SMART ELECTRIC TOOTHPASTE DISPENSER

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Abstract

This paper documents the design, testing, and integration process of our smart toothpaste dispenser. This toothpaste dispenser is designed for those who want to optimize their oral health and those who are physically challenged by the simple task of squeezing toothpaste onto their toothbrushes. The toothpaste dispenser is adjustable for the amount of toothpaste users want to use, and have features such as battery monitoring and high portability. The project is realized by using simple but yet well-designed electrical circuit and mechanical components. In the test result, the toothpaste dispenser was able to dispense consistently dispense toothpaste within 0.05 gram of the toothpaste weight expected. Due to the fact that this device would be likely to be used in high humidity locations such as bathroom, we originally try to implement the feature of waterproofing, but the schedule for our design project was much tighter than we expected therefore we could not finish implementing such a feature. At the end, our project was successfully realized with room to improve.

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1. Introduction

1.1 Objective

Brushing our teeth may seem to be an arbitrary task in our daily life that goes over our heads, but are we doing it right? According to a study of the rational use of fluoride toothpaste, an adult should only use about 0.5 gram (a pea size) of toothpaste and a child should only use 0.25 gram of toothpaste for the best result [1]. However, many people have the habit of covering their whole surface of toothbrush bristles with toothpaste resulting in excessive amount of toothpaste used, which could eventually harm their oral health. Besides the fact that people tend to overuse toothpaste, there are also people who find the physical task of squeezing toothpaste from the tube challenging.

To tackle these problems, we propose to design an electric toothpaste dispenser that accurately control the amount of toothpaste dispensed each time in order to prevent overusing toothpaste. The dispenser should also be simple to use even for those who are physically challenged by squeezing toothpaste manually.

1.2 Background

The majority of the toothpaste dispensers in the market are manual. After purchasing one existing model of toothpaste dispenser and disassembling it, we discovered that a mechanical manual pump was used to suck toothpaste from the tube. The manual pump consists of a silicone container with two silicone one-way control valves. When the rubber container is squeezed, the toothpaste buffered in the container goes out to the user, and when the container is released, the elasticity of the container creates suction and pumps the toothpaste out of the tube.

However, this manual pump does not always work smoothly. The one-way valve frequently allows backflow unexpectedly and the user may not get toothpaste out after squeezing multiple times. When there is a little toothpaste left in the tube or the tube is left unused for a few days, the toothpaste dries, and the suction created by the user is then not strong enough to get the toothpaste out. Those electrical toothpaste dispensers currently on market generally dispense the same amount of toothpaste every time which cannot be adjusted by the user. Also, the dispenser does not have any interface for the users to know the time and the current settings. Besides, the existing devices may not be portable since battery power is not an option for those devices.

1.3 High-level Requirement

- The user should be able to input and adjust a preset value between 0.2 to 0.8 gram and the toothpaste dispenser should be able to dispense the preset amount with accuracy of 0.1gram.
- Micro-controller should be able to orchestrate the sensor, buttons, LCD screen and DC motor which drives the pump to smooth the process of detecting the toothbrush and dispensing toothpaste, while allowing users to visualize and adjust the amount of toothpaste to be dispensed.
- The whole system should be easy to clean and easy to assemble.

2. Design

Our design consists of 4 different modules: power module, I/O module, control and software module, and mechanical module. The power module regulates voltages and provides power for the whole system, the mechanical module includes the shell and the pump, the I/O module includes LCD screen, push buttons, IR sensors and motor drive, and the processor module orchestrates all the parts in I/O module.

