Smart Toothpaste Dispenser

Design Document

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1. Introduction

1.1 Objective

When people manually squeeze toothpaste from the tube, they tend to overdose on toothpaste and experience difficulty getting the last。 According to a study of the rational use of fluoride toothpaste, a child should use a pea size (0.25 grams) of toothpaste and an adult should use about 0.5 grams of toothpaste each time for the best effect [1]. However, many people cover the entire brush with toothpaste for each use, which results in using 1~1.5 grams of toothpaste [2], largely exceeding the optimum amount. In addition, when most of the toothpaste in the tube is used, users may need to roll the tube up or use a toothpaste squeezer to get the rest out. This process is usually annoying, and much toothpaste may get wasted.

Because of the tendency of overdosing and wasting toothpaste, we propose to design an electric toothpaste dispenser, which can accurately control the amount of toothpaste dispensed each time and prevent toothpaste overdosing. With a peristaltic pump installed, the dispenser effectively gets the toothpaste out of the tube and reduce the wasted toothpaste.

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.

Figure 1：Existing Manual Toothpaste Dispenser

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.

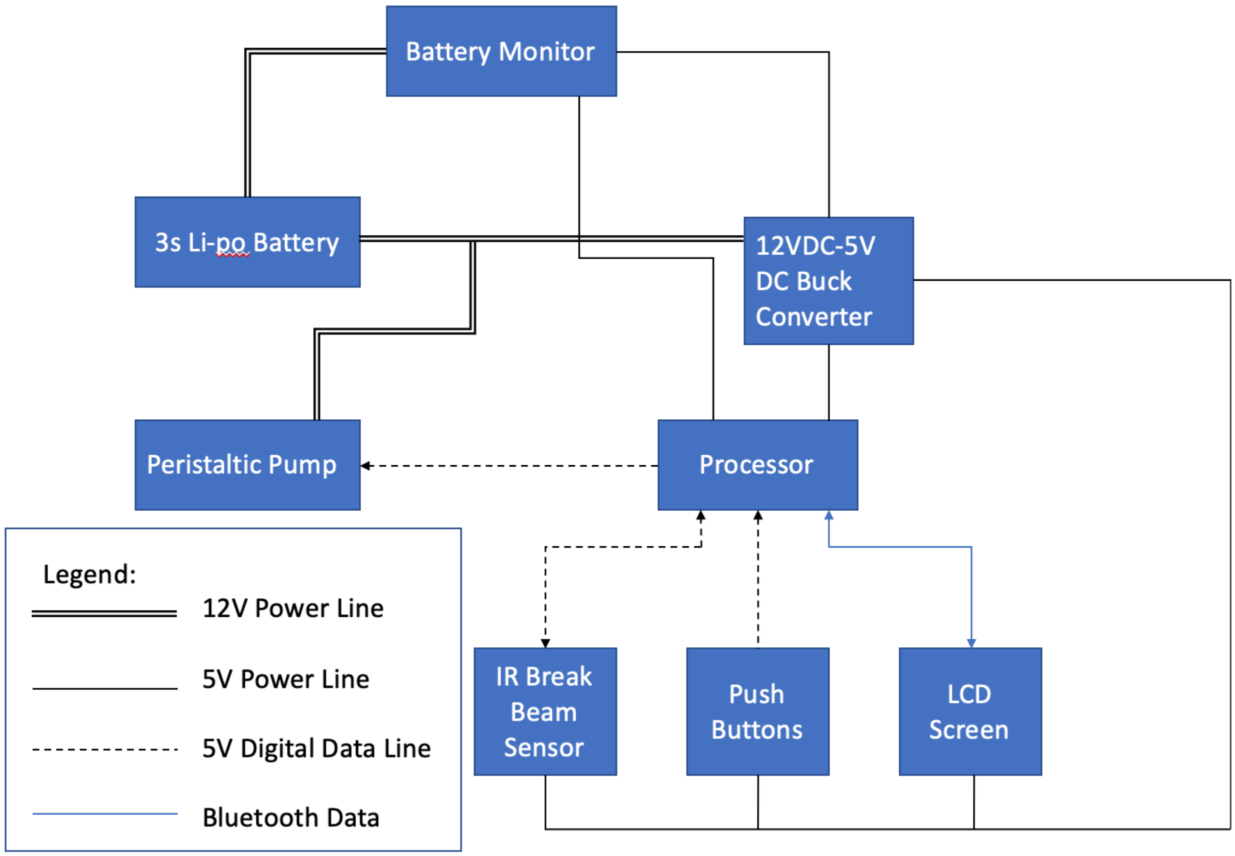
Those electrical toothpaste dispensers currently on market generally dispense the same amount of toothpaste every time which cannot be adjusted by the user. Also, the dispenser does not have any interface for the users to know the time and the current settings. Besides, the existing devices may not be 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 toothpaste dispenser should meet the IP13 rating for solid and water resistance.

