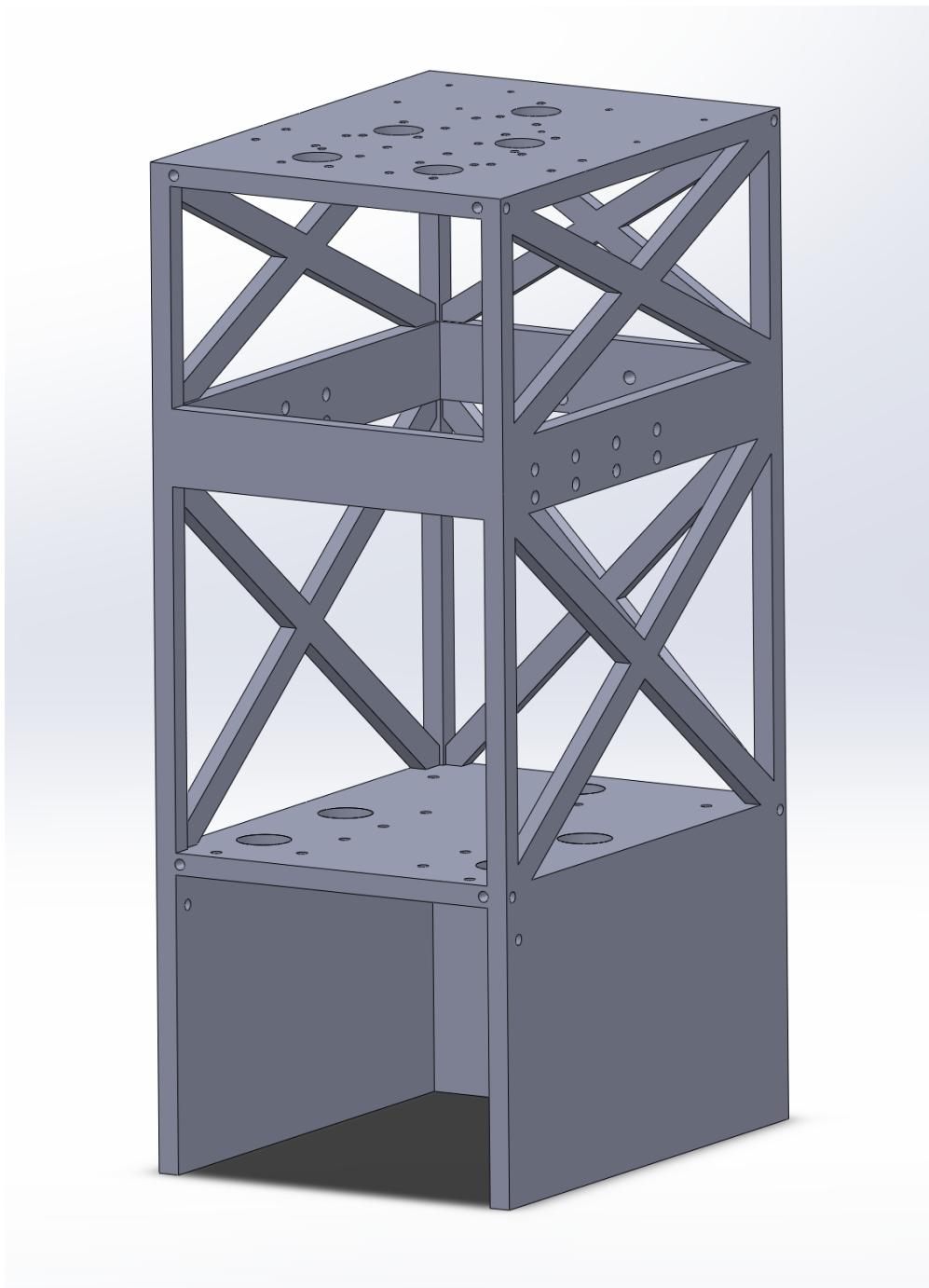


Figure 3.12: Housing: Skeleton

<sup>151</sup> The Housing walls were altered to include a slit because there are some screws in the  
<sup>152</sup> skeleton of the product that would press up against the walls if we kept the second iteration's  
<sup>153</sup> design. The slit was created to give the screws space and ensure that the components inside  
<sup>154</sup> are not putting pressure on each other.

