ECE 445: Design Document 2

Electric Paintbrush Cleaner

Luis Bibian (bibian2), John Kriston (jkristo2), Yael Legaria (legaria2)

Team 65

TA: Madison Hedlund

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Contents

1 Introduction

1.1 Problem and Solution Overview

When painting, it is commonplace for painters to have a cup or jar of water used to clean their paintbrush when switching between colors. However, after only a handful of times of dipping the paintbrush in the water to clean it, the water becomes heavily stained with residual paint. As the unclean water starts seeping into the brush, this leads to the unwanted mixing of colors on the canvas. This is especially problematic when working with acrylic paints due to their thick consistency compared to other types of paint such as watercolor [1]. In addition to quickly contaminating the painter's rinse water, acrylic paints also require the proper disposal of acrylic paint wastewater due to the plastic particles present in the paint. Although having a designated cup of water to clean the paintbrush is a simple way to combat unwanted color mixing, the overall problem is that it is highly inconvenient for painters to continuously get up to empty and refill their cup, as this ultimately disrupts the painting process.

Our proposed solution is to create a device that allows the user to easily get a fresh supply of clean water while properly handling the disposal of the contaminated rinse water. To achieve this, a clean water receptacle will receive clean water when dictated by the user in bursts of approximately 0.25 liter portions from a clean water storage tank which holds a maximum of 2.5 liters of water. Before a new supply of clean water is routed to the cleaning receptacle, the contaminated rinse water is drained into a filtration system that will filter the acrylic paint particles out of the rinse water when the user is finished painting. Once the filtration process is complete, the user can remove the dried acrylic paint particles and dispose of them in the trash can, and the clean water storage tank will be replenished with the recycled water.

1.2 Background

To mitigate the problem of contaminated rinse water interfering with the quality of a painting, painters will usually either use two separate containers of water to clean their brush (one for getting most of the paint off the brush, and the other for rinsing the brush after the first clean), or a very large tupperware/bucket of water such that any paint that is rinsed into the water will achieve a higher degree of dilution with the larger volume of water. However, neither of these solutions fix the problem of the designated cleaning water getting heavily contaminated with different colors - they instead only serve to slow down the process.

Furthermore, there is a need for a product that can ease the painting process for painters working with acrylic paint. Acrylic paints are popular amongst beginner, intermediate, and advanced painters alike for their longevity once put on a canvas and their "forgiveness of mistakes" [1]. But because of their thicker consistency when compared to watercolor paints, acrylic paints contaminate rinse water at a faster rate, and the plastic particles present in acrylic paint require proper disposal. Acrylic paint particles that contaminate rinse water are harmful to septic systems due to their potential to clog sewage pipes [2], but many painters neglect the treatment of acrylic wastewater because it is a seemingly tedious process. For these reasons, the need for a product that makes the filtration process for painters hassle-free cannot be overstated. In order to properly handle the treatment of acrylic paint wastewater, our solution aims to assist the user in automating the filtration process proposed by Golden Artist Colors Inc. [3], which is essentially a scaled-down version of the treatment process employed in municipal water systems.

The closest product that currently exists on the market for brush cleaning is the STYLPRO makeup brush cleaner [4], which cleans makeup brushes with a motorized-handheld device that spins the makeup brush around in a small bowl of water to get any residual makeup out of it. However, this product does not address our initial problem of the water easily getting stained during the painting process since the STYLPRO is only intended for a single use before the user has to manually refill the bowl. Additionally, the STYLPRO is not designed to handle brushes that are stained with acrylic paint, as brushes that are stained with makeup do not require the filtration of any residual particles that exist in the rinse water.

1.3 Visual Aid

Figure 1 illustrates the two main functions of the proposed solution. Through a user interface module, the user can request a refill of clean water, causing the wastewater to drain into the filtration tank to be replaced by clean water routed to the paintbrush cleaning receptacle. The user can also request to filter the wastewater, causing the acrylic paint particles to flocculate as they separate from the water and begin to form solid clumps easy for filtering.

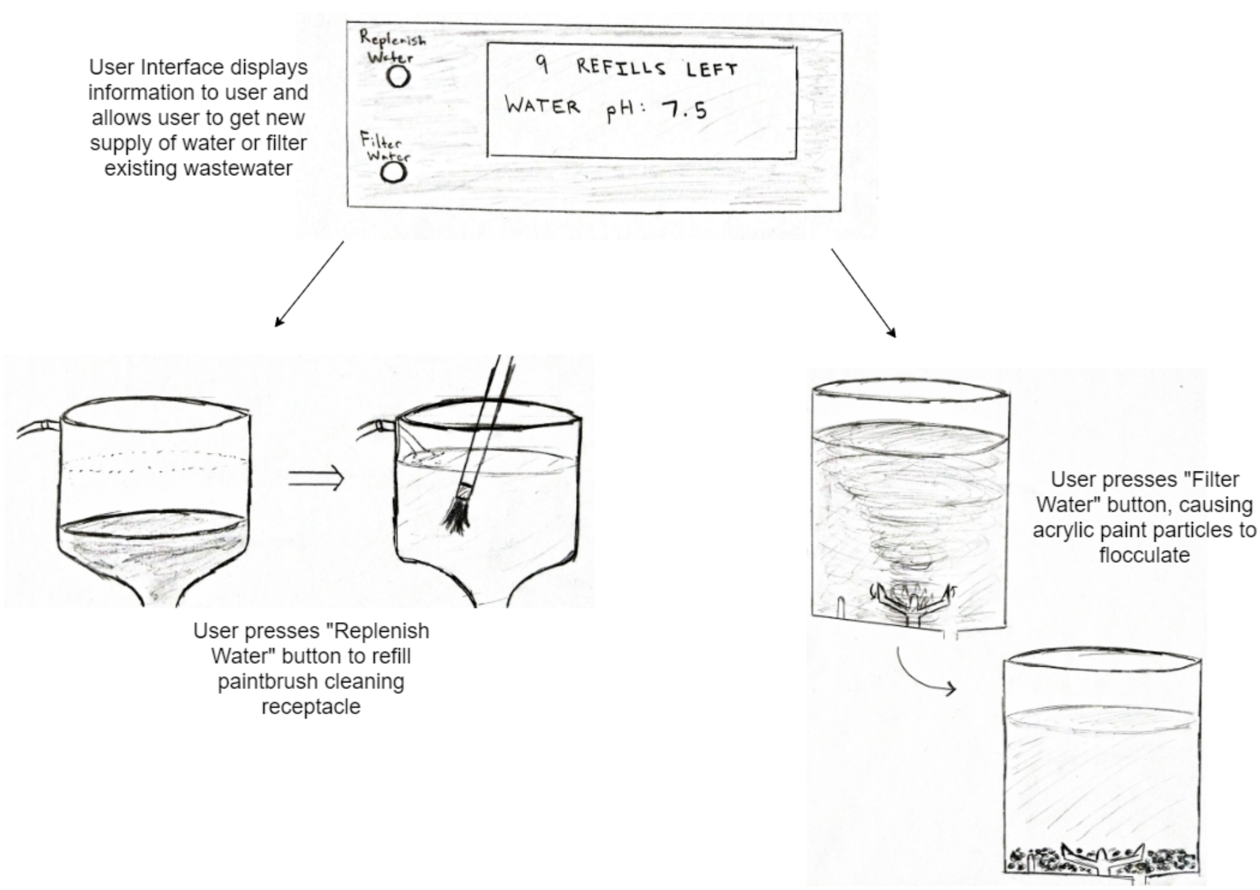

Figure 1: Block Diagram of Electric Paintbrush Cleaner

1.4 High-Level Requirements

- The user can request at least eight refills of water to the paintbrush cleaning receptacle during each painting session for a water storage tank filled with 2.5 liters of water.
- The treated water's pH at the end of the filtration cycle must sit between a pH of 6.5 and 8.5 to be considered acceptable for recycling.
- The filtration system must demonstrate the ability to remove acrylic paint particles from the treated wastewater, indicated by the transition of the wastewater from opaque to transparent.

