COLOR DETECTING AUTOMATIC PAINT DISPENSER

ECE 445 DESIGN DOCUMENT - FALL 2024

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1 Introduction

1.1 Problem:

Whenever a painter starts a new project they always begin by mixing their desired colors on their palette using some combination of cyan, magenta, yellow, and black. However, the painter will inevitably run out of paint, and then will need to mix the exact color that they had before. This part of the process is very frustrating and time consuming, especially for artists that are bad at mixing colors. Instead of learning color theory or buying the direct color from the tube, we will save time and money by designing a machine that can determine the pigments required to mix any color using a formulaic approach supplied with data from RGB sensors, the device will also automatically mix the color using a combination of base primary colors following the CMYK color palette.

1.2 Solution:

The user of the device will "scan" the desired color by using a color sensor that detects the RGB values of a surface using red, green, blue and 'clear' photodiodes. The device will send the RGB values of the color to the onboard mcu which will do some simple calculations to convert the RGB value of the color to CMYK format using conversion formulas. This is the same principle behind color printers which create color images by mixing cyan, magenta, yellow, and black. The MCU will then communicate with 5 motor drivers, each connected to a stepper motor hooked up to a peristaltic pump. These will dispense the appropriate amount of white, cyan, magenta, yellow and black paint into a cup. The components will be powered by a 24 volt power supply with a voltage regulator and the final result should be a paint cup with the color that was scanned before. Ideally the person using this tool never needs to actually do any dispensing/experimenting, they can just scan a color and apply it directly on the canvas/work surface.

We would use fluid acrylics in our design, because this type of paint is easy to work with and also easy to pump. The peristaltic pumps work by pumping a fluid from one reservoir through a silicon tube to another location. When pumping, the most important detail is the proportion of paint pumped as that will lead to the correct color. We plan to experiment with the pumps initially and calculate the stepper motor time for the amount of paint pumped. We would then use the ratio we calculate in the microcontroller to get the adequate amount of time each specific motor needs to be turned on for each motor. The way a peristaltic pump works is that there is a roller that pinches a tube with the paint so it can dispense the paint. When the rotation stops, there is no drip or paint loss since the roller is still pinching the tube. In addition, the roller will dispense a fixed volume of paint each rotation.

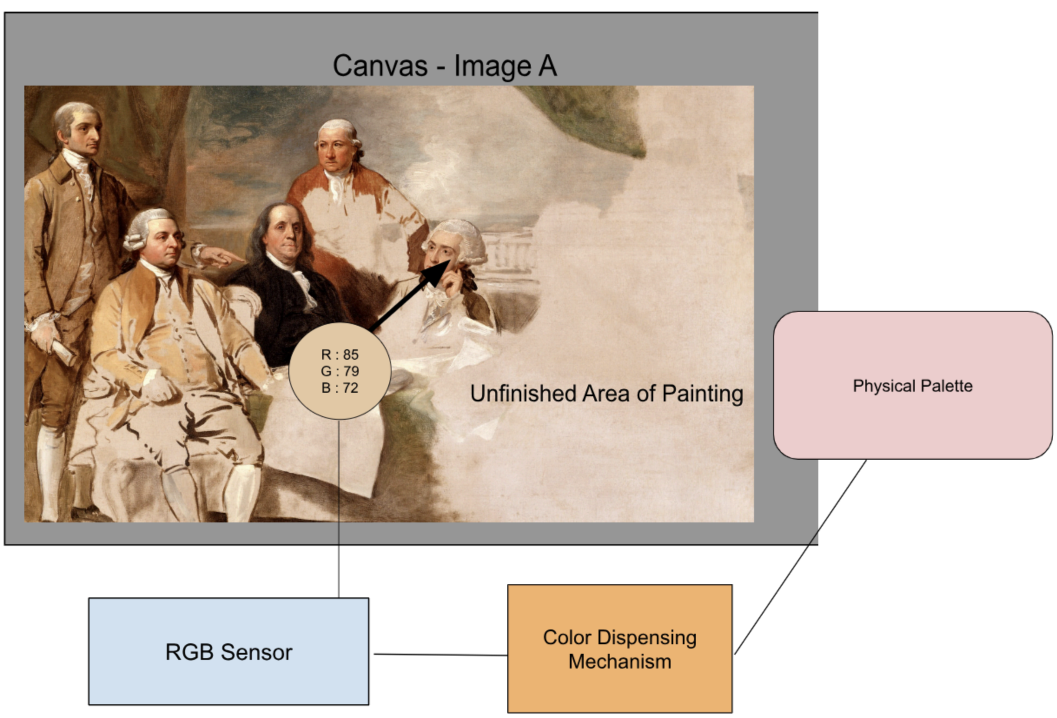
There are 6 formulas used to convert RGB to CMYK (the model used in printers. Really these values are just proportions, suppose C is 0.5 and we want 100mL of white paint in the mixture, the amount of Cyan paint needed is 100mL of White * 0.5 = 50mL. We run the motor for x amount of time at some specific settings and see how much x mL of liquid gets dispensed. If the process ends up being too difficult with our acrylics then we will switch to a paint that is more watery.