155

***Dispenser***

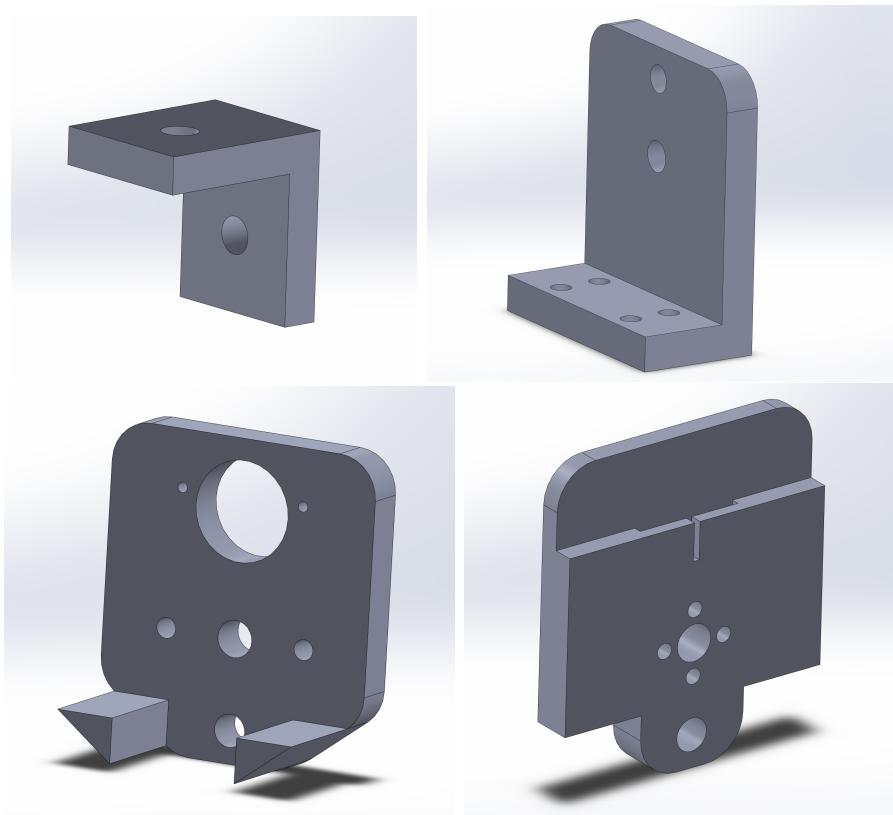


Figure 3.13: Dispenser System : Brackets - for connecting to housing, guide shaft, stabilizing syringe, and pushing down syringe plunger