2 Design

2.1 Block Diagram

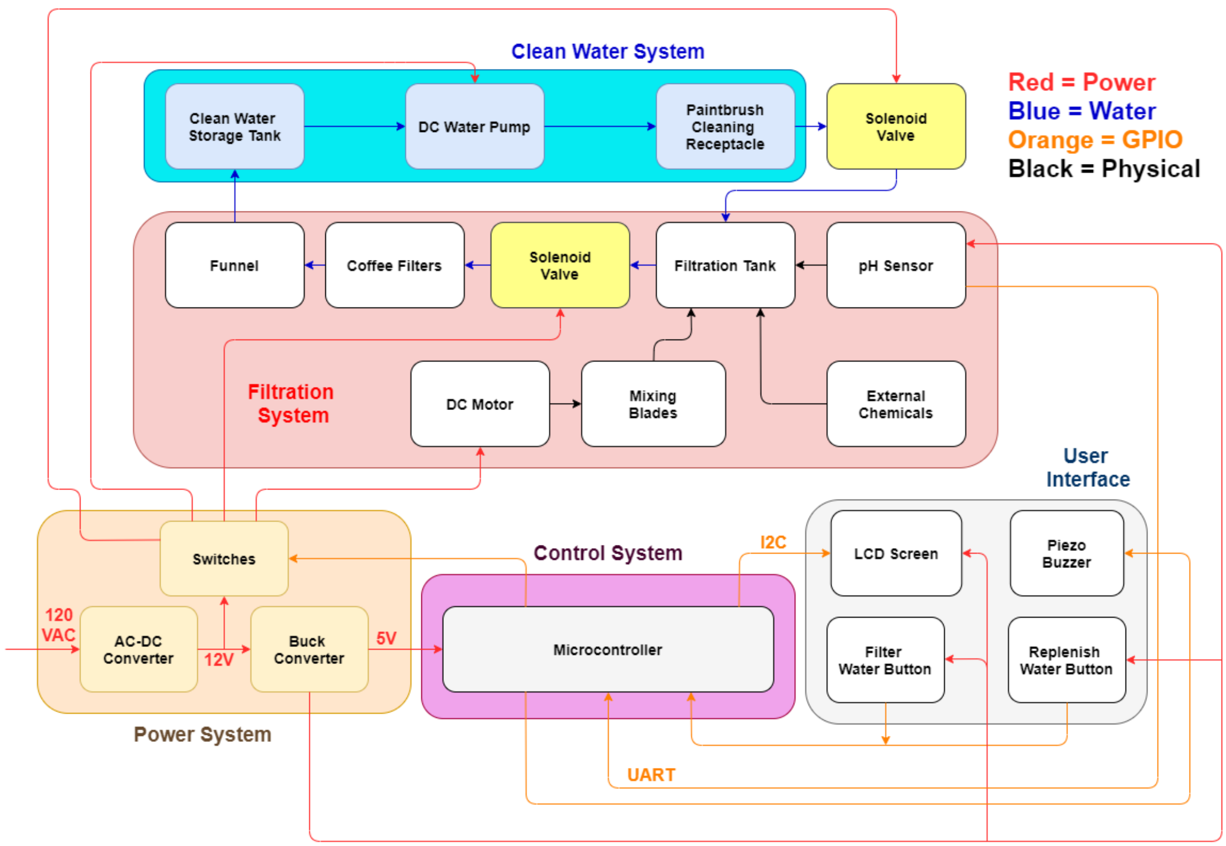

Figure 2: Block Diagram of Electric Paintbrush Cleaner

Figure 2 depicts the functional block diagram of the device. On startup, the user presses the "replenish water" button to fill the cleaning receptacle with fresh water from the clean water storage tank, with the clean water directed up to the cleaning receptacle via a dc water pump and tubing system. When the user wants to get a new supply of water, pressing the "replenish water" button again empties the dirty water from the receptacle into the filtration tank through a solenoid valve before refilling the clean water receptacle with new water. As contaminated water pours into the filtration tank, the microcontroller keeps track of the wastewater's pH using the pH sensor, while also keeping track of the amount of water in the filtration tank based on how many times the user has requested a refill of clean water.

From the pH of the wastewater along with its volume, the microcontroller computes the amount of aluminum sulfate solution the user should add to the contaminated water and displays this value to the LCD screen. To filter the wastewater, the user adds the amount of aluminum sulfate solution specified by the LCD screen to the filtration tank and then presses the “filter water” button, causing the dc motor to turn the mixing blades to begin the flocculation process. Once enough time has passed for the aluminum sulfate to take effect, the piezo buzzer will beep two times to signal the user to add the correct amount of hydrated lime powder as specified by the LCD screen. After adding the hydrated lime powder, the user presses the “filter water” button once again to resume the treatment of the wastewater, causing the dc motor and mixing blades to mix the solution to ensure even distribution of the hydrated lime powder. When sufficient time has passed for the acrylic paint particles to fully separate from the water, the microcontroller switches on a solenoid valve to release the treated water from the filtration tank, allowing the recycled water to fill into the clean water storage tank via a funnel as the flocculated paint particles are collected in the coffee filters. The piezo buzzer will beep three times when the filtration is complete.