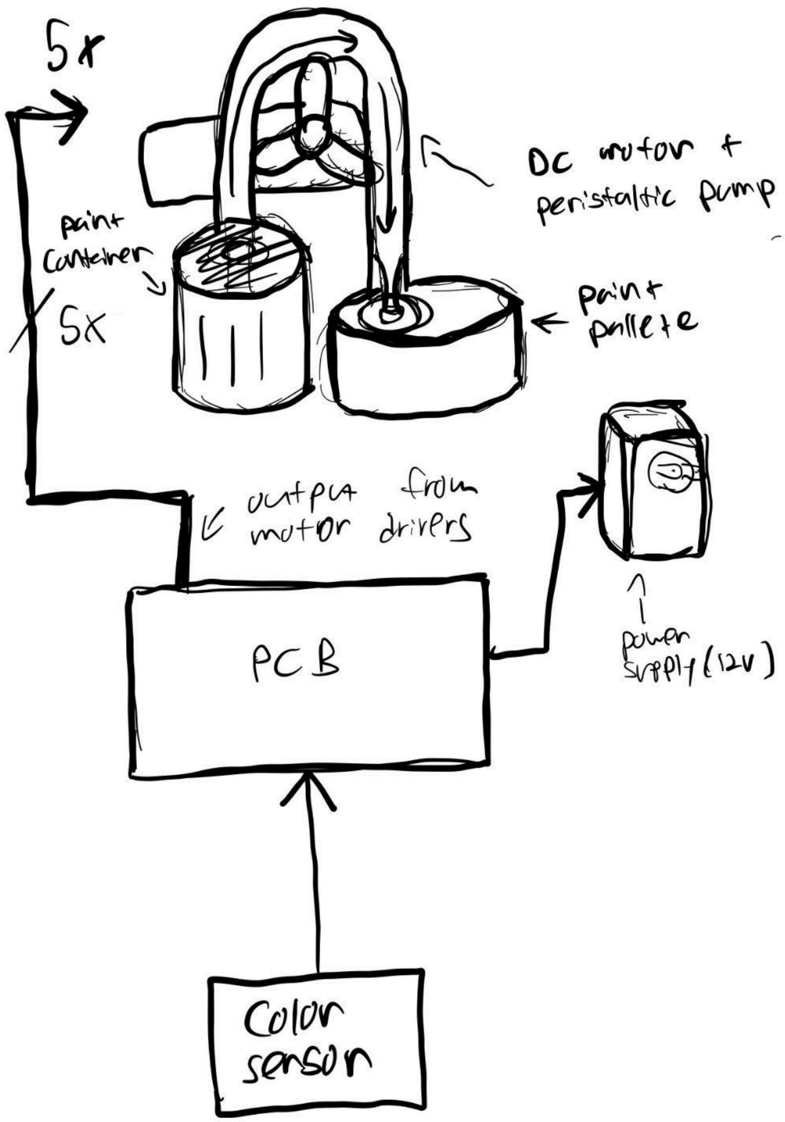
- $R' = R/255$
- $G' = G/255$
- $B' = B/255$

- ❖ K = 1-max(R', G', B')
- ❖ C = (1-R'-K) / (1-K)
- ❖ M = (1-G'-K) / (1-K)
- ❖ Y = (1-B'-K) / (1-K)

1.3 Visual Aid:

An additional graphic is provided below to further demonstrate the problem that we are trying to solve with our machine. Suppose an famous artist had access to our device - then the amount of time they would spend mixing paint would decrease, and as a result the number of paintings that artist can produce in a lifetime would go up - resulting in less abandoned artworks. The massive painting , “Treaty of Paris” depicted below, which was one of Benjamin West’s abandoned works. West’s easel was likely much smaller than the actual canvas, we can realistically assume that he must have spent hours mixing the paint required to produce this massive artwork, our device attempts to fix this problem.




5x
DC motor +
peristaltic pump
paint
container
5x
paint
pallete
output from
motor drivers
PCB
power
supply (12V)
Color
sensor

1.4 High Level Requirements:

Our first high level requirement is the color sensor accuracy, so how well it can detect the color that is provided. This is necessary to evaluate in order to ensure that the color detection is right so that we can dispense the desired color that was inputted. Our color sensor must be able to capture the precise RGB values of the inputted color for the overall project to work correctly.

- The color sensor must have an accuracy of ±5% when detecting the RGB values of a surface. This means that when comparing the detected RGB values to a reference color, the deviation in each of the RGB values (R, G, and B) should not exceed 5% of the original input value. For example, if the sensor detects a color with RGB values (200, 150, 100), the acceptable margin of error would be within 5%, resulting in values between (190-210), (143-158), and (95-105) respectively.

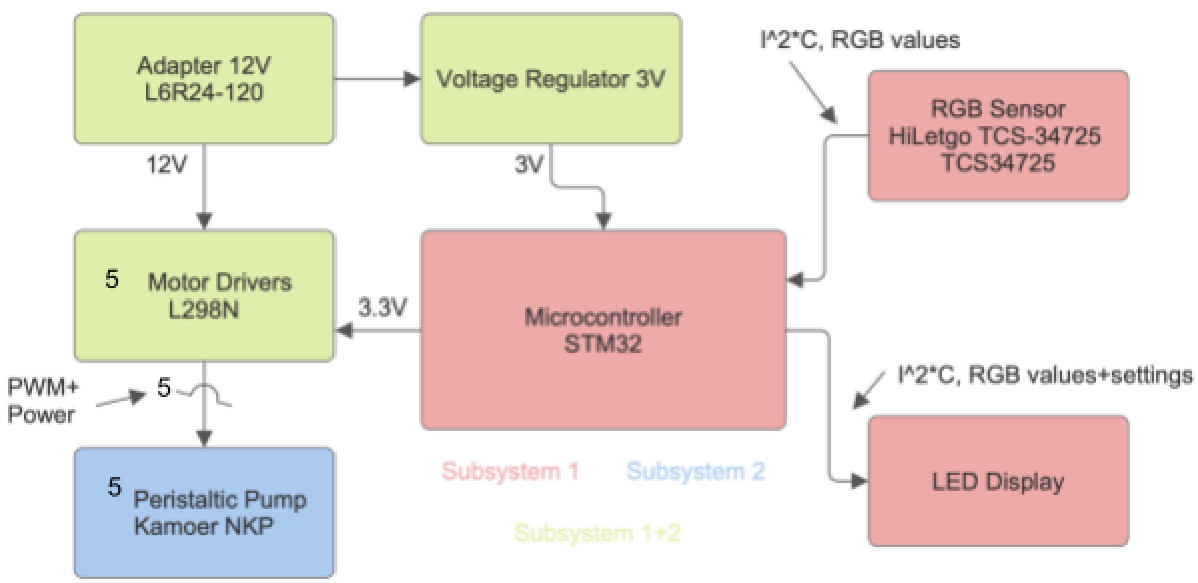
Our second high level requirement is motor precision, so that they can dispense the correct amount of paint to make the required color. We need to ensure that the motors respond correctly and are able to accurately dispense the paint so that we have the right ratio of colors to generate the desired color that was inputted.