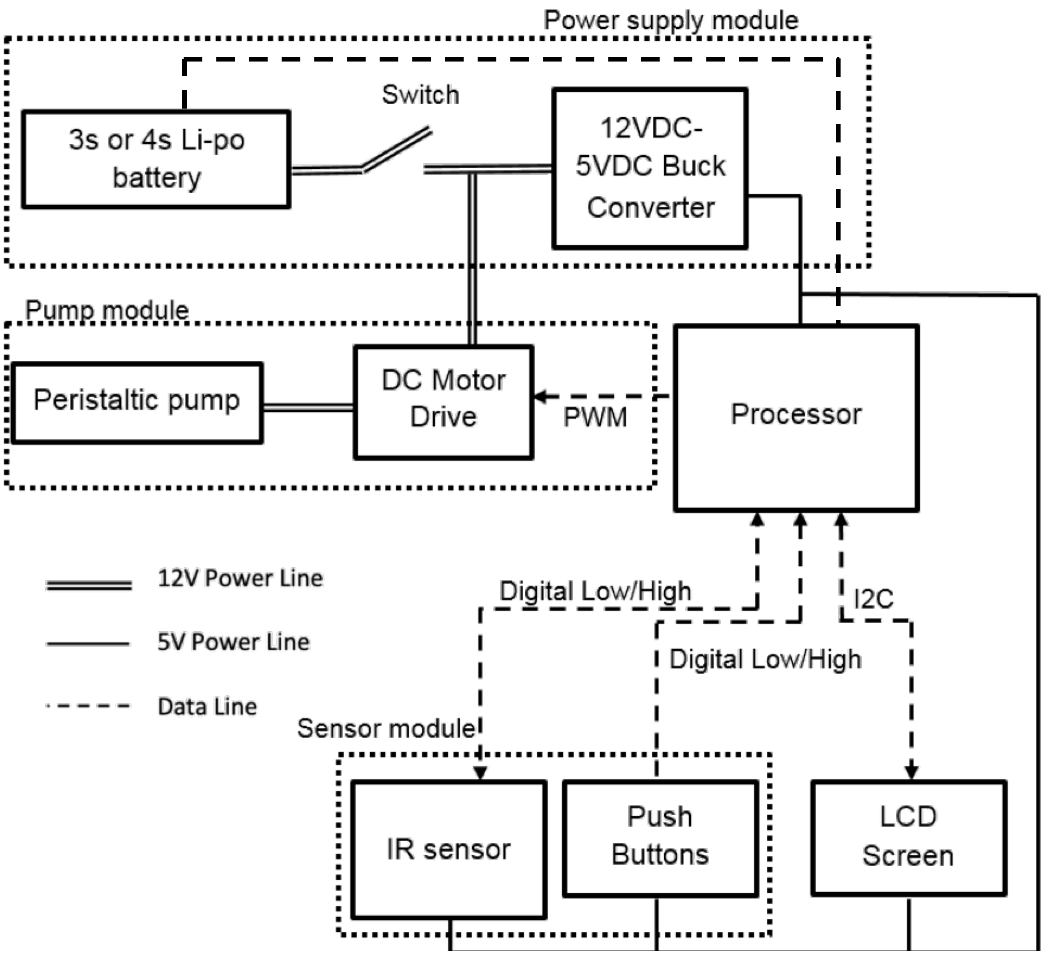

Figure 1: Block Diagram

2.1 Mechanical Module

Dispense Mechanism:

For dispensing toothpaste, we have considered implementing many different dispense mechanisms. For example, we considered using a pressing mechanism to press again the body of the toothpaste tube to imitate a human hand. The problem of a pressing mechanism is that the shape of the toothpaste tube is not uniform, and therefore is difficult to achieve squeezing the same amount of toothpaste. And then, we came across a peristaltic pump, which is what we implemented for our dispense mechanism for our final design. It solve the problem of difficult to quantify how hard to squeeze the toothpaste tube that the pressing mechanism persists. The peristaltic pump is powered by a voltage of 12VDC, and the amount of toothpaste being pumped out is simply proportional to the time the pump operates.

The rate of toothpaste being dispensed by the peristaltic pump is 0.1g/sec according to our tests. The amount dispensed will be controlled by controlling the activation time of the pump. The pump will take on the role of dispensing toothpaste of the preset amount with accuracy under 10 seconds.

Dispenser Shell

For the dispenser shell, we would like our design to be as compact as possible. We chose to 3D print our dispenser shell to fit all the components, including the pumping system, the sensors, the processors and the LCD screen. The shell also includes a toothpaste dock for placing the toothpaste tube. We modified a toothpaste cap for the toothpaste dock, we drilled a hole on the toothpaste cap for the insertion of the tube from the peristaltic pump, and we put an O-ring inside of the cap for a better seal between the opening of the toothpaste and the cap. In order to change toothpaste tubes, the user only need to twist the old toothpaste off the toothpaste dock, take the cap off the new toothpaste, and twist the new toothpaste onto the toothpaste dock.

2.2 Power Module

Our whole system is powered by a rechargeable 3S Li-po battery(12VDC). For the components that only requires 5VDC, we used a buck converter to convert 12VDC to 5VDC. The reason we chose a rechargeable 3S Li-po battery is that the peristaltic pump required a 12VDC power source, and stepping down from 12VDC to 5VDC to incorporate all the other components can be easily done by a buck converter.

2.3 I/O Module

LCD screen and push buttons

In order to let users know the current remaining battery and the amount of toothpaste to be dispensed for each time, a display is needed in our system. At first, we choose to use several LED segment displays to show the numbers and then find that a 16*2 LCD screen is more suitable in this case and the LCD screen can communicate with the processor under the I2C protocol.