2.2 Physical Design

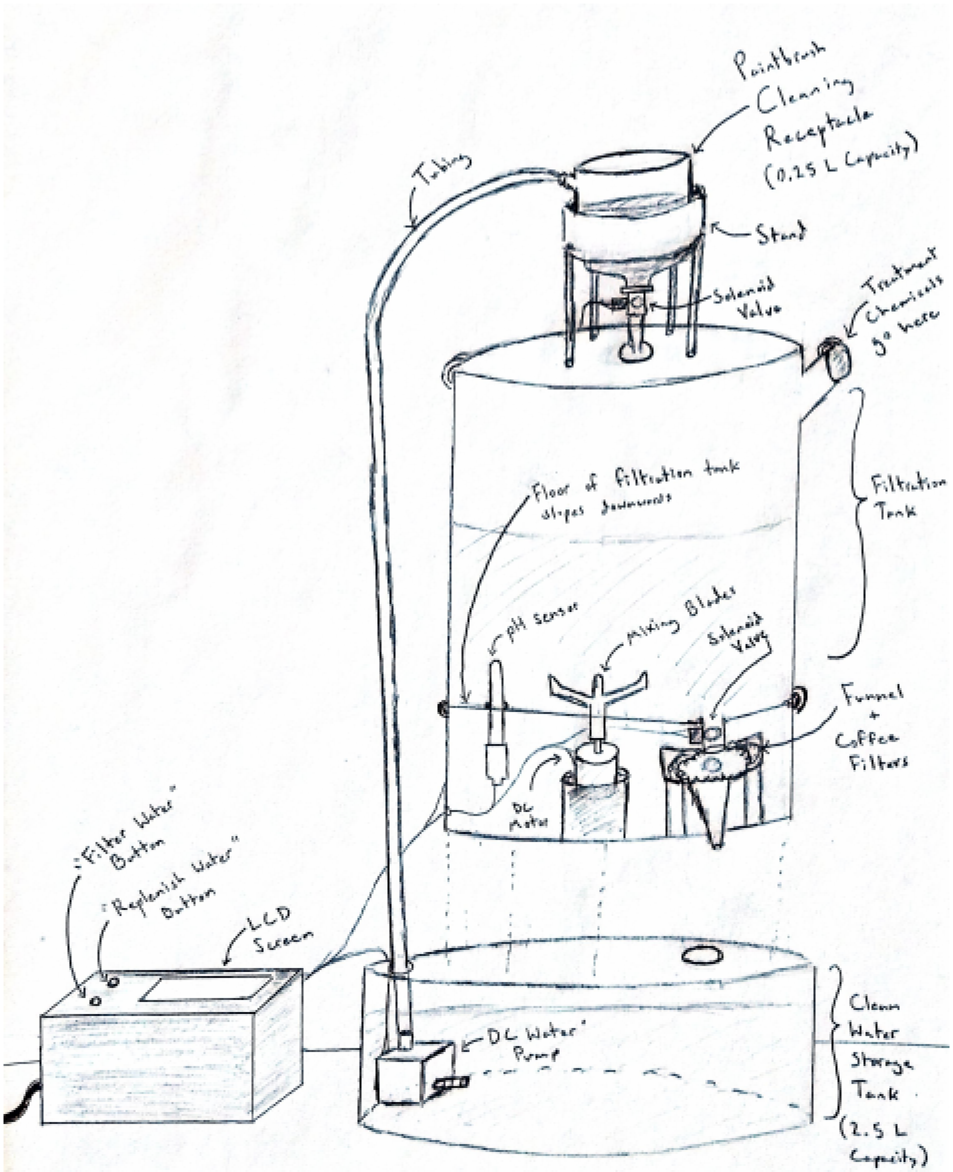

Figure 3: Electric Paintbrush Cleaner Physical Design

Figure 3 illustrates the physical design of our proposed solution. The paintbrush cleaning receptacle sits over the filtration system, which is positioned on top of the clean water storage tank. The overall device is designed such that gravity will naturally direct the contaminated wastewater downwards, as this enables the solenoid valves to open and close off the flow of water on command. Adjacent to the water distribution and treatment system is the user interface, which allows the user to choose when to receive refills of clean water and when to start the filtering process.

2.3 Control System

The control system is responsible for controlling when the solenoids, motor, and pump are switched on, processing the data from the pH sensor, displaying information to the LCD screen, and handling user input. The control system plays an integral role in governing the flow of water between the separate components of the overall system.

2.3.1 Microcontroller

The microcontroller is powered from the 5 V output of the power system's buck converter and awaits high signals from either of the buttons on the user interface before carrying out the designated functions. The microcontroller's GPIO pins are connected to the MOSFETs, the LCD screen, the user interface buttons, and the pH sensor. In addition to sending/receiving signals from the hardware peripherals, the microcontroller also keeps track of how much water the user has used up. The microcontroller chosen for this project is the ATmega328P microcontroller since it can be easily programmed using Arduino sketches by burning the Arduino bootloader to the chip. The ATmega328P also has sufficient digital pins needed to drive the MOSFETs and other peripherals. The necessary requirements and verifications for the microcontroller are displayed in Table 1.

Table 1: Microcontroller Requirements and Verifications

Requirement	Verification
The microcontroller can provide 5V ± 10% to the gate of the MOSFETs via digital output pins for a continuous duration of at least two minutes.	A. Connect pin 15 of microcontroller to MOSFET gate. B.Set output of pin 15 to HIGH. C. Measure voltage across pin 15 and GND, observing signal on oscilloscope for two minutes. D. Repeat for pins 16, 18, and 19.
The microcontroller's digital inputs can register a voltage of less than 1V as a logical LOW and greater than 4V as a logical HIGH.	A. Connect output of bench power supply to pin 4 of microcontroller. B. Connect pin 15 of microcontroller to external LED. C. Write and upload Arduino sketch setting output of pin 15 to HIGH if pin 4 reads HIGH, while keeping pin 15 LOW if pin 4 reads LOW. D. Set output of power supply to 0.9V, and ensure LED stays off, set output of power supply to 4.1V and ensure LED turns on. E. Repeat process replacing pin 4 with pin 6.
The microcontroller can transmit and receive data over UART at a baud rate of 9600 bits per second.	A.Connect microcontroller RX and TX pins to a USB to TTL adapter. B. Start PuTTY session on PC with serial speed set to 9600 baud. C. Write and upload Arduino sketch to read available serial data and print back received data via serial port. D. Send text to microcontroller via PuTTY terminal and verify that sent text is received back.
The microcontroller can display text to the LCD Screen via the I2C protocol.	A. Connect microcontroller SDA and SCL pins to LCD screen's I2C adapter. B. Upload I2C 'Hello World LCD' sketch from LiquidCrystal library to microcontroller. C. Verify that 'hello world' text is displayed on LCD screen.

2.4 Power System

The power system is responsible for supplying power to each of the device modules, providing outputs of 12 V dc and 5 V dc from a 120 V ac input. The 12 V dc supply will be directly available from an ac-dc converter that plugs into the wall, whereas the 5 V dc supply is obtained from a buck converter that steps the 12 V from the ac-dc converter down to a usable 5 V. In addition to the power converters, the power system also consists of four MOSFETs that are used as switches to switch the dc motor, dc water pump, and two solenoids on and off.

2.4.1 AC-DC Converter

The ac-dc converter converts a 120 V ac input to a 12 V dc output, which is used to supply power to the dc motor, dc water pump, and solenoids. The 12 V output is also used as an input to the buck converter. Because the ac-dc converter serves as the main power source for all of the electrical components, the converter is responsible for maintaining a sufficient current supply, with maximum estimates of 60 mA for the pH sensor, 550 mA for each solenoid, 2 A for the dc motor, 1 A for the dc water pump, 40 mA for the LCD screen, and 200 mA for the microcontroller. The requirements and verifications for the ac-dc converter are displayed in Table 2.

2.4.2 Buck Converter

The buck converter steps down the 12 V from the ac-dc converter to a usable 5 V for the microcontroller and the dc gear motor. A switching converter was chosen over a linear regulator to prioritize efficiency given the significant voltage differential between the available 12 V input and the required 5 V output. Our buck converter of choice is the VXO7805-500 manufactured by CUI Inc., which accepts an input range of 6.5 V - 36 V and provides an output current of up to 500 mA. The requirements and verifications for the buck converter are displayed in Table 2.

Table 2: Power Converter Requirements and Verifications

Requirement	**Verification**
The ac-dc converter must maintain an output voltage of 12V within ± 5%, while supplying at most 3.5A of continuous current.	A.Program dc electronic load to draw 3.5A of current. B. Use a multimeter to measure the current drawn, verifying that the current being supplied is at most 3.5A. C. Measure output voltage of ac-dc converter with oscilloscope, making sure voltage remains between 11.4V and 12.6V.
The buck converter must maintain an output voltage of 5V within ± 5%, while supplying at most 300mA of continuous current.	A.Program dc electronic load to draw 300mA of current. B. Use a multimeter to measure the current drawn, verifying that the current being supplied is at most 300mA. C. Measure output voltage of buck converter with oscilloscope, making sure voltage remains between 4.75V and 5.25V.
The buck converter can reach an efficiency of at least 80% when supplying 100mA of current.	A. Program dc electronic load to draw 100mA of current. B. Measure current and voltage at buck converter input, as well as current and voltage buck converter output. C. Divide output power by input power and ensure buck converter efficiency is at least 80%.

2.5 MOSFETs

The MOSFETs are used as simple switching mechanisms to turn the electromechanical components on and off. Since the microcontroller can only source a limited amount of current, the MOSFETs act as switches to drive the dc water pump, dc motor, and solenoids directly from the power system by connecting them to the 12 V output of the ac-dc converter. A low-side configuration for the MOSFETs is necessary to allow the microcontroller to switch the MOSFETs without the need for a gate driver. The requirements and verifications for the MOSFETs are displayed in Table 3.