- If the motor dispenses 50 mL at 100% duty cycle, a 5% decrease in duty cycle could reduce the volume to 47.5 mL, which is still within acceptable error for most use cases. Since we have 5 motors and the error for each motor will add up, we expect <1% error per each motor in order to have < 5% total error.

Our third high level requirement is overall accuracy of the colors, so how accurate the resulting color is compared to the original color that was inputted. We have to make sure that the project works correctly by putting the resulting color that was dispensed back into the RGB sensor and verifying that it matches the original color that was inputted. We will repeat this process multiple times to ensure consistency and accuracy.

2 Design

2.1 Block Diagram:



2.2 Subsystems:

Subsystem 1 (Color Classifier) :

Materials:

- Adafruit AS7262 6-Channel Visible Light / Color Sensor Breakout
- STM32 Series MCU
- 5 x Motor Driver TMC2209-LA-T
- Custom pcb for Microcontroller management
- Standard button
- 24 volt power supply (EMITEVER 24V DC Power Supply, 30W LED Power Adapter, Lighting Transformers,Input AC 100-240V UL-List)

The Color Classifier subsystem will have all the logic for the design. It will have a pcb that contains input from a color sensor and a microcontroller to process the input from the color sensor. This will all happen when a button is pressed and a high signal is sent. The motor drivers are also placed on the PCB to interface with the microcontroller to receive the processed signals once the color is processed. We will use a 24 volt power supply in order to power this system. A voltage regulator circuit will be used in order to get the voltage to the 3 volts needed for the microcontroller.

The RGB sensor connects to the STM32 MCU via I2C. The STM32 then interfaces with the motor controllers using PWM signals to command the paint dispensing subsystem based on the CMYK values.

There are 6 formulas used to convert RGB to CMYK (the model used in printers. Really these values are just proportions, suppose C is 0.5 and we want 100mL of white paint in the mixture, the amount of Cyan paint needed is 100mL of White * 0.5 = 50mL. We run the motor for x amount of time at some specific settings and see how much x mL of liquid gets dispensed. If the process ends up being too difficult with our acrylics then we will switch to a paint that is more watery.

- $R' = R/255$
- $G' = G/255$
- $B' = B/255$
- $K = 1-\max(R', G', B')$
- $C = (1-R'-K) / (1-K)$
- $M = (1-G'-K) / (1-K)$
- $Y = (1-B'-K) / (1-K)$

Next, the volume of paint for each primary color (cyan, magenta, yellow, black, and white) is determined based on these proportions. For example, if the desired volume is 100 mL, the amount of cyan paint would be: Cyan Paint=100×C

This calculation is repeated for magenta, yellow, black, and white. If the cyan component C=0.5, then the system will dispense 50 mL of cyan paint.

Subsystem Requirement:

The high-level requirement for our subsystem is the accuracy of the color sensor, specifically its ability to detect and capture the exact RGB values of the provided color. Ensuring precise color detection is critical because the entire system depends on converting the scanned color into the correct proportions of cyan, magenta, yellow, black, and white for paint mixing. If the sensor inaccurately reads the color, the resulting mixture will not match the intended shade. Accurate color detection is essential for achieving the desired outcome.

- ➢ The color sensor must have an accuracy of ±5% when detecting the RGB values, so the detected RGB values to a reference color, the deviation in each of the RGB values (R, G, and B) should not exceed 5% of the original input value.

Requirements	Verification
The RGB color sensor must detect RGB values with an accuracy of ±5% compared to a reference standard. This detection accuracy must be maintained for all colors.	Equipment Needed: Standard color samples, RGB color sensor, Multimeter (DMM) Test Procedure: 1. Place the RGB sensor 2 cm from a reference color sample. 2. Measure the RGB values of the reference sample using the RGB values from the paint manufacturer as the ground truth. 3. Record the RGB values detected by the sensor. 4. Compare the detected values with the reference values to check if they are within ±5%.
The color detection latency must be less than 100 ms after pressing the button for the sensor to output the color value.	Equipment Needed: Oscilloscope, timing software. Test Procedure: 1. Connect the output of the RGB sensor to an oscilloscope. 2. Connect the RGB sensor to the MCU, set up a timer to measure the latency using software. 3. Press the sensor activation button and monitor the time from button press to RGB output on the oscilloscope. 4. Ensure that the time delay is less than 100 ms.
The sensor subsystem must consume less than 50 mA at 3.3V during operation.	Equipment Needed: Multimeter (DMM) set to measure current, variable power supply. Test Procedure: 1. Power the sensor subsystem at 3.3V using a variable power supply. 2. Measure the current draw using the DMM

	connected in series with the sensor subsystem. 3. Ensure that the current is less than 50 mA during continuous operation.
The final color mixture must match the input color with a ΔE (CIE76 color difference) of less than 5 when tested using a colorimeter.	Equipment Needed: RGB sensor, RGB reference color samples. Test Procedure: 1. Input a color using the RGB sensor and let the system dispense and mix the paint. 2. Measure the resulting color using a RGB sensor. 3. Calculate the ΔE between the input and output colors. Ensure that the ΔE is less than 5
The system must complete the color mixing process in less than 30 seconds for any given color.	Equipment Needed: Stopwatch, test colors. Test Procedure: 1. Input a target color using the RGB sensor. 2. Start the stopwatch as the system begins dispensing paint. 3. Stop the stopwatch once the paint has been fully dispensed and mixed. 4. Verify that the entire process takes less than 30 seconds.
The system must not exhibit any leaks or spills when dispensing paint during continuous operation	Equipment Needed: Paper towels, graduated cylinder. Test Procedure: 1. Operate the paint dispensing system continuously. 2. Monitor for any leaks or spills. 3. Ensure that no paint leakage occurs over the test duration.