2. Design

2.1 Block Diagram



2.2 Physical Design

Our design includes using peristaltic pump to pump out toothpaste from the tube as shown in *Figure 3*. We have tested our current peristaltic pump and we found it capable of pumping out from the tube with a rate of around 0.08 grams/sec.

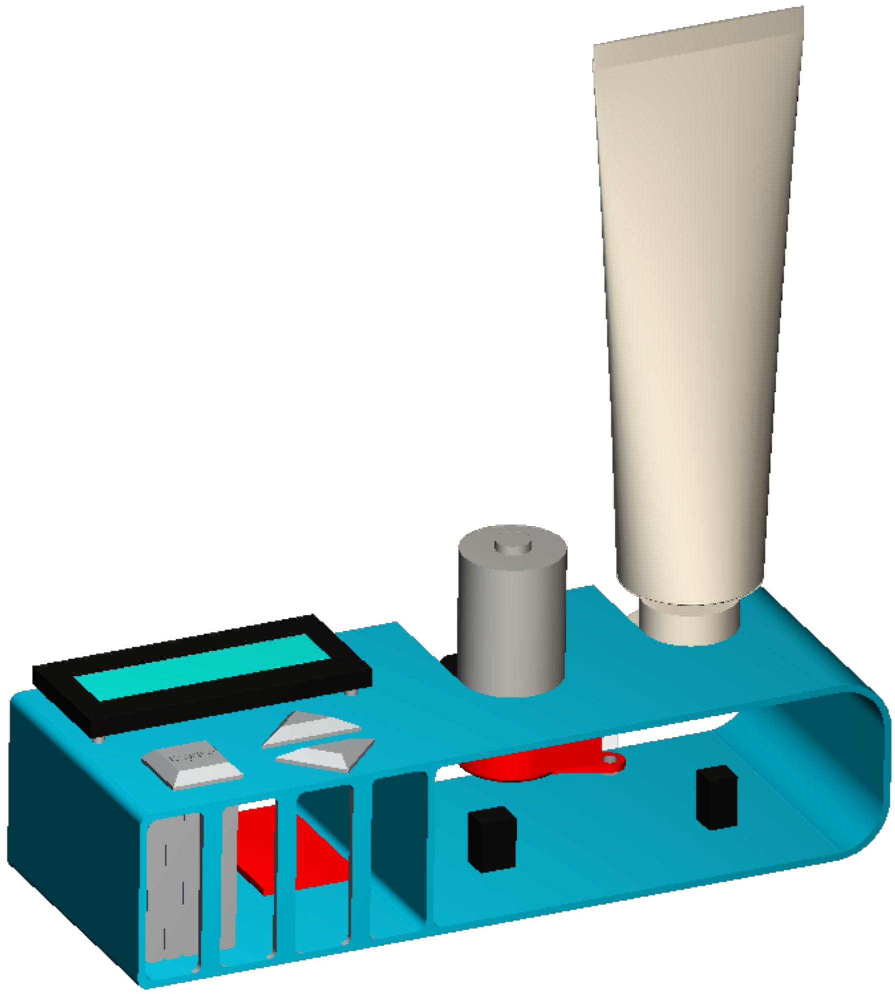


Figure 3: Primary Design Configuration

2.3 Block Design

2.3.1 Mechanical Design

a. Dispenser Shell

- Functional Overview

The dispenser case or supporting structure will be mostly plastic and 3D printed. It holds the components, including the pumping system, the sensors, the processors and the screen in place. The shell will also ensure the toothpaste is securely inserted in order to dispense properly.