Table 3: MOSFET Requirements and Verifications

Requirement	**Verification**
MOSFET drain-source channel must conduct upon the application of 5V $\pm$ 10% to the gate via the microcontroller.	A. Connect MOSFET drain to one terminal of a 100Ω resistor, with the other terminal of the resistor connected to power supply. B. Attach a 10kΩ pull-down resistor to gate of MOSFET, tying it to GND. Connect source of MOSFET to GND. C. Configure ammeter to measure current into drain of MOSFET. D. Apply a voltage greater than threshold voltage from microcontroller digital output pin to transistor gate, verifying that current is conducting from drain to source.
MOSFET operates at a temperature no greater than 70° C when driving its corresponding electromechanical component.	A. Connect solenoids, dc motor, and dc water pump to MOSFETs as detailed in Figure 5. B. Apply 5V to gate of each MOSFET from lab bench power supply. C. After one minute, measure temperature of MOSFETs with IR thermometer and verify that temperature is no greater than 70° C.
Voltage drop across MOSFET drain-source terminals must be less than 0.2V when it is conducting.	A. After performing previous verification, while each MOSFET is still conducting, place a voltmeter across the drain and source terminals and measure the voltage drop.

2.6 Clean Water System

The clean water system is responsible for controlling the flow of clean water throughout the system. This system consists of a clean water storage tank, a paint brush cleaning receptacle, and a dc water pump. The main purpose of this system is to deliver clean water to the user in a timely manner, and plays an essential role in providing the user with an uninterrupted painting experience.

2.6.1 Clean Water Storage Tank

The clean water storage tank initially holds the entire supply of the clean water used for rinsing paintbrushes. The clean water storage tank physically sits below the filtration system. Before using the device, the user can separately fill the clean water storage tank to a maximum capacity of 2.5 liters, which will be indicated by a physical marking on the tank. The requirements and verifications for the clean water storage tank are displayed in Table 4.

2.6.2 Paintbrush Cleaning Receptacle

The paintbrush cleaning receptacle is the designated station where the user can rinse their paintbrushes. Tubing is connected to the top of the cleaning receptacle to deliver new water, while a solenoid is positioned at the bottom of the cleaning receptacle to empty dirty water into the filtration tank. The requirements and verifications for the paintbrush cleaning receptacle are displayed in Table 4.

Table 4: Clean Water Storage Tank and Cleaning Receptacle Requirements and Verifications

Requirement	Verification
The clean water storage tank can securely hold up to 2.5L of water without any leaks coming from the tank.	A. Fill up the clean water tank to the designated water level and carry it around to make sure no water leaks from the bottom of the tank.
The paintbrush cleaning receptacle can hold up to 0.25L of water without any water spilling from the top during the user's normal cleaning motion.	A. Fill up the paintbrush cleaning receptacle with 0.25L of water. B. Dip a paintbrush into the paintbrush cleaning receptacle and swish it around quickly, making sure that the water level remains below the tip of the receptacle.

2.6.3 Dc Water Pump

The dc water pump is responsible for delivering water from the clean water storage tank to the cleaning receptacle. The dc water pump is powered from the 12 V output of the ac-dc converter and sits within the clean water tank. The dc water pump turns on immediately after the user presses the "replenish water" button. The requirements and verifications for the dc water pump are displayed in Table 5.

Table 5: Dc Water Pump Requirements and Verifications

Requirement	Verification
The dc water pump can deliver 0.25L of water from the clean water storage tank to the cleaning receptacle within five seconds of the MOSFET switching the pump on.	A. Fill up the clean water tank with 2.5L of water. B. Apply a 5V dc signal from a lab bench power supply to the gate of the MOSFET, starting a timer as soon as the voltage is applied. C. Measure how much time it takes for the water in the paintbrush cleaning receptacle to reach the 0.25L mark, stopping the timer as soon as this mark is reached. D. Repeat steps A through C three more times to makes sure the performance of the dc water pump is consistent.

2.7 Filtration System

The filtration system is used to take the wastewater from the paintbrush cleaning receptacle and remove the acrylic paint particles from the water, allowing the user to both recycle the water and efficiently separate and safely dispose of the acrylic plastics. To achieve this, the filtration system relies on the use of aluminum sulfate and hydrated lime powder to cause the acrylic paint particles to clump together and coagulate. While the aluminum sulfate is used to initiate the coagulation of the acrylic paint particles, the hydrated lime powder is used to balance out the acidity of the aluminum sulfate to increase the effectiveness of the coagulation. The filtration system is a very environmentally conscious addition to our project because it promotes the saving of clean water as well as impedes the pollution of the community's water system.

2.7.1 Solenoid Valves

The solenoid valves open and close when triggered by the microcontroller to control the flow of water from the cleaning receptacle to the filtration tank, and from the filtration tank into the funnel and coffee filter. The requirements and verifications for the solenoid valves are displayed in Table 6.

Table 6: Solenoid Valves Requirements and Verifications

Requirement	**Verification**
The solenoid valves open and close within 1.5 seconds of the MOSFETs switching the solenoids on and off.	A. Apply a 5V dc signal from a lab bench power supply to the gate of the MOSFET, starting a timer as soon as the voltage is applied. B. Stop the timer as soon as the solenoid valve audibly clicks open, ensuring that the elapsed time is less than 1.5 seconds. C. Repeat steps A and B, this time changing the 5V signal to a 0V signal and measuring how long it takes for the solenoid to audibly click closed.

2.7.2 Dc Motor

The dc motor is used to turn the mixing blades in the filtration tank to mix the aluminum sulfate and hydrated lime powder into the wastewater, ensuring a thorough and even distribution. The dc motor is placed in a compartment that sits between the two levels of the filtration system, with its shaft locking into an insert at the bottom of the filtration tank, similar to a blender. The requirements and verifications for the dc motor are displayed in Table 7.

Table 7: Dc Motor Requirements and Verifications

Requirement	Verification
The dc motor can maintain a speed of at least 100 RPM when the filtration tank is at maximum capacity.	A. Fill the filtration tank with 2.5L of water. B. Attach the shaft of the dc motor to the mixing blades and place a piece of white tape on the shaft. C. Apply 12V dc to the motor terminals and measure the speed of the motor using a stroboscope, ensuring that the RPM is at least 100 RPM.

2.7.3 pH Sensor

The pH sensor is used to measure the pH of the wastewater as it is treated by the aluminum sulfate and hydrated lime powder, ensuring that it is within a safe range to begin filtering. The pH sensor is powered with 5 V from the buck converter and is connected to one of the microcontroller's analog input pins. After measuring the pH of the collected wastewater, this data is used to calculate exactly how much chemical agent must be added for a successful filtration. This will ensure no chemical is wasted due to excessive use, saving the consumer money in the long term. The requirements and verifications for the pH sensor are displayed in Table 8.

Table 8: pH Sensor Requirements and Verifications

Requirement	**Verification**
The pH sensor must return a pH reading to the microcontroller that indicates a measurement accurate to within ± 0.3 pH of actual values.	A. Dissolve 5.0g of aluminum sulfate in 1.5L of distilled water to create a 0.01 Molar solution of aluminum sulfate with a pH of 2.0. B. Measure the pH of the aluminum sulfate solution with a pH strip to confirm a pH of 2.0. C. Measure the pH of the aluminum sulfate solution with the pH sensor, ensuring that the measured pH is between 1.7 and 2.3.

2.7.4 Coffee Filters

The coffee filters are placed within the funnel and used to capture the flocculated acrylic paint particles. After each use, the user is responsible for disposing of the coffee filters and replacing them. The requirements and verifications for the coffee filters are displayed in Table 9.

Table 9: Coffee Filters Requirements and Verifications

Requirement	**Verification**
The coffee filters must not tear during the filtering of the treated wastewater.	A. Treat 2.5 L of wastewater with aluminum sulfate and hydrated lime powder, allowing the acrylic paint particles to flocculate. B. Open the solenoid valve between the filtration tank and the funnel, allowing all of the treated wastewater to pour out of the filtration tank. C. Once the filtration tank is empty, check that the coffee filters have not torn.