Subsystem 2 (Paint Dispenser) :

Materials:

- 5 x Small peristaltic pump 24V stepper motor

- Custom 3d printed casing for holding pumps

○ Printing at idea lab / material to be used: PLA

- Wires for connections
- 3d printed reservoirs for paint
- 24 volt power supply (same one as Color Classifier subsystem)
- Silicon tubing for peristaltic pump + caps for ends of tubes

The Paint Dispenser will receive signals from color classifiers in order to pump the correct materials. The motors will drive the peristaltic pumps to pump the paint from the paint reservoirs into a central location centered around the 3d printed pump holder. The artist can put their palette in this area and mix around their colors once every paint needed for that color is dispensed.

To control the paint dispenser motors, we will use PWM to regulate the speed of the motors, which is directly proportional to the paint flow rate. The PWM duty cycle will determine how fast each motor rotates, and this can be adjusted dynamically based on the volume of paint required.

The motor speed is calculated based on the pump's flow rate, which can be measured experimentally (e.g., 10 mL per second at 100% duty cycle). To dispense the correct amount of paint, we will adjust the motor run time t as follows: $t = (\text{Desired Volume}/\text{Flow Rate}) \times \text{Duty Cycle}$

For instance, if the desired volume is 50 mL and the flow rate is 10 mL per second at 100% duty cycle, the motor would need to run for 5 seconds.

We will also experiment with the optimal PWM duty cycle to ensure motor precision, likely operating in the 70-90% range for the best control without stalling or losing efficiency.

A low-flow peristaltic pump works by squeezing a flexible silicon tube with rollers, creating positive displacement that pushes the paint through the tube without any backflow. The rollers are attached to a rotating mechanism powered by a stepper motor, which controls the flow rate.

Each rotation of the pump moves a fixed volume of fluid, which means the total volume dispensed is proportional to the number of rotations. This provides precision in controlling the amount of paint, and we will calibrate the system to determine the volume per rotation. This will be done by measuring how much paint is dispensed after each pump rotation under different conditions.

The MCU interfaces with the motor driver via PWM signals. These signals control the speed of the motors, determining the amount of paint dispensed.

Subsystem requirement:

The second high-level requirement is motor precision, which is essential for dispensing the correct amount of paint to achieve the desired color. The stepper motors must respond accurately to the calculated ratios, ensuring each primary color (cyan, magenta, yellow, black, and white) is dispensed in the right proportions. If the motors fail to dispense the exact amounts, the resulting color will deviate from what was inputted. Precise motor control is crucial to maintaining consistency in color mixing and ensuring that the final paint matches the user's expectations.

- ➢ If the motor dispenses 50 mL at 100% duty cycle, a 5% decrease in duty cycle could reduce the volume to 47.5 mL, which is still within acceptable error for most use cases. Since we have 5 motors and the error for each motor will add up, we expect <1% error per each motor in order to have < 5% total error.

Requirements	Verification
The peristaltic pump must dispense paint with an accuracy of ±2.5 mL for a target volume of 100 mL.	Equipment Needed: Graduated cylinder, stopwatch. Test Procedure: 1. Command the pump to dispense 100 mL of paint. 2. Collect the dispensed paint in a graduated cylinder and measure the actual volume. 3. Repeat this test 5 times and ensure that the volume dispensed is within ±2.5 mL of the target volume for each trial.
The paint flow rate must be controllable from 5 mL/sec to 10 mL/sec with a tolerance of ±0.5 mL/sec.	Equipment Needed: Graduated cylinder, stopwatch, PWM controller. Test Procedure: 1. Set the motor speed using the PWM controller to achieve different target flow rates (5 mL/sec, 7.5 mL/sec, 10 mL/sec). 2. Collect paint in a graduated cylinder for 10 seconds and measure the dispensed volume. 3. Verify that the flow rate is within ±0.5 mL/sec of the target rate.
The peristaltic pump must stop dispensing paint within 1 second of receiving a stop command to prevent over-dispensing.	Equipment Needed: Oscilloscope, graduated cylinder, stopwatch. Test Procedure: 1. Send a command to stop the pump while it is dispensing. 2. Measure the time taken for the motor to stop using an oscilloscope to track the stop signal vs. motor response. 3. Ensure that the pump stops within 1 second and check for any residual paint flow.
The motor speed must be controlled within a tolerance of ±5% for each PWM duty cycle	Equipment Needed: Oscilloscope, PWM controller, tachometer.

(e.g., 50% PWM should result in a flow rate within ±5% of the target speed).	Test Procedure: 1. Set the motor to operate at different PWM duty cycles (25%, 50%, 75%, 100%). 2. Measure the flow rate at each setting using a graduated cylinder. 3. Verify that the measured flow rates are within ±5% of the expected values.
The motor subsystem must operate with a current draw of less than 1A at full load.	Equipment Needed: Multimeter (DMM) set to measure current, variable load. Test Procedure: 1. Connect the motor subsystem to a variable load and run the motor at full speed (100% PWM duty cycle). 2. Measure the current draw using a DMM. 3. Verify that the current draw is less than 1A.