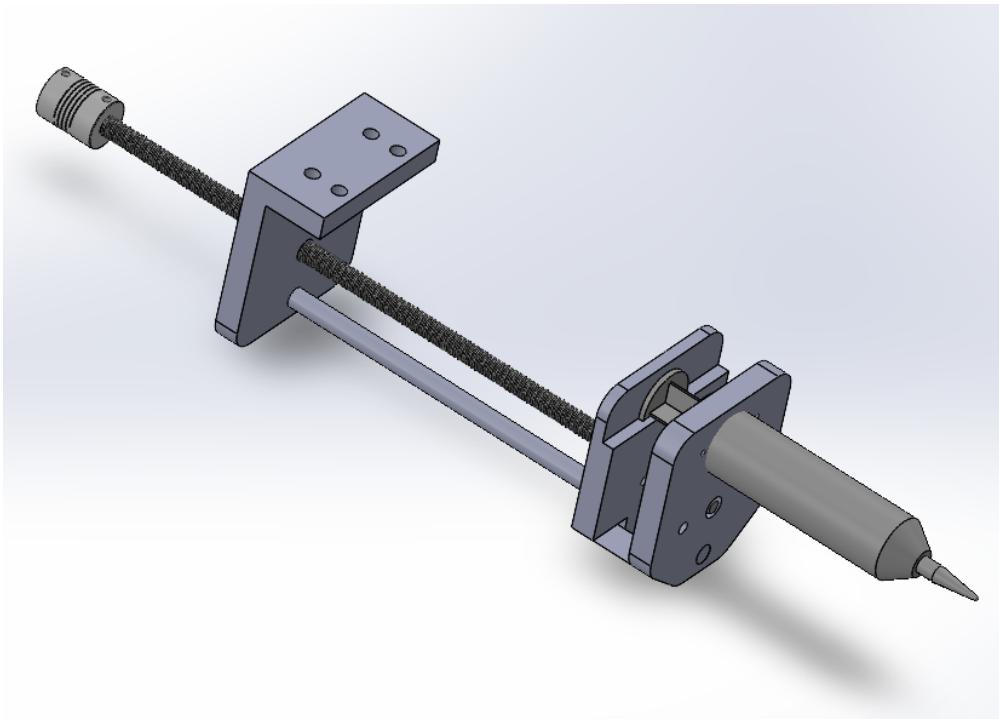


Figure 3.14: Dispenser System : Full assembly

156      The final iteration finalizes all brackets needed for the dispenser system, and includes a  
157      complete view of all the parts put together. We have included a L-bracket that connects the  
158      dispenser to the casing, an L bracket that holds the guide rod, a syringe bracket to stabilize  
159      and hold the syringe in place, and finally, the plate that holds the plunger, and moves with  
160      the screw to push the plunger down.