2.8 User Interface

The user interface allows the user to control when a new supply of clean water is directed to the clean water receptacle, as well as when the filtration process should begin. An LCD screen displays information to the user regarding how many refills are left, the current pH of the wastewater, and how much aluminum sulfate or hydrated lime powder is needed to treat the wastewater. Additionally, a buzzer is used to alert the user during the filtration process.

2.8.1 Push Buttons

The device has two push buttons. The first push button allows the user to request a refill of new water for the cleaning receptacle, and the second push button is used to start and resume the filtration process once the proper amounts of aluminum sulfate and hydrated lime powder have been added. The requirements and verifications for the push buttons are displayed in Table 10.

Table 10: Push Button Requirements and Verifications

Requirement	Verification
The push buttons connect the digital input pins of the microcontroller with a signal corresponding to a logical HIGH when pressed, and LOW when unpressed.	A. Wire the two push buttons to the microcontroller using pull-down resistors as shown in Figure 4. B. Connect a voltmeter across pin of the microcontroller and GND of the microcontroller. C. Verify that a voltage greater than 4V is measured on the voltmeter when the button is pressed, and that a voltage less than 1V is measured on the voltmeter when the button is unpressed. D. Repeat steps A through C replacing pin with pin.

2.8.2 LCD Screen

The LCD screen is powered from the buck converter's 5 V output and displays information to the user, such as how many refills of clean water the user has left and the amount of aluminum sulfate and hydrated lime powder to add during the filtration process. The LCD screen is connected to the microcontroller via an I2C adapter to free up extra pins on the microcontroller. The requirements and verifications for the LCD screen are displayed in Table 11.

Table 11: LCD Screen Requirements and Verifications

Requirement	Verification
The text on the LCD screen should be readable by the user from a distance of up to at least 3 feet from the device.	A. Run the 'Hello World LCD' sketch on the microcontroller to upload text to the LCD screen. B. Using a tape measure, measure a distance of 3 feet away from the LCD screen. C. Ensure that the text is still eligible to read from the measured distance.

2.8.3 Piezo Buzzer

The piezo buzzer is used specifically for alerting the user during the filtration process. Because the aluminum sulfate and hydrated lime powder need time to take effect, having a buzzer allows the user to walk away from the device during these waiting periods. The requirements and verifications for the piezo buzzer are displayed in Table 12.

Table 12: Piezo Buzzer Requirements and Verifications

Requirement	Verification
Buzzer can output sounds at a noise level of at least 40dB.	A. Run Arduino sketch to output a continuous tone to the buzzer. B. Measuring the output noise with a decibel meter, place a microphone at least six inches away from the piezo buzzer. C. Verify on the decibel meter that the noise output is greater than or equal to 40dB.
Buzzer can produce audible tones from a minimum range of 300Hz to 1000Hz.	A. While performing the previous verification, change the Arduino sketch to output a 300Hz tone and then a 1000Hz tone, verifying that both tones remain over 40dB.

2.9 Tolerance Analysis

Overall, the most critical feature for the project is the filtration system. If the filtration system does not properly filter the water, then we are no longer offering any unique or useful solution to our problem, and we fail our second high level requirement. In addition, the filtration system is a two-part system. First, the aluminum sulfate and hydrated lime powder must be properly dispensed and mixed into the contaminated wastewater. Second, the treated wastewater then must be filtered through a funnel and a coffee filter to collect the flocculated acrylic paint particles. If anything goes wrong in these two steps, then the filtration system will not work.

The main challenge that comes with the implementation of the filtration system is accurately determining the amounts of aluminum sulfate and hydrated lime powder needed to effectively separate the particulates from the water. The aluminum sulfate causes the acrylic paint particles to coagulate, but since aluminum sulfate is acidic in nature, adding it to the wastewater decreases the overall pH. Because aluminum sulfate is most effective as a coagulant at pH levels between 5.0 and 7.0, the hydrated lime powder is used to bring the pH of the wastewater back up, decreasing its acidity. Therefore if the incorrect amounts of either of these chemicals are added to the wastewater, what we will end up with is a solution of treated water that is not fit for recycling, which would automatically cause us to fail our second high-level requirement; this makes the pH range requirement the most difficult one to meet. In order to successfully implement the filtration system, we will need to quantify how much aluminum sulfate and hydrated lime powder are needed to change the pH of a specific volume of liquid to a target value.

Our second high level requirement states that the acceptable range for the pH of the recycled water is between 6.5 and 8.5. If we start with the a pH of 7 assuming we have an ideally pure solution of water, then we can analyze the worst-case scenarios for how much aluminum sulfate and hydrated lime powder we can add. First, the aluminum sulfate will lower the pH, corresponding to an increase in acidity. 15-25 mg/L of aluminum sulfate is reported to lower pH by 0.4-1.5 units [5]. So if we want to lower the pH by 0.4 to give us the lower end of our allowed pH range (7.0 - 0.4 = 6.6), we can add 3.75 mg of aluminum sulfate for every 0.25 liters of wastewater (the amount produced for each refill) by Equation (1).

$$\frac{15mg\ Al_2(SO_4)_3}{1L\ Water} \cdot 0.25L\ Water = 3.75mg\ Al_2(SO_4)_3\ \textit{to decrease pH by 0.4} \qquad [1]$$

To evaluate the tolerance for potential errors in the measurement of aluminum sulfate, a 6.25 mg amount of aluminum sulfate lowers the pH by 1.5 as calculated in Equation (2), bringing us down to a pH of 1 unit under our accepted range (7.0 - 1.5 = 5.5).

$$\frac{25mg\ Al_2(SO_4)_3}{1L\ Water} \cdot 0.25L\ Water = 6.25mg\ Al_2(SO_4)_3\ \textit{to decrease pH by 1.5} \qquad [2]$$

To raise the pH back up, we need to add the hydrated lime powder. Two tablespoons of hydrated lime powder has been found to raise the pH of a solution by 1 unit on average [5]. Thus if we added 2 tablespoons of hydrated lime powder after adding 6.25 mg of aluminum sulfate, we will end up at the lower end of our range, allowing us to still meet our second high-level requirement by Equation (3).

$$7.0\ units - 1.5\ units + 1.0\ unit = 6.5\ units\ on\ the\ pH\ scale \qquad [3]$$

Similarly, adding two tablespoons of hydrated lime powder after adding 3.75 mg of aluminum sulfate still puts us within range to meet our second high-level requirement by Equation (4). This also tells us that if we want to find the tolerance for reaching the upper limit of the pH scale, then the acrylic wastewater can have a pH of up to 7.9 by Equation (5).

$$7.0\ units - 0.4\ units + 1.0\ unit = 7.6\ units\ on\ the\ pH\ scale \qquad [4]$$

$$8.5\ units + 0.4\ units - 1.0\ unit = 7.9\ units\ on\ the\ pH\ scale \qquad [5]$$

2.10 Schematics and Pseudocode

Figure 4 depicts the schematic of the control system for the electric paintbrush cleaner, consisting of the microcontroller, the LCD screen, the buck converter, the pH sensor board, and the piezo buzzer. Figure 5 depicts the schematic layout for the wiring of the electromechanical components (i.e. dc motor, dc water pump, and two solenoids). The device psuedocode is shown in Figure 6.