2.3 Hardware Design:

The hardware design of the color-detecting automatic paint dispenser integrates the following major components and circuits:

Microcontroller (STM32 MCU):

- The STM32 microcontroller will serve as the core processing unit, responsible for interpreting RGB sensor data, converting the values to CMYK, and controlling the paint dispensing system through PWM (Pulse Width Modulation).
- The STM32 is chosen for its high performance, real-time processing capabilities, low power consumption, and compatibility with I2C communication to interface with the RGB sensor and motor driver.

RGB Sensor (Adafruit AS7262 6-Channel Visible Light / Color Sensor Breakout):

- The RGB sensor will detect the red, green, and blue intensities of the color, alongside ambient light and 'clear' photodiode readings.
- The sensor communicates with the MCU via an I2C interface, sending continuous data regarding the detected color. The conversion of these RGB values to CMYK is handled by formulas implemented within the MCU.

- For precise detection, the sensor needs to be placed at an optimal distance (approximately 2 cm) from the color sample to avoid reading errors.
- The sensor is powered at 3.3V, drawn from the STM32.

Motor Drivers (TMC2209-LA-T):

- Five TMC2209-LA-T stepper motor drivers are used to control the 24V stepper motors that drive the peristaltic pumps. The TMC2209-LA-T driver allows for high-precision, low-noise control of the stepper motors, which is essential for accurately dispensing paint volumes.
- Each motor driver receives control signals from the STM32F103C8T6 microcontroller to adjust the steps and speed of the stepper motor, controlling the amount of paint dispensed.
- These drivers are configured to enable microstepping, which allows finer control of motor rotation. While bi-directional control is available, only forward operation is used to dispense paint. The TMC2209-LA-T's features, such as smooth torque and silent operation, ensure stable and precise pump operation without vibration.
- Power for the motor drivers comes from the 24V supply, regulated as necessary.

Peristaltic Pumps (Kamoer KPHM100 24V Stepper Motor):

- The flow rate of each pump is controlled by adjusting the number of motor steps and speed, based on the required amount of each color. The silicon tubing used in these pumps is highly flexible, facilitating precise control over the paint volume.
- The Kamoer KPHM100 peristaltic pumps, each driven by a 24V stepper motor, are used to dispense paint colors (cyan, magenta, yellow, black, and white). Peristaltic pumps are ideal for this application because they provide accurate volumetric control without any risk of backflow or leakage, ensuring clean and precise paint mixing.
- Calibration is performed to establish the exact volume dispensed per motor step, allowing the software to accurately control the paint ratios needed for color matching.

Power Supply (24V):

- The entire system is powered by a 24V DC supply. The power is distributed between the MCU, motor drivers, and RGB sensor. A voltage regulator is used to step down the voltage to 3.3V for the MCU and sensor.
- The system's current draw is carefully monitored to ensure it remains within the limits (less than 1A for motors under load).

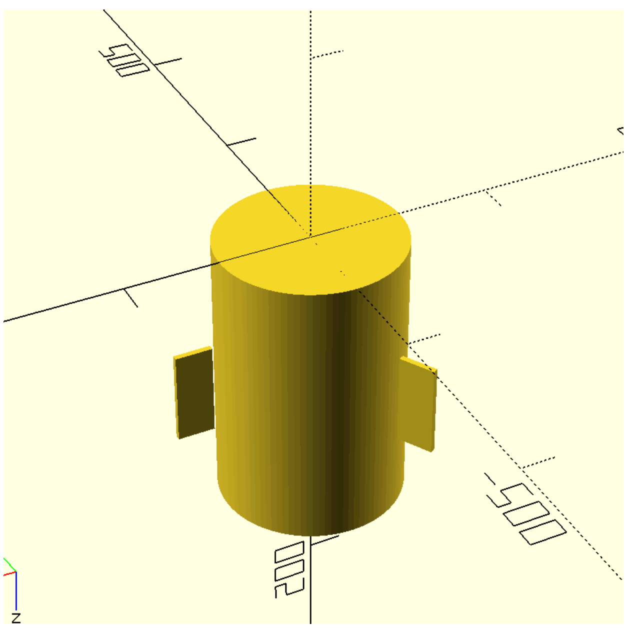
User Interface (Buttons & LCD Display):

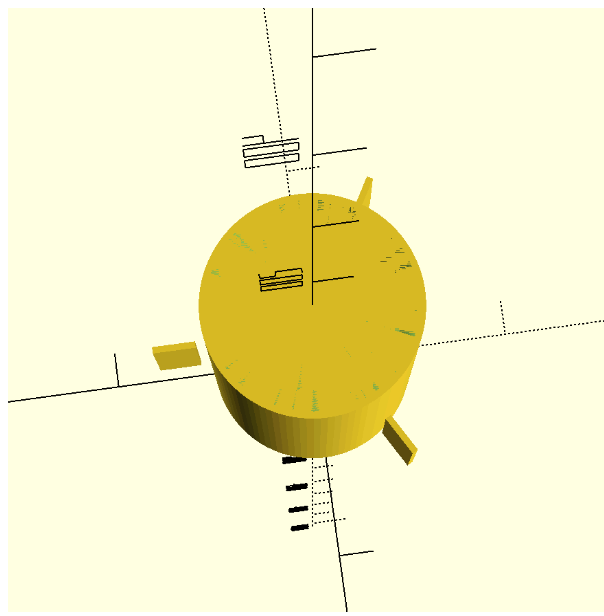
- A button is used to trigger color detection. Once pressed, the RGB sensor reads the color and sends the data to the MCU for processing.
- A simple LCD display can be added to show the color values (RGB or CMYK), the paint volumes being dispensed, or error messages, if necessary. The display connects via I2C or SPI depending on the chosen model.

Custom PCB:

- A custom PCB integrates all components, including the RGB sensor interface, STM32 MCU, and motor driver circuits. The PCB design ensures minimal signal interference, stable power distribution, and compact component layout.
- The PCB includes a voltage regulation circuit to step down 24V to 3.3V for low-power components like the MCU and RGB sensor.