161    **3.3.2 Final Manufacturing Drawings for Custom Parts**

<sub>162</sub> Chapter 4

<sub>163</sub> Software Design

<sub>164</sub> 4.1 First Iteration

<sub>165</sub> 4.1.1 Preliminary Diagrams

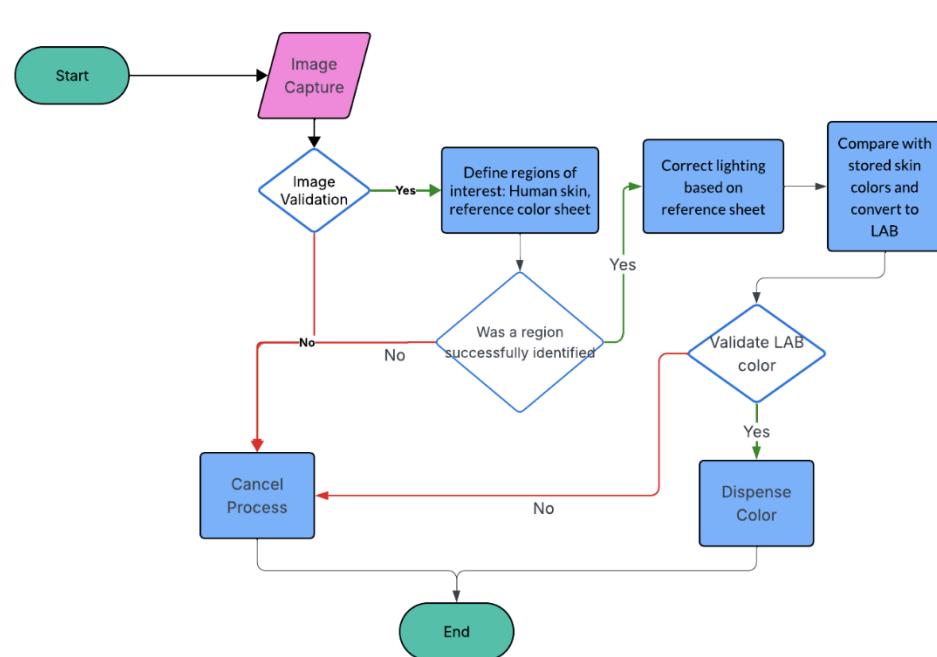


Figure 4.1: Initial Flowchart for Control Logic

<sup>166</sup> **4.1.2 User Flow Diagram**

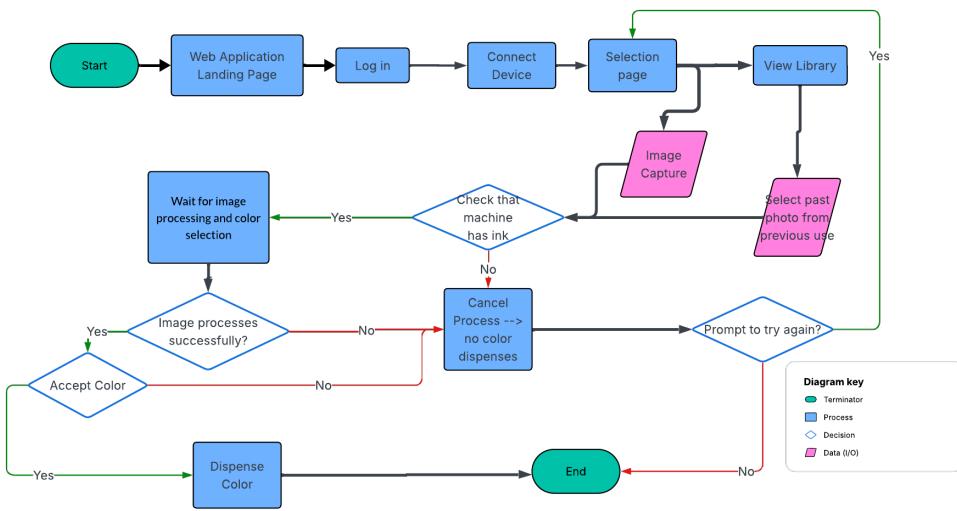


Figure 4.2: User Flow Diagram

<sup>167</sup> **4.1.3 Techstack**

- <sup>168</sup> Operating systems: Linux on Raspberry Pi
- <sup>169</sup> Libraries: OpenCV, NumPy, Pandas, Haar Cascade Classifier
- <sup>170</sup> Frameworks: React
- <sup>171</sup> Languages: Python

## 172 4.2 Second Iteration

### 173 4.2.1 Lo-fi/Mid-fi Designs

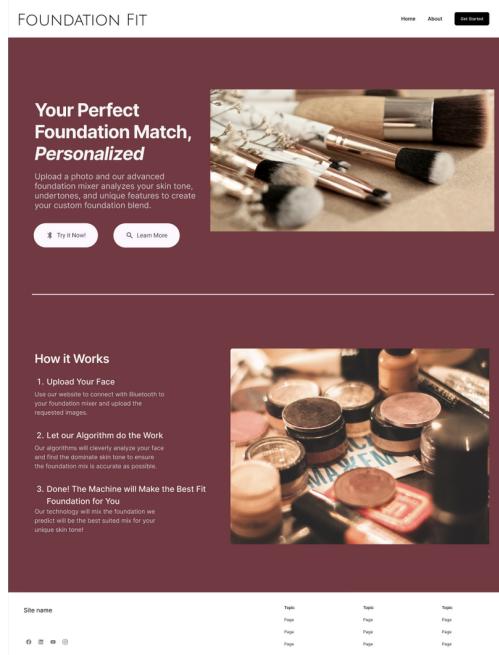


Figure 4.3: Initial Figma Mockup: UI/UX - Landing page.