In order to let users adjust the amount of toothpaste to be dispensed in the next time, we choose to use one push button which indicates “increase” and one push button which indicates “decrease” for users to modify a integer ranging from 1 to 9. This value is, at the same time, displayed onto the LCD screen. The circuit for push buttons is designed that when the button is pushed, a 5V voltage will be generated and when it is released, a 0v voltage will be generated.

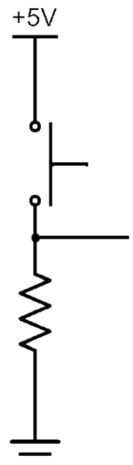

Figure 2: Button Circuit

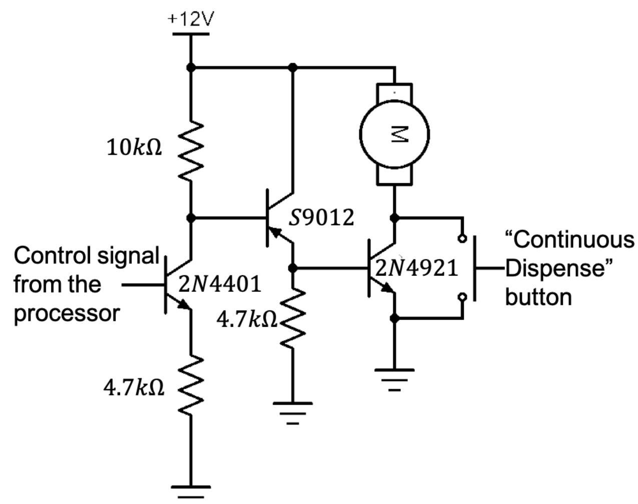

Figure 3: Motor Drive Circuit

IR Sensor and Motor Drive

Our project needs to be able to identify when a toothbrush is inserted into the dispensing slot. In this sense, we tested 3 types of sensors: infrared proximity sensor, infrared break beam sensor, and ultrasonic distance sensor, and we find out that the infrared break beam sensor fits our requirement. When users insert a toothbrush between 2 IR sensors, the voltage of the sensors are 5V and when there is no toothbrush, the voltage will be 0V instead.

Our system also needs some mechanism to drive a step down motor

2.4 Control and Software Module

In order to fully orchestrate different parts in I/O modules, some control logic is needed in the software module and we choose to use the ATMEGA328P as the central processing unit. There two I/O logic flows, and the first is the IR beam sensors and motor drive. When users insert a toothbrush into the dispensing slot, the IR beam sensors will have a 5V voltage and will be interpreted as logic HIGH by the processor, and then the processor will output a 5V voltage to the motor drive for seconds based on the preset amount of toothpaste. This toothpaste level, which is a global variable in the code, can be modified by users in the second I/O flow: when the system is first booted up, it will show a default toothpaste level(set to 4) on the LCD screen and users can increase and decrease this global value by (+) and (-) push buttons