Paint container 3D Models





```
// Parameters for container and mounts
container_diameter = 100; // Diameter of the paint container (in mm)
container_height = 150;   // Height of the paint container (in mm)
wall_thickness = 3;       // Thickness of the container wall (in mm)
mount_width = 20;         // Width of each pump mount (in mm)
mount_height = 50;        // Height of each pump mount (in mm)
mount_spacing = 5;        // Spacing between mounts and container (in mm)

// Function to create a cylindrical container
module paint_container() {
    difference() {
        // Outer cylinder
        cylinder(h = container_height, d = container_diameter, $fn=100);
        // Inner cylinder for wall thickness
        translate([0, 0, wall_thickness])
            cylinder(h = container_height - wall_thickness,
                     d = container_diameter - 2 * wall_thickness, $fn=100);
    }
}

// Module for creating pump mounts on the side of the container
module pump_mount() {
    translate([container_diameter/2 + mount_spacing, 0, container_height / 2 - mount_height / 2])
        cube([mount_width, wall_thickness, mount_height]);
}

// Assembly of the container with mounts
module paint_container_with_mounts(num_mounts = 2) {
    paint_container();
    for (i = [0 : num_mounts - 1]) {
        rotate([0, 0, 360 / num_mounts * i])
            pump_mount();
    }
}

// Render the final paint container with mounts
paint_container_with_mounts(3); // Change to desired number of mounts
```

2.4 Software Design:

The software running on the STM32 MCU will control the following system aspects:

RGB to CMYK Conversion Algorithm:

- The core of the software is the RGB to CMYK color conversion, which follows these formulas:
  - $R' = R / 255, G' = G / 255, B' = B / 255$
  - $K = 1 - \max(R', G', B')$
  - $C = (1 - R' - K) / (1 - K)$

- M = (1 - G' - K) / (1 - K)
- Y = (1 - B' - K) / (1 - K)

- These formulas calculate the proportions of cyan, magenta, yellow, and black needed to match the target color. The final CMYK values determine the amount of each color to be dispensed.

I2C Communication Protocol:

- The MCU interfaces with the RGB sensor using the I2C communication protocol. The sensor sends RGB data to the MCU, which reads the data at a regular interval (approximately every 100 ms).
- I2C is also used for communication with the LCD display if it is included.

PWM Motor Control:

- Each motor driving the peristaltic pumps is controlled by a PWM signal generated by the MCU. The software dynamically adjusts the PWM duty cycle based on the required paint volume, calculated using the CMYK values.
- The paint volume to be dispensed for each color is computed using the formula: Dispensed Volume = Total Volume × (C, M, Y, K)
- The PWM signal is adjusted to run the motors for the required time to achieve the calculated volume of paint.

Calibration and Testing Routines:

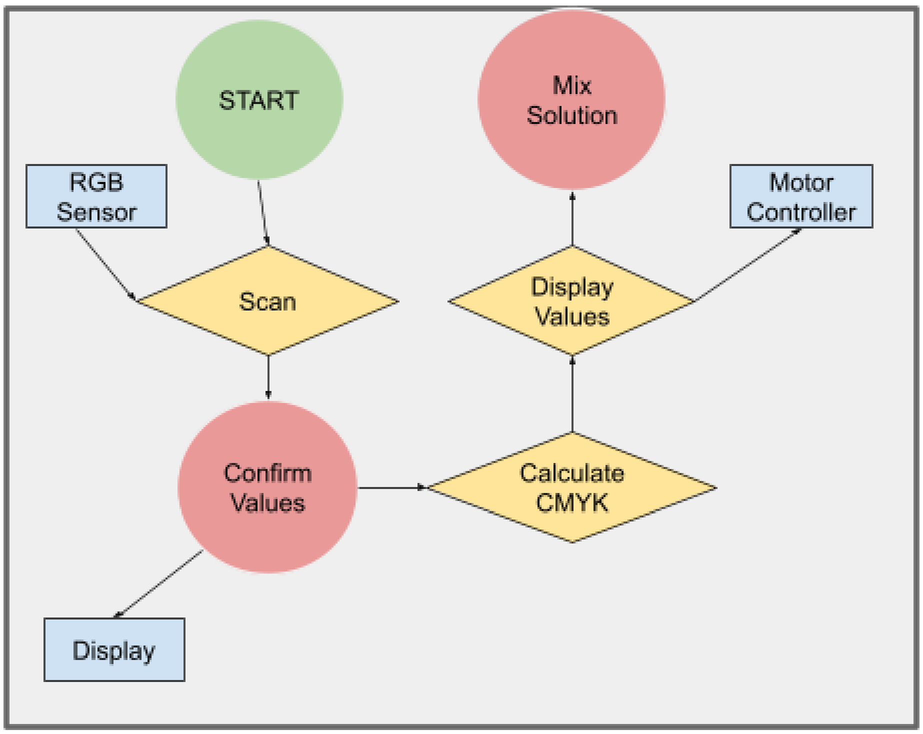
- A calibration routine is included to measure the volume of paint dispensed per pump rotation. This allows the system to adjust motor run times for precise control.
- During operation, the system will test the dispensed color against the input RGB color using a feedback loop with the RGB sensor. If the output color doesn't match within a tolerance ($\Delta E < 5$), the system will adjust the paint mixture.

Error Handling and Safety Features:

- The software monitors the motors and pumps for issues like overloading or stalling. If the current draw exceeds a predefined threshold, the system will stop the motors and alert the user via the LCD.
- In case of leaks or flow issues, the system will pause and request user intervention.