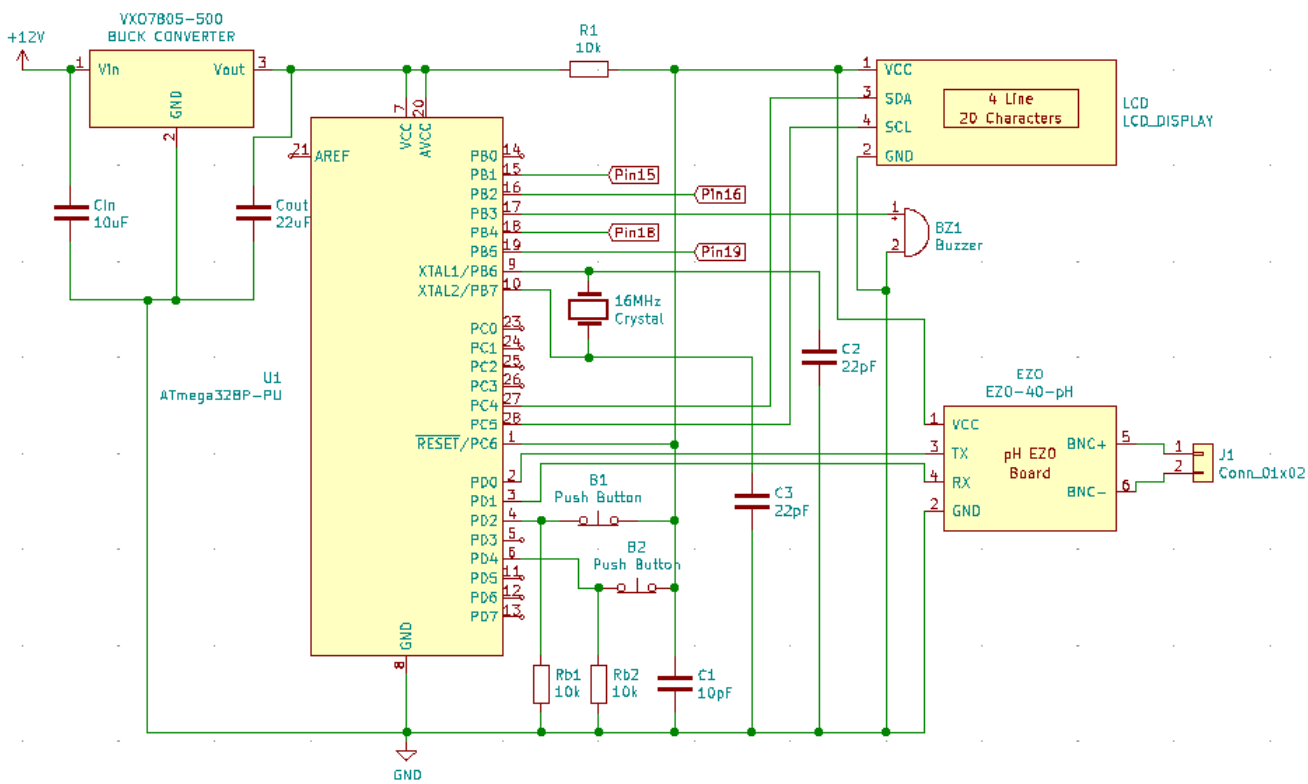

Figure 4: Control System Schematic for Electric Paintbrush Cleaner

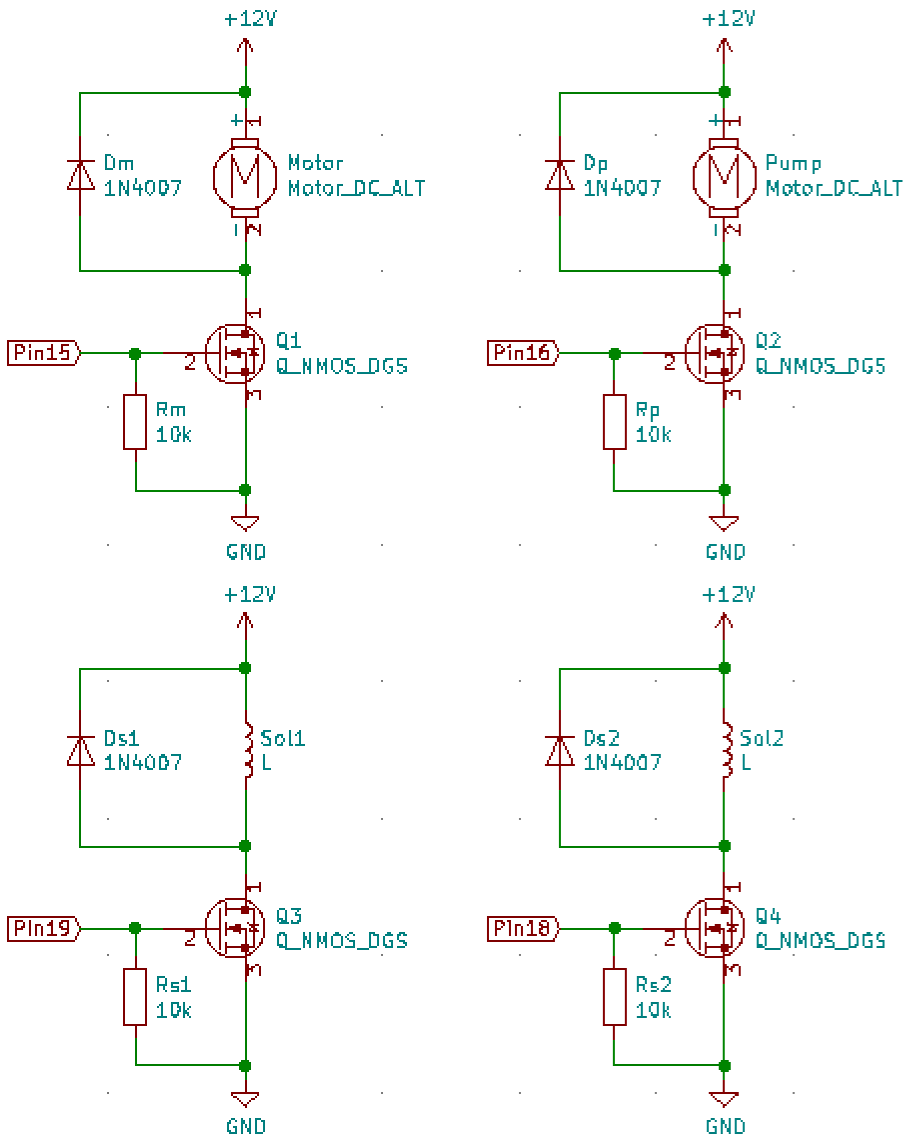

Figure 5: Electromechanical Components Schematic for Electric Paintbrush Cleaner

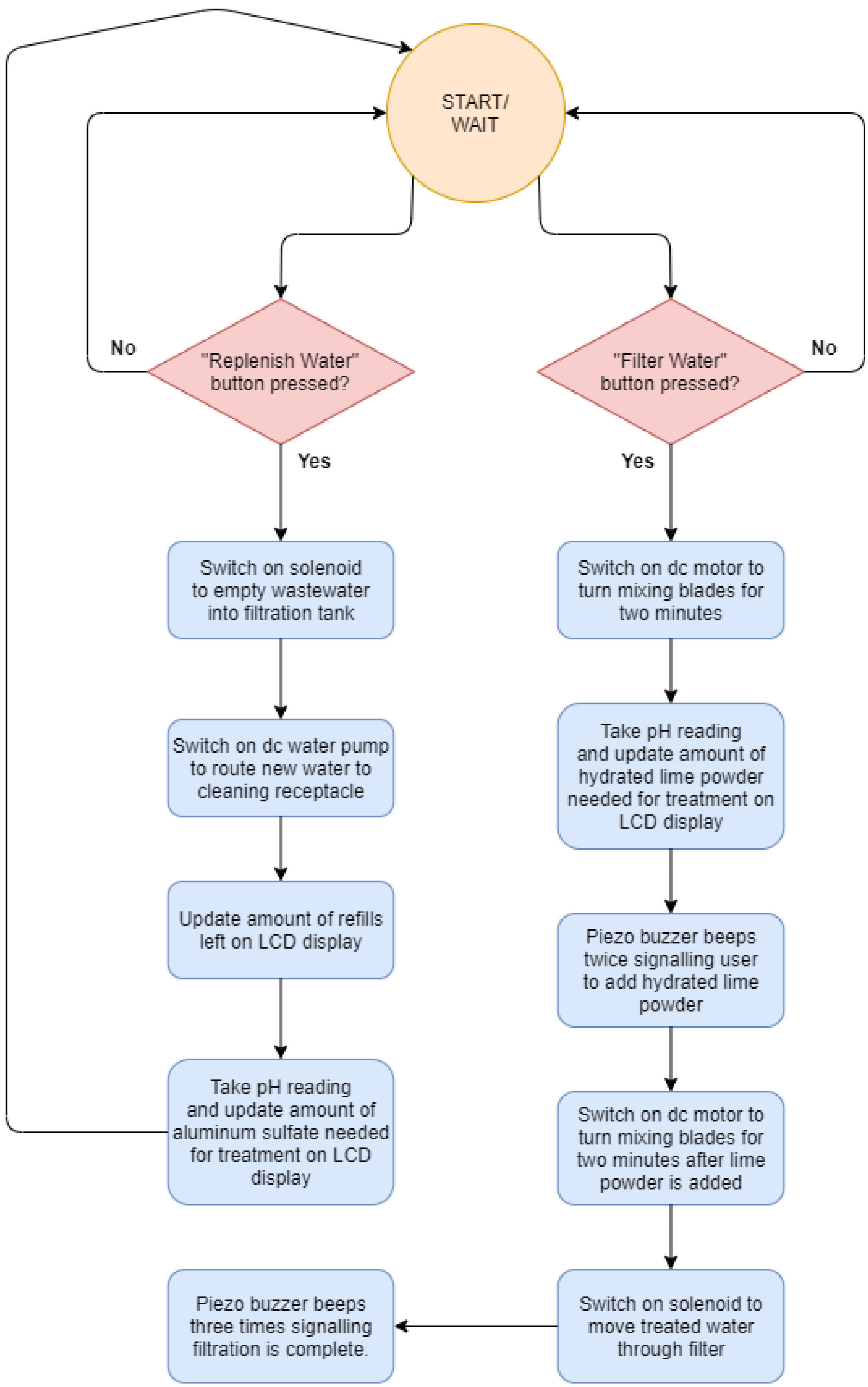

Figure 6: Electric Paintbrush Cleaner Pseudocode

3 Project Differences

3.1 Overview

For our original solution, we proposed a device that would clean paintbrushes by spraying clean water down onto the paintbrush, allowing dirty water to be collected in a removable water collection receptacle sitting below the paintbrush. Upon the insertion of the paintbrush into the device, a PIR sensor would detect the motion of the paintbrush and trigger a dc water pump, directing clean water from a storage tank on top of the device down to a spray valve positioned over the paintbrush. After rinsing the paintbrush, a rotating brush system actuated forward by a stepper motor would clean the bristles of the paintbrush to remove any dried paint particles.

Our newly proposed solution differs from our previous solution in three major aspects. The first major change for our new design is that we have removed the motorized brush system that was proposed in our initial design entirely. Realistically, we were not sure how effective a rotating cleaning brush would be at cleaning a paintbrush given the flexibility and density of paintbrush bristles. Additionally, the wait time experienced by the user during the deployment of the brush system would require more time for cleaning than if the user was to just swish their paintbrush around in a regular cup of water, making the cleaning process more less convenient than it should be.

The second major change for our new design is that paintbrushes will now be inserted vertically into a cleaning receptacle for cleaning instead of horizontally into a cleaning compartment where a spray valve directs water onto the paintbrushes. While our previous solution was not equipped to handle brushes of various sizes due to the constraints of directing water from a spray valve of a fixed size, our new solution is designed to work with any paintbrush that can have its bristles dipped into the circumference of a regular mug. Replacing the spray valve with a cleaning receptacle also allows for a more efficient use of cleaning water compared to the previous design.

Finally, the most significant change for our new solution is that its use is now focused around the implementation of a filtration system. Because our previous design had no way of filtering or recycling the contaminated rinse water, it was intended for use among painters working with watercolor paints. However, since the new design filters the rinse water, allowing water to be recycled and acrylic particles to be disposed of, this product is targeted towards painters working with acrylic paints, as this market has an intrinsically higher need/demand compared to watercolor paints due to reasons previously mentioned.

Comparing the advantages and disadvantages of the two designs, each design comes with its own set of trade-offs. Although our new design is more environmentally friendly since it gives users the ability to filter acrylic paint water, this comes at the cost of the overall compactness of the product since the filtration system causes the new design to take up more physical space than the original design. With the addition of the filtration system, the new design also requires more maintenance on behalf of the user. While the cleaning brush was the only component that would need to be replaced by the user after multiple uses in the previous design, the new design requires the user to replace the coffee filters after each filtration cycle, and the user is also responsible for providing their own supply of aluminum sulfate and hydrated lime powder. Although the filtration process is not fully automated since dispensing varying amounts of chemical treatments would be a separate project in and of itself, our new design does manage to reduce the work put in by users who want to properly dispose of acrylic wastewater.