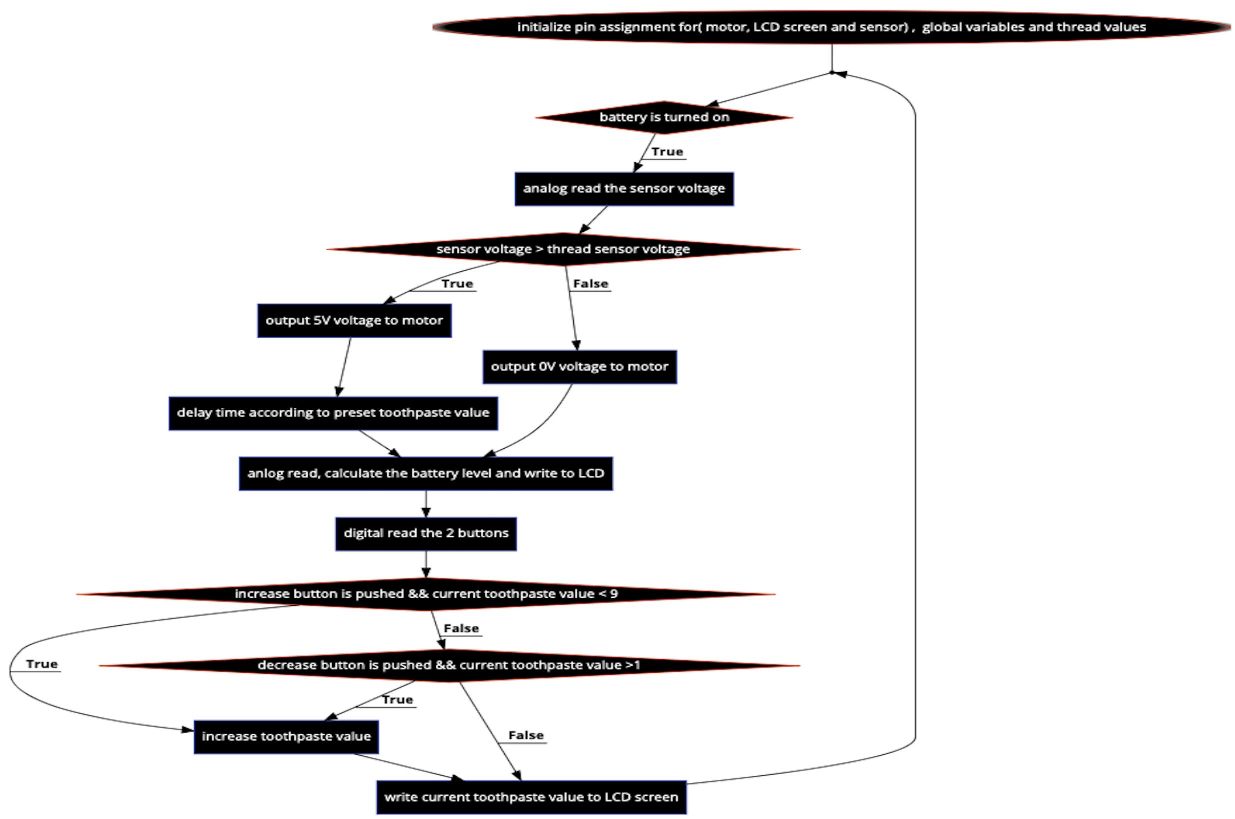

Figure 4: Flow Chart

3.Verifications

3.1 Mechanical Module

Dispenser Shell

Requirement	Verification
The shell must have dimensions within 20 cm*10 cm*8 cm and be able to fit all the necessary components.	The shell of our final design has dimensions of 214*80*50 mm.
The shell should reach standard IP53 [6]to ensure the components won’t be corrupted by moisture and water.	As we try to integrate all the different modules together, we did not want to corrupt the functionality of the whole project as they were loosely connected together, therefore we did not put all the component into a air seal bag for water-proofing or testing for this requirement.

The shell should have a toothpaste dispensing slot for the users to insert toothbrushes and dispense toothpaste onto the toothbrushes.	Insert a toothbrush into the dispense slot and the toothpaste is dispensed onto the toothbrush bristles.

Dispense Mechanism

Requirement	Verification
The dispensing mechanism is able to dispense a designated amount of toothpaste within 0.1 gram precision.	Dispense a preset amount of toothpaste onto a scale and check the weight difference is within 0.1 gram of the table we created. The table for each preset level is created by dispensing toothpaste of that preset level 5 times and take the average weight as the expected weight of that preset level.
The dispensing mechanism should be able to dispense at least 80% of the toothpaste in the tube with minor assistance from the user.	Continuously dispense the toothpaste until the pump is unable to dispense anymore toothpaste, then we check the weight of the toothpaste dispensed is indeed larger than 80% of the net weight stated on the toothpaste.

3.2 Power Module

Requirement	Verification
The power unit can be powered by a 3s Li-po battery around 12V.	The device remains its full functionality with a 3S Li-po battery.
The power unit should be able to prevent fire or electric shock hazard even if user uses the wrong battery rating.	Steady-state current at any part of the circuit does not exceed its maximum limit.
The power unit should be able to stay safe(grounded) even if water drops on its shell.	The voltage between anywhere on the shell and the ground is less than12V.

3.3 I/O Module and Control Module

LCD Screen and Push Buttons

Requirement	Verification
The LCD screen should be able to communicate with the microcontroller successfully.	The number shown on LCD screen has digit ranging from 1 to 10.

The LCD screen should allow interrupts from buttons.	The the buttons (+) / (-) is pressed, the toothpaste level shown on the LCD increments and decrements correspondingly.

IR Beam Sensors and Motor Drive

Requirement	Verification
The sensor should be able to sense when an object is inserted into the toothpaste dispensing slot.	when a toothbrush is inserted into the dispensing slot, a logic HIGH is detected by processor using digitalread( ).
Motor drive should function correctly when a toothbrush is detected by sensors.	When a toothbrush is inserted into the dispensing slot, a 5V is sent to motor drive and motor rotates correspondingly.
Motor drive should drive motor thus squeeze different toothpaste amount according to the toothpaste level set by user.	Tested each toothpaste level from (1-9), and the amount of dispensed toothpaste is within 0.04g from each expected value.

4. Costs

4.1 Parts

Following is a starter table for parts costs. Add cell contents as well as rows and, if necessary, columns. Update the table number according to your sequence. Note that columns 1 and 2 are set up for centered text (words) and columns 3-5 (numbers) are set up for right-alignment so that decimal points align.