User Interaction:

- The software also handles user inputs such as button presses to start color detection and initiate the paint mixing process. Once the button is pressed, the RGB sensor is activated, the color is read, and the necessary paint amounts are calculated and dispensed.
- Feedback on the process, including the amount of paint dispensed or any errors, can be displayed on the LCD screen.



2.5 Tolerance Analysis:

Motor Speed Tolerance: The flow rate of the peristaltic pump is affected by motor speed, which is controlled by PWM. Small variations in PWM can cause deviations in the volume dispensed. For instance, a 5% deviation in the PWM signal may result in ±5% variation in the amount of paint dispensed. If the motor dispenses 50 mL at 100% duty cycle, a 5% decrease in duty cycle could reduce the volume to 47.5 mL, which is still within acceptable error for most use cases. We will experimentally calibrate the system to find the optimal range for the PWM duty cycle to minimize this error.

Since we are now using stepper motors, the tolerance analysis will focus on step accuracy rather than PWM duty cycle. The volume of paint dispensed is directly proportional to the number of motor steps. Any deviation in the step count or motor performance could affect the dispensing volume. Suppose we determine that each full step of the stepper motor dispenses V_step mL of paint. For example, if 200 steps dispense 50 mL, then: $V_{step}=50\ mL/200=0.25$ mL per step.
Let's say we need to dispense a volume V (e.g., 100 mL of paint). The required number of steps N_steps would be: $N_{steps}=V/V_{step}$. For 100 mL, using our example value for Vstep: $N_{steps}=100/0.25=400$ steps. Stepper motors typically have a positional accuracy of ±5%. A 5% error in step count could lead to an over or under-dispensing volume. Thus, the maximum deviation in volume due to motor inaccuracy ΔV would be: $\Delta V=N_{steps}\times V_{step}\times 0.05$
For 100 mL (400 steps), this becomes: $\Delta V=400\times 0.25\times 0.05=5$ mL. A ±5% motor accuracy translates to a potential volume deviation of ±5 mL when dispensing 100 mL of paint. This is within our acceptable tolerance range (5%).

Color Detection Tolerance: As mentioned earlier, the color sensor has a tolerance of ±5% in detecting RGB values. This tolerance means that slight variations in the detected color could result in small discrepancies in the final mixed paint color. For example, if the desired cyan component is 0.5, a 5% sensor error could lead to a value between 0.475 and 0.525, resulting in a variation of ±2.5 mL for a 100 mL mix. We will conduct repeated trials to determine if this tolerance level affects the overall paint mixing process.

The color sensor tolerance is defined as ±5% in RGB values. To translate this into a measurable color difference, we use the CIE76 color difference formula, which quantifies perceptible color differences using ΔE values. $\Delta E < 2$ is generally imperceptible to the human eye, while $\Delta E < 5$ is often acceptable in color-matching applications. For two colors with RGB values (R1, G1, B1) and (R2, G2, B2), the ΔE is given by: $\Delta E^2=(R2-R1)^2+(G2-G1)^2+(B2-B1)^2$. Suppose the sensor reads an RGB value of (200, 150, 100) for a target color, with a ±5% error range: $R2=200\pm10, G2=150\pm7.5, B2=100\pm5$. Consider the upper bound for each color component: (210, 157.5, 105). Calculating ΔE: $\Delta E^2=(210-200)^2+(157.5-150)^2+(105-100)^2$. $\Delta E=\approx13.46$. A ΔE of 13.46 indicates a noticeable color difference, so further calibration and averaging readings from the sensor might be necessary to improve accuracy. Repeated trials will help in reducing color detection error by fine-tuning the RGB-to-CMYK conversion process.

By calibrating the system and considering these tolerances, we can ensure that the color mixing process remains accurate and consistent within an acceptable range of error.

3 Cost and Schedule

3.1 Cost Analysis:

We can expect a salary of $40/hr * 2.5 * 70hr = $7000 for each team member. For our team of three members, the total labor cost will come out to be 7000 * 3 = 21,000.

Catalog/Part #	Description	Qty	Recvd	Price	Ext Price
TMC2209-LA-T	Motor Driver TMC2209-LA-T	5	5	$5.58	$27.90
USBLC6-2SC6Y	USBLC6-2SC6Y	5	5	$0.42	$2.10
STM32F103C8T6	Microcontroller	2	2	$5.51	$11.02
LCD 1602	LED Display	1	1	$3.65	$3.65
1528-4661-ND 4661	Silicone Tubing	5	5	$2.26	$11.30
L6R24-120	Power Adapter	1	1	$6.41	$6.41
LD1086DT33TR	Linear Voltage Regulator IC Positive Fixed 1 Output 1.5A DPAK	1	1	$1.30	$1.30

Catalog/Part #	Description	Qty	Recvd	Price	Ext Price
3779	Adafruit AS7262 6-Channel Visible Light / Color Sensor Breakout	1	1	$19.95	$19.95

Catalog/Part #	Description	Qty	Recvd	Price	Ext Price
Kamoer KPHM100	Small peristaltic pump 24V stepper motor	3	3	$20.90	$62.70
EMITEVER 24V DC Power Supply, 30W LED Power Adapter, Lighting Transformers,Input AC 100-240V UL-List	Power Supply	1	1	$14.98	$14.98

Part	Manufacturer	Quantity	Price	Link	Model Number
RGB Color Sensor	AdaFruit	1	$20	hhttps://www.adafruit.com/product/3779	3779
Power Adapter	EMITEVER	1	$6.59	Power Supply	EMITEVER 24V