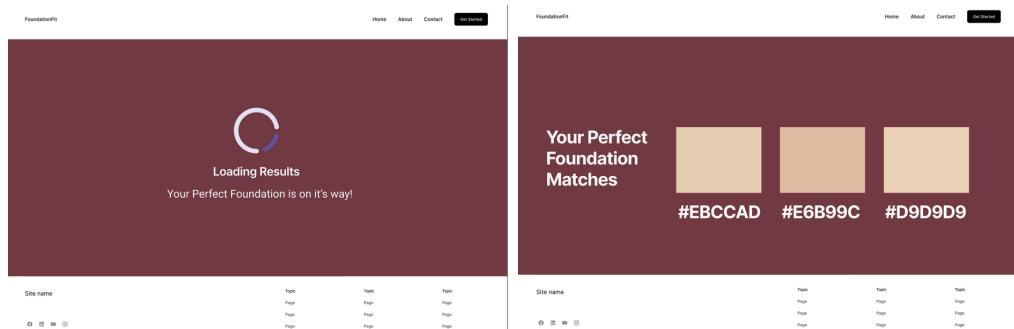


Figure 4.4: Initial Figma Mockup: UI/UX - Loading the foundation shades.

<sup>174</sup> 4.2.2 Basic Logic and Functionality

```

# 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 4.5: 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 4.6: Pseudocode: Embedded System.

<sub>175</sub> 4.2.3 Core Features of Algorithm

<sub>176</sub> 4.3 Third Iteration

<sub>177</sub> 4.3.1 Final Product



178

# Chapter 5

179

## Electrical Systems Design

180

### 5.1 First Iteration

181

#### 5.1.1 Initial Wiring Diagrams

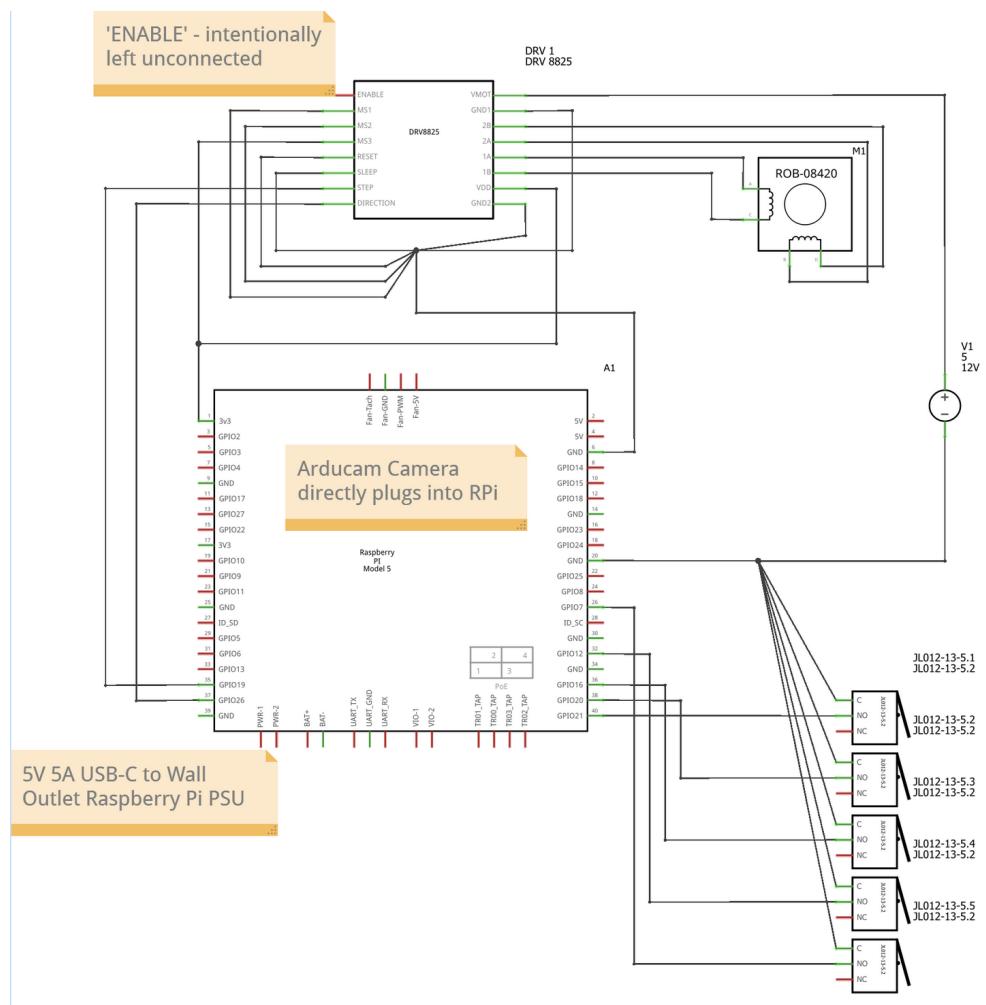


Figure 5.1: Preliminary Wiring Diagram

### 182 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

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

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

$$P_{RaspberryPi} = 10W$$

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