Table 1: Hardware Cost

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)
ATMEGA328	Microchip Technology	8.5	1.96
Peristaltic Pump	INTLLAB	10	8
Device Shell	(3D printed)	5	5
IR sensor	ON semiconductor	10	2
PCB	PCBgogo	5	2
LCD Screen	Sparkfun	10	8
3s Li-Po battery		12	9
Wires and boards		2	2
Total		**62.5**	**37.96**

4.2 Labor Cost

Assume $25/h hourly rate for developers.

Total labor cost = 8h/week * 12 week *3people *25/h=$7200

5. Conclusion

5.1 Accomplishments

We met all three of our high level requirements for this project, including a dispensing precision of 0.1gram, a reasonable water resistivity, and an interactive LCD screen for user interface. To use our toothpaste dispenser, the user press the button on the device to adjust the dispensing amount which is displayed on the LCD screen. Then the user can insert a toothbrush in the designated slot where the toothpaste is automatically dispensed. Besides the apparent functionality, we also achieved a compact size that fits most of the spaces. In addition, the dispenser's simple structure allows fast disassembly and easy cleaning.

5.2 Uncertainties

Even though we achieved a high toothpaste dispensing precision, the dispensing mechanism is not reliable enough for the same high precision every single time. Two factors tend to fill the pipe with air which prevent a proper dispensing. One factor is the air leaked into the pipe through the connector between the toothpaste tube and the pump. Because we use a feed-forward control method for the motor control, dispensing time is the only variable we control, so much less or even no toothpaste can be dispensed if a big bubble exists in the pipe. The other factor is the elasticity of the toothpaste tube. When the device is left idle for a few minutes, the toothpaste tube tends to expand because of its internal tension. The expansion sucks air into the tube from the pipe, causing big air bubbles in the pipe, which affect the normal dispensing.

5.3 Ethical Considerations

Our design prioritize the user safety. We removed the 110V wall plug from our original design to avoid any high voltage hazard. With our current usage of 3s Li-po battery, we used special precautions in our design to avoid short circuit and fire hazard. According to IEEE Code of Ethics, it is important to be aware of and to inform the potential damage to people or the environment caused by our design [2]. We have paid extra attentions to the field where users may be harmed.

5.4 Future Work

We can improve four aspects of the project for better reliability and convenience. We may make the device more compact. Since our current design includes multiple circuit board and jump wires among them, the room it takes is more than actually needed. So by merging different boards to one, we can shrink the size significantly and make it even more portable. We may make the device more power efficient. Voltage divider method are our primary circuit design for battery management. Yet, this method consumes high energy. We can user transistors or relays to substitute the voltage divider circuit for less power consumption. We can also make the device less vulnerable to water. Our current design protects the device from splashing water. By simplifying the circuit to one circuit board and wrapping up. Last, as mentioned in section 5.2, our pumping precision varies after the device idling for a few minutes because air gets into the system. We may look for better sealing technique and add an one-way valve in the pipe for the toothpaste to flow only in one direction and block air from entering the system.

Bibliography

[1] Davies, R. M., Ellwood, R. P. and Davies, G. M., "The rational use of fluoride toothpaste," *International Journal of Dental Hygiene,* vol. 1, pp. 3-8, 2003.

[2] Institute of Electrical and Electronics Engineers, "IEEE Code of Ethics," 2019. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html.

Appendix A The Complete Requirement and Verification Table

Requirement	Verification	Status
The shell must have dimensions within 20 cm*10 cm*8 cm and be able to fit all the necessary components.	Measure the dimensions of the shell	✓
The shell should reach standard IP53to ensure the components won't be corrupted by moisture and water.	1. Spray water at any angle up to 60% from the vertical at the dispenser. 2. Insert a toothbrush into the dispensing slot and check that there is toothpaste being dispensed. 3. Check the LCD screen is still displaying information intended. 4. Press the button to change the preset value and check the preset value of toothpaste is changing accordingly on the LCD screen	X[1]
The shell should have a toothpaste dispensing slot for the users to insert toothbrushes and dispense toothpaste onto the toothbrushes.	Insert a toothbrush into the dispense slot and see if the toothpaste is dispensed onto the toothbrush bristles.	✓
The dispensing mechanism is able to dispense a designated amount of toothpaste within 0.1 gram precision.	1. Dispense the lowest preset amount of toothpaste onto a scale。 2. Read from the scale to see if the dispensed toothpaste's weight is within 0.1 gram accordingly.	✓

[1] The water resistant design was implemented but not tested as described.