In addition to providing a solution for the disposal of acrylic paint wastewater, our new design excels over the previous design in its ability to make efficient use of the reserved cleaning water. In our original solution, every paintbrush would receive the same amount of water from the spray valve regardless of its size, meaning that paintbrushes with finer tips would use up more water than necessary, and paintbrushes with larger tips would potentially require multiple rinses. Because our new solution implements a clean water receptacle that gives the user full control over when to receive a new supply of clean water, this allows the user to replace the water as frequently as they desire. This design aspect of our newly proposed solution is especially important considering that when working with multiple colors, it makes sense for painters to only use a fresh supply of clean water when switching between colors, as this prevents the unwanted mixing of colors on the canvas.

3.2 Analysis

In order to quantify the improved efficiency of our new solution with regard to water consumption, we can compare the number of times that each of our two design iterations can clean an inserted paintbrush. Both of our solutions make use of the same dc water pump as well as the same 2.5 liter maximum capacity of clean water held in the storage tank. Because our original solution cleaned paintbrushes using a continuous stream of water, the number of rinses attainable was determined by taking the amount of time required to clean a single brush and multiplying by the flow rate of the water dispensed by the water pump. Given that an average of four seconds would be required to clean each paintbrush under the spray valve's stream of water, along with the dc water pump's flow rate of 9.16 liters per minute, Equation (6) highlights how our original solution could only rinse a paintbrush four times before running out of clean water.

$$\frac{1\ rinse}{4\ sec} \cdot \frac{60\ sec}{1\ min} \cdot \frac{1\ min}{9.16\ L} \cdot 2.5\ L = 4.07\ rinses \approx 4\ rinses \qquad [6]$$

Because our new solution enables users to control how often they receive a fixed amount of water, there is some flexibility in the amount of paintbrush rinses our new solution provides to painters. Our new solution's clean water receptacle is designed to hold a maximum of 0.25 liters of clean water, meaning that the receptacle can be filled up ten times by Equation (7).

$$\frac{1\ refill}{0.25\ L} \cdot 2.5\ L = 10\ refills \qquad [7]$$

Therefore for our new solution, the amount of times a user can rinse their paintbrush depends entirely on the amount of rinses they decide to use per refill. This number can vary based on several factors, such as the size of the paintbrush and the amount of each paint color the painter plans to use. Due to this variability, a safe assumption is that users can rinse their paintbrush in the cleaning receptacle four times before the water becomes too murky and needs to be refilled. A more optimistic figure would be seven rinses per refill, while the absolute worst-case scenario would be one rinse per refill, although this figure is highly unlikely. Taking these three estimates into consideration, our new solution can provide users with a worst-case of ten total rinses, an average of 40 rinses, and a best-case of 70 rinses for 2.5 liters of water stored in the clean water tank. Equations (8), (9), and (10) evaluate the overall improvement of our new design compared to the original design for each of these cases.

$$Estimated\ Minimum\ Efficiency\ Improvement : \left(\frac{10\ rinses}{4\ rinses}\right) = 2.5x\ More\ Rinses \qquad [8]$$

$$Estimated\ Average\ Efficiency\ Improvement : \left(\frac{40\ rinses}{4\ rinses}\right) = 10x\ More\ Rinses \qquad [9]$$

$$Estimated\ Maximum\ Efficiency\ Improvement : \left(\frac{70\ rinses}{4\ rinses}\right) = 17.5x\ More\ Rinses \qquad [10]$$

4 Cost Analysis and Schedule

4.1 Cost Analysis

4.1.1 Cost of Labor

Assuming each of us works 10 hours per week at an hourly rate of \$35/hour over the course of 10 weeks, the total cost of labor is \$26,250, as calculated in Equation (11).

$$3 \cdot \frac{\$35.00}{1\,hour} \cdot \frac{10\,hours}{1week} \cdot 10\,weeks \cdot 2.5 = \$26,250 \qquad [11]$$

4.1.2 Cost of Parts

The parts required to complete our project, along with their respective costs are outlined in Table 13. Overall, the estimated cost for parts is $276.57.