## 186 5.2 Second Iteration

### 187 5.2.1 Circuit Building

## 188 5.3 Third Iteration

### 189 5.3.1 Final Wiring Diagrams

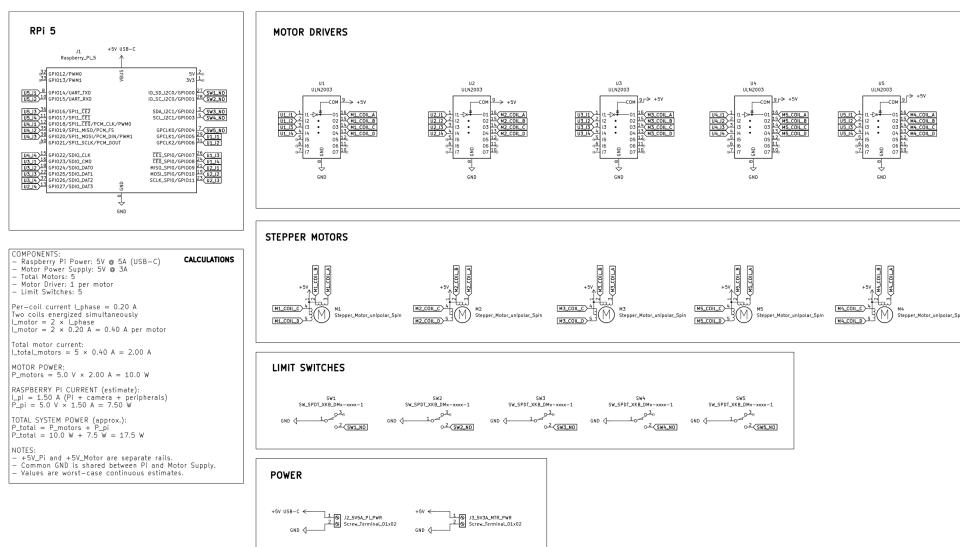


Figure 5.2: Final Wiring Diagrams

<sup>190</sup> **5.3.2 Final Power Calculations**

<sup>191</sup> **5.3.3 Circuitry**

<sup>192</sup> Chapter 6

<sup>193</sup> Final Product

<sup>194</sup> 6.1 Testing Protocol

<sup>195</sup> 6.2 Integration

<sup>196</sup> 6.3 System Performance

<sub>197</sub> Chapter 7

<sub>198</sub> Discussion

<sub>199</sub> 7.1 Limitations

<sub>200</sub> 7.2 Future Work

201 **Chapter 8**

202 **Conclusion**

203 **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         |
| <b>Total Estimated Cost</b>              |                              |          | <b>\$346.49</b> |

Table 8.1: Key Hardware Elements.

<sup>204</sup> References

## <sup>205</sup> Bibliography

<sup>206</sup> [1] Sophie Smith. Billions of beauty packaging goes unrecycled every year – theindustry.beauty. 2024. Accessed 2024.  
<sup>207</sup>