	3. Keep increasing the preset value by 1 and repeat step A and B until the preset value reaches 10.	
The dispensing mechanism should be able to dispense at least 80% of the toothpaste in the tube with minor assistance from the user.	1. Insert a brand new toothpaste tube into the dispenser. 2. Start running the peristaltic pump to pump out the toothpaste onto a scale until no more toothpaste can be dispensed. 3. Check the toothpaste dispensed by the peristaltic pump is more than 80% of the net weight stated on the toothpaste.	✓
The power unit can be powered by a 3s Li-po battery around 12V.	The device remains its full functionality with a 3S Li-po battery.	✓
The power unit should be able to prevent fire or electric shock hazard even if user uses the wrong battery rating.	Steady-state current at any part of the circuit does not exceed its maximum limit.	✓
The power unit should be able to stay safe(grounded) even if water drops on its shell.	The voltage between anywhere on the shell and the ground should be less or equal to 12V.	✓
The microcontroller should receive data from sensors and control peristaltic pump correctly by PWM.	The toothbrush should be detected when placed under the sensor and the preset amount of toothpaste should be dispensed by the pump.	✓
The microcontroller should be able to detect toothbrush by measuring the voltage change at output pin of the sensor.	1. Connect the microcontroller to the output pin of the sensor. 2. Insert a toothbrush inside the dispensing slot. 3. A '!' character will be shown on the LCD screen to indicate microcontroller has detected a toothbrush.	✓
The microcontroller should be able to control the peristaltic pump to change the amount of dispensed toothpaste via pulse width modulation (PWM).	1. Connect the analog output pin of microcontroller to DC Motor. 2. Press the dispense button twice, 1 for 1s and the other for 5s.	✓

	3. There should be a larger amount of toothpaste dispensed in the second time.	
The I2C LCD screen should communicate with microcontroller on a 2-wire I2C bus to allow microcontroller write up to 32 bytes of data on to the screen.	1. Turn on the toothpaste dispenser. 2. The LCD will be flushed and a line of “ LCD CONNECTED ” will be shown on the screen.	✓
The LCD screen should allow interrupts from buttons.	The buttons (+) / (-) is pressed, the corresponding value shown on the LCD should increment or decrement correspondingly.	✓
The sensor should be able to sense when an object around 2.9 cm*1.6 cm*1 cm, which is the size of a typical toothbrushes head, is inserted into the toothpaste dispensing slot and under dispense mechanism.	1. Install the sensor inside the dispensing slot 2. Check the output voltage of the sensor when no toothbrush is inserted 3. Insert toothbrushes inside the dispensing slot and check the output voltage of the sensor 4. Compare the two output voltage results to determine the difference between the outputs is above 2 volts.	✓
The sensor should be able to function in high humidity environment such as bathrooms.	Repeat the verification process from Requirement 1 in a room with 80% relative humidity, which is the typical peak of RH a bathroom will reach.	X
The sensor should be able to communicate with the microcontroller by analog signals.	1. Connect the output pin of the sensor to the microcontroller. 2. Insert a toothbrush inside the dispensing slot. 3. Check if the microcontroller can detect the toothbrush by the output pin voltage.	✓