Table 13: Cost Breakdown of Required Parts

Description	**Manufacturer**	**Part Number**	**Quantity**	**Unit Price**
MOSFET	Nexperia	PSMN022-30PL	2	$0.90
Buck Converter	CUI Inc.	VXO7805-500	1	$2.36
AC-DC Converter	Signcomplex	ZF120A-1204000	1	$15.58
pH Sensor	Atlas Scientific	ENV-40-pH	1	$75.00
pH Sensor Board	Atlas Scientific	EZO-pH	1	$40.00
Solenoid Valve	Plum Garden	PL-220101	2	$9.55
DC Water Pump	DFRobot	FIT0563	1	$9.29
DC Motor	Greartisan	12V 200RPM	1	$15.99
LCD Screen	SunFounder	I2C LCD2004	1	$12.99
Microcontroller	Atmel	ATMEGA328P	1	$2.08
Pack of Pushbuttons	Sparkfun	COM-10302	1	$5.85
Aluminum Sulfate (2 lbs)	FDC	16828-12-9	1	$11.99
Hydrated Lime Powder (2 lbs)	Hi-Yield	33362	1	$14.99
Miscellaneous (PCB/Manufacturing)	Various	Various	N/A	$60.00
Total				**$276.57**

4.1.3 Total Costs

Taking both the cost of labor and the cost of parts into account, the estimated total cost of the project is displayed in Table 14. Overall, the total estimated cost of the project is $26,526.57.

Table 14: Total Cost Evaluation

Item	**Associated Cost**
Labor	$26,250
Parts	$276.57
Total	$26,526.57

4.1.4 Schedule

Table 15 describes the weekly breakdown of our assigned tasks up until the completion of the project and the final presentation.

Table 15: Weekly Project Schedule

Week	**Luis**	**John**	**Yael**
Week 1	Finalize and order necessary parts.	Talk to machine shop regarding physical design of device.	Start 3D modeling of device's outer construction.
Week 2	Start verifications for clean water system.	Start verifications for filtration system.	Finalize PCB Design.
Week 3	Begin assembling physical construction of clean water system.	Refine measurements needed for proper flow of water throughout filtration system.	Start writing code and begin verifications for control system and user interface.
Week 4	Start combining clean water system with filtration system.	Test control code with each individual subsystem.	Test control system.
Week 5	Integrate subsystem with full system.	Integrate subsystem with full system.	Integrate subsystem with full system.
Week 6	Update clean water system if needed.	Update filtration system if needed.	Update control system or user interface if needed.
Week 7	Start final paper.	Start extra credit poster.	Start final presentation.
Week 8	Prepare for mock presentation and final demonstration.	Prepare for mock presentation and final demonstration.	Prepare for mock presentation and final demonstration.
Week 9	Complete final presentation, final paper, and poster.	Complete final presentation, final paper, and poster.	Complete final presentation, final paper, and poster.

5 Ethics and Safety

The first ethical/safety issue we can expect to face is dealing with the separation of water from the electrical components of our system. As cautioned by section 7.8.1 in the IEEE code of ethics, we need to face the possibility of water coming into contact with subsystems such as the power or control subsystem if the proper precautions are not taken [6]. In order to prevent the risk of electric shock to individuals, our team plans on grounding all electrical components and having covers for all the electrical components. This way, water will come in contact with the covers instead of the actual conductive elements. In addition, we plan on making our design durable enough to help prevent any spillage of water from the receptacles.

Our group also acknowledges section 7.87 of the IEEE code of ethics, and realizes there may be flaws to our design, and "we must seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others" [6]. Our main goal is to allow painters to focus on painting itself, instead of having to refill their clean water jar multiple times during the painting process. We know if our system takes too long to refill the water, or if there is not enough clean water at a given time, our solution will not be of any use to painters. This is why our group would like to try out our prototype with painters in the industry right now, and get advice on how we can improve our design. In addition, all outside parts, whether it be the MOSFETs or the ac-dc converter, will be cited as being sourced from outside distributors. Our group will credit contributors to our project in this way.

Furthermore, our group plans on creating a safety manual that informs all users of the potential risks associated with using our system, and the precautions they can take to minimize these risks. These precautions include, but are not limited to, not exceeding the max water level of the clean water tank, replacing the coffee filters after each use, always ensuring the water system is working smoothly without any clogging, and making sure there is sufficient aluminum sulfate and hydrated lime powder at all times for the filtration system to work properly. This lab manual is tentative, and subject to change. This safety manually will closely resemble those which are distributed with similar water appliances such as in-home decorative water fountains.

An important addition to this lab manual will be the safety precautions which should be taken when working with the new chemical agents for our filtration process as well as the first-aid measures in case of an emergency. For example, before working with an aluminum sulfate solution, one should always wear the appropriate personal protective equipment. Since aluminum sulfate solutions can cause skin/eye irritation, the user should always use safety goggles and gloves before starting the filtration process. If the solution is accidentally exposed to the skin or eyes, one should immediately flush/rinse the exposed area with water for up to 20 minutes. Furthermore, if the solution is accidentally ingested, a person should drink a large quantity of water or milk and should not induce vomiting [7]. We understand that children are likely to be around the machine considering painting is a very common children's activity, however, we will make it clear in the manual that the filtration process should only be carried out by a responsible adult, following the important safety guidelines. In addition, the chemical agents should be stored in a cool area out of reach from children to further avoid the possibility of an accident.

Conveniently, working with calcium hydroxide requires the same PPE, goggles and gloves, as our aluminum sulfate solution since it too can cause skin/eye irritation. When exposed to the eyes or skin, the same measures should be followed: flushing the exposed area with water for up to 20 minutes. However, when ingested, unlike with aluminum sulfate, one should at most only drink small sips of water, and instead focus on flushing out their mouth [8]. It is important to properly distinguish the two in the lab manual considering they are quite opposite. We believe the best course of action is including clearly labeled safety data sheets of both chemical agents into the lab manual thus giving the user all the information he/she needs in case of an emergency. These safety precautions once again are in support of the IEEE guidelines set in place to hold paramount the safety of the consumer [6].

Finally, as stated by the IEEE code of ethics 7.8.3, our group must "be honest and realistic in stating claims or estimates based on available data" [6]. A great example is the amount of water our clean water storage tank will be able to hold. Right now we expect this tank to hold 2.5 liters of clean water at a time, and that a painter can refill his or her cleaning receptacle at least eight times with this original water. However, if this number changes after trial and error, we will need to inform the user of this change. In addition, if we feel the rate of water being pumped through the system is too slow or too fast, this is something that must be addressed immediately. Our system will also not be considered a success unless it is easy to use. Adequate water supply at all times is the main factor for ease of use.

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