					DC Power Supply, 30W LED Power Adapter, Lighting Transformers,Input AC 100-240V UL-List
Motor Drivers	AITRIP	5	$15	https://www.amazon.com/DIYables-Driver-Arduino-ESP8266-Raspberry/dp/B0BPG7PYY5/ref=asc_df_B0BPG7PYY5/?tag=hyprod-20&linkCode=df0&hvadid=693627986596&hvpos=&hvnetw=g&hvrand=15065093603732671245&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9022185&hvtargid=pla-2185933692462&psc=1&mcid=bfcf5adb136c36578eeca9722c13633a	L298N
Peristaltic Pumps	KAMOER	5	$50	Small peristaltic pump 24V stepper motor	Kamoer KPHM100
Microcontroller	STMicroelectronics	1	$25	https://www.amazon.com/STM32-Nucleo-Development-STM32F446RE-NUCLEO-F446RE/dp/B01I8XLEM8/ref=asc_df_B01I8XLEM8/?tag=hyprod-20&linkCode=df0&hvadid=692875362841&hvpos=&hvnetw=g&hvrand=9407457550079006694&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9022185&hvtargid=pla-2281435178298&psc=1&mcid=a3c5de240bef37169656321cacbbaa86&hvocijid=9407457550079006694-B01I8XLEM8-&hvexpln=73	STM32
LED Display	Universal-Solder Electronics	1	$3.65	https://www.digikey.com/en/products/detail/universal-solder-electronics-ltd/LCD%25201602%25202X16%2520BLUE-WHITE/16821383?utm_adgroup=&utm_source=google&utm_medium=cpc&utm_campaign=PMax%20Shopping_Product_Medium%20ROAS%20Categories&utm_term=&utm_content=&utm_id=go_cmp-20223376311_adg-_ad-__dev-c_ext-_prd-16821383_sig-Cj0KCQjw3vO3BhCqARIsAEWblcC6Chjyhymuf1PPkszq1A2YmB8k4SleOZYyUIQvgNFdJ53G2ziqpVkaAiNIEALw_wcB&gad_source=1&gbraid=0AAAAADrbLlhSvlRt5N9p41KSAPnniffFg&gclid=Cj0KCQjw3vO3BhCqARIsAEWblcC6Chjyhymuf1PPkszq1A2YmB8k4SleOZYyUIQvgNFdJ53G2ziqpVkaAiNIEALw_wcB	LCD 1602
Silicone	Adafruit	5	$12.5	https://www.digikey.com/en/products/detail/adafru	1528-4661-N

Tubing				it-industries-llc/4661/13170953?utm_adgroup=&utm_source=google&utm_medium=cpc&utm_campaign=PMax%20Shopping_Product_Medium%20ROAS%20Categories&utm_term=&utm_content=&utm_id=go_cmp-20223376311_adg-_ad-__dev-c_ext-_prd-13170953_sig-Cj0KCQjw3vO3BhCqARIsAEWblcC3nOYrDQRKDtYtP469J9nVnCIb8Nhbnj3kA_aojOvbpjvz88WKze0aAjk4EALw_wcB&gad_source=1&gbraid=0AAAAADrbLlhSvlRt5N9p41KSAPnniffFg&gclid=Cj0KCQjw3vO3BhCqARIsAEWblcC3nOYrDQRKDtYtP469J9nVnCIb8Nhbnj3kA_aojOvbpjvz88WKze0aAjk4EALw_wcB	D 4661
Paint	TMOL	1	$15	https://www.amazon.com/Supplies-Painting-Pigments-Beginners-Professional/dp/B0DD3R847F/ref=asc_df_B0DD3R847F/?tag=hyprod-20&linkCode=df0&hvadid=692875362841&hvpos=&hvnetw=g&hvrand=8361564263867815223&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9022185&hvtargid=pla-2281435179978&mcid=6122605939a731c9b3d2403ed70de013&hvocijid=8361564263867815223-B0DD3R847F-&hvexpln=73&th=1	TMOL 24 pack

The estimated cost for parts in this device before shipping is around $135. Assuming a shipping cost of 10% and a sales tax of 7% we can expect the total cost to be around $158. As calculated above, assuming a salary of $40/hr * 2.5 * 70hr = $7000 for each team member. For our team of three members, the total labor cost will come out to be 7000 * 3 = $21,000. The total cost comes out to $21,000+$158=$21,158.

3.2 Schedule:

Week	Task	Team Members
1-2	Finalize detailed subsystem designs and complete block diagram	All
3-4		Rajeev, Alexander

	Order components and finalize PCB design	
4-5	Prototype the paint dispensing mechanism and develop RGB to CMYK conversion algorithm	Lucky, Rajeev
5-6	Begin integrating RGB sensor with the MCU, test initial color detection accuracy	Lucky, Alexander
7-8	Complete motor control and PWM testing, calibrate paint dispensing mechanism	Alexander, Rajeev
9-10	Integrate all subsystems and conduct end-to-end tests	All

4 Discussion of Ethics and Safety

There are several ethical and safety concerns that need to be addressed. In terms of ethics, a primary concern is transparency by fully informing the users about the true capabilities and limitations of the color detecting automatic paint dispenser. For example, the limitation of the

RGB to CMYK color conversion process is something that must be addressed as there can be scenarios where the inputted color and the resulting color do not match properly. According to the IEEE Code of Ethics, statements made about the accuracy of a product must have evidence of extensive testing and validation so that users are not misled. ACM's ethical guideline also highlights the importance of developing technology in the consumer's best interests while following proper design practices and techniques. Safety is also a big concern, given that there are electrical, mechanical, and chemical components in our project. The 24 volt power supply could pose risks such as short circuits or shocks if not insulated. Complying with the IEEE Safety Standards and following their instructions regarding grounding and electronic protection will allow us to prevent any accidents. Precautions should be taken to prevent chemicals and paints from touching the user's skin and ventilation to prevent inhalation of harmful particles. Mechanical parts like stepper motors and peristaltic pumps could pose physical risks if not properly enclosed. Improper disposal of paint waste could cause environmental harm, so it's essential to follow EPA guidelines for chemical disposal and ensure the project minimizes waste and contamination.

5 Citations

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