Appendix B 3 Sided View of the Device

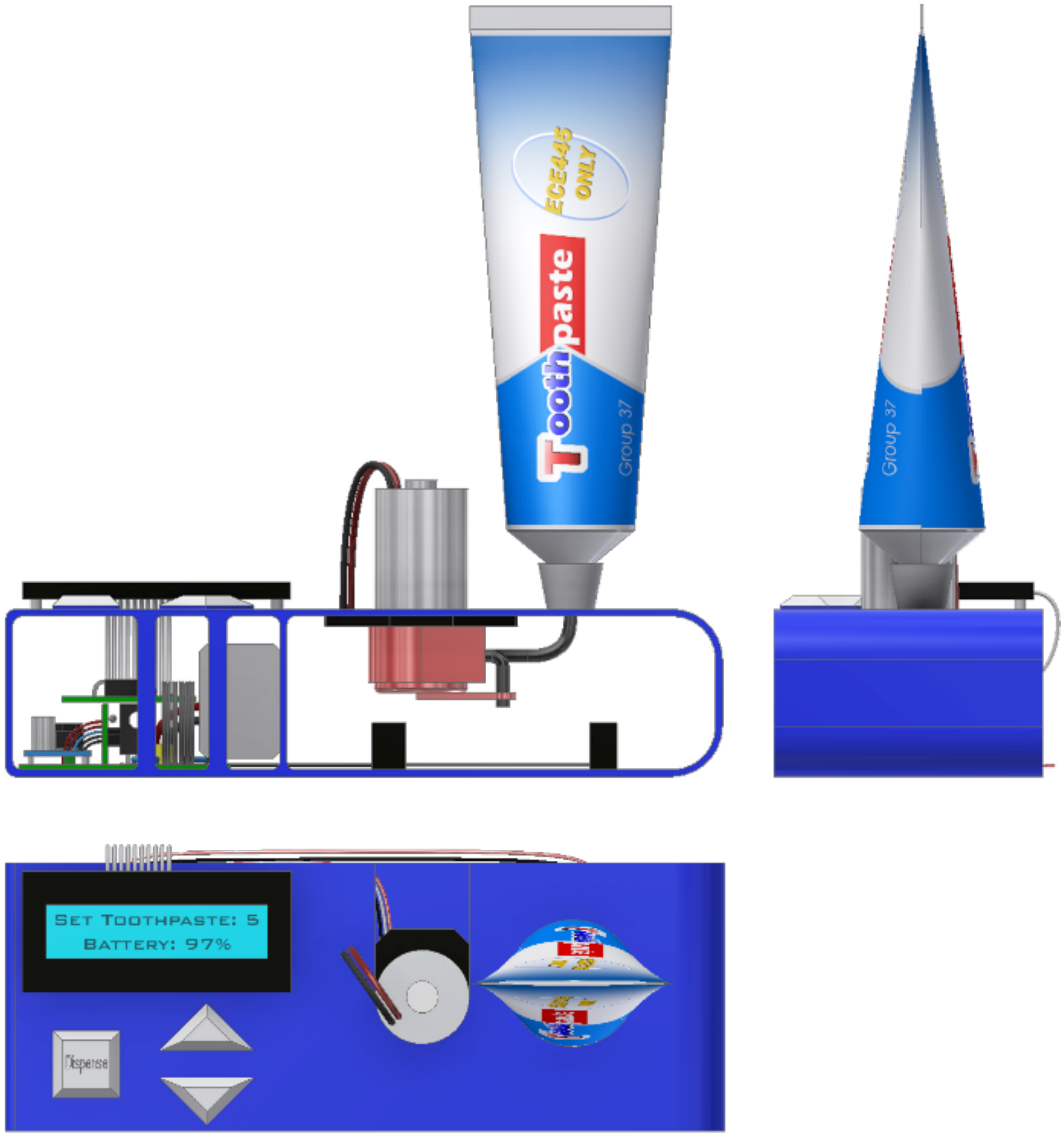

Figure 5: 3 Sided View

Appendix C PCB Design

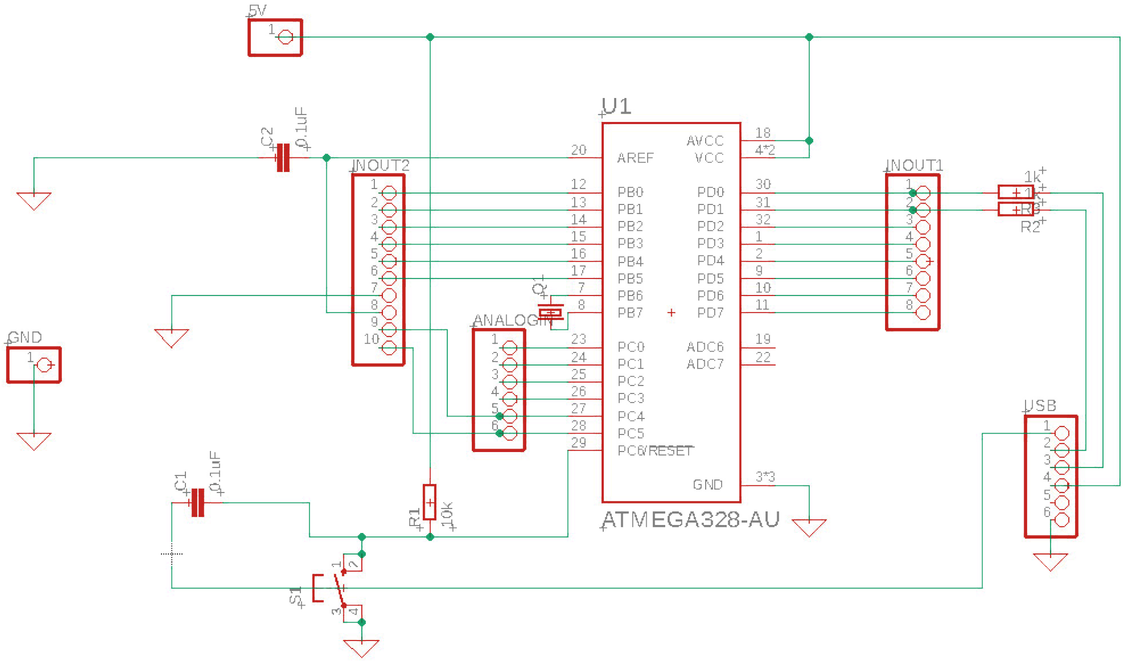

Figure 6: Processor Circuit Diagram

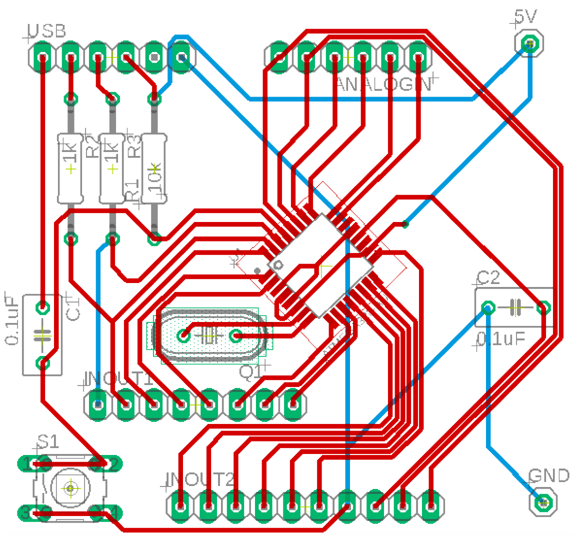

Figure 7: Processor Circuit Footprint

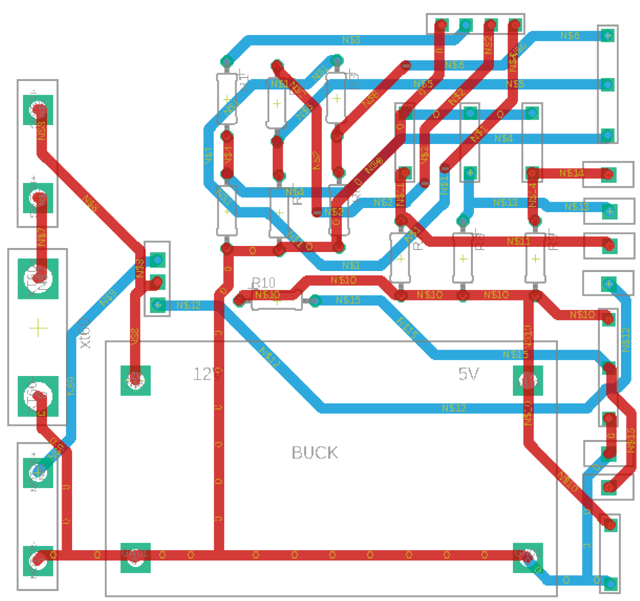

Figure 8: Power Board Footprint

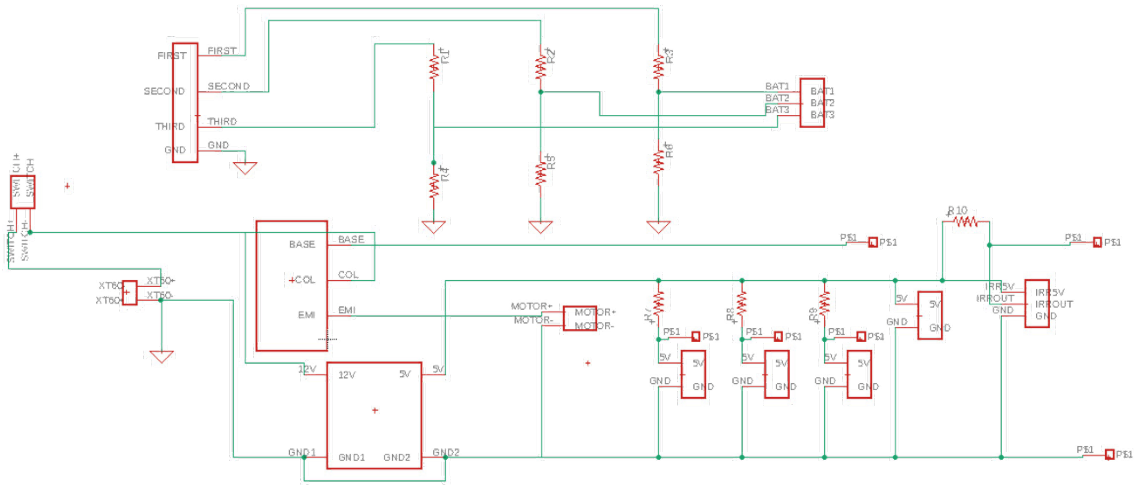

Figure 9: Power Board Circuit Design