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 should reach standard IP53 [6]to ensure the components won't be corrupted by moisture and water.	A. Spray water at any angle up to 60% from the vertical at the dispenser. B. Insert a toothbrush into the dispensing slot and check that there is toothpaste being dispensed. C. Check the LCD screen is still displaying information intended. D. Press the button to change the preset value and check the preset value of toothpaste is changing accordingly on the LCD screen
The shell should have a toothpaste dispensing slot for the users to insert toothbrushes and dispense toothpaste onto the toothbrushes.	A. Insert a toothbrush into the dispense slot and see if the toothpaste is dispensed onto the toothbrush bristles.

b. Dispense Mechanism

- Functional Overview

A peristaltic pump is used to get the toothpaste out of the tube and dispense it onto the toothbrush. The peristaltic pump is powered by a DC motor and dispense toothpaste at a rate about 0.1grams/sec. 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.

Requirement	Verification
The dispensing mechanism is able to dispense a designated amount of toothpaste within 0.1 gram precision.	A. Dispense the lowest preset amount of toothpaste onto a scale B. Read from the scale to see if the dispensed toothpaste's weight is within 0.1 gram accordingly.

	C. 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.	A. Insert a brand new toothpaste tube into the dispenser. B. Start running the peristaltic pump to pump out the toothpaste onto a scale until no more toothpaste can be dispensed. C. Check the toothpaste dispensed by the peristaltic pump is more than 80% of the net weight stated on the toothpaste.

2.3.2 Power Supply

- Functional Overview

The device can be powered by either an 110VAC power outlet or a battery pack between 10V and 12V. The two power sources cannot be connected simultaneously, since such connection may cause a short circuit and damage the battery. The simultaneous connection will be prevented mechanically by a SPDT switch.

There will be a converter used to step down the voltage further to meet the requirement of the processor.

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 should be less or equal to 12V.

2.3.3 Control Unit

All the components in control unit are designed collectively to detect the existence of a toothbrush and allow users to see and modify the preset amount of toothpaste, which is intuitively represented by integers.

a. Microcontroller

- Functional Overview

A microcontroller, chosen to be PSOC4 BLE (Bluetooth Low Energy) [3] processor, controls the sensors, buttons and LCD screen by receiving, analyzing and sending signals across the above three components.

Requirement	Verification
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.	A. Connect the microcontroller to the output pin of the sensor. B. Insert a toothbrush inside the dispensing slot. C. 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).	A. Connect the analog output pin of microcontroller to DC Motor. B. Press the dispense button twice, 1 for 1s and the other for 5s. C. There should be a larger amount of toothpaste dispensed in the second time.

b. LCD Screen [4] and Push Buttons

- Functional Overview

The LCD screen displays the preset amount of toothpaste to be dispensed, which is represented as a sequence of integers from 1 to 10. The amount of toothpaste to be dispensed will increase with the increase of number displayed.

Users can adjust the amount of toothpaste by pushing the increase button (+) and decrease button (-) several times to achieve the desired amount of toothpaste.

Requirement	Verification

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.	A. Turn on the toothpaste dispenser. B. 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.

c. Object Detection Sensors

- Functional Overview

The sensors will be able to detect when users insert toothbrushes into the dispense slot. We are currently testing out 3 types of sensors: infrared proximity sensor, infrared break beam sensor, and ultrasonic distance sensor.

Requirement	Verification
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.	A. Install the sensor inside the dispensing slot B. Check the output voltage of the sensor when no toothbrush is inserted C. Insert toothbrushes inside the dispensing slot and check the output voltage of the sensor D. 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.	A. 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.
The sensor should be able to communicate with the microcontroller by analog signals.	A. Connect the output pin of the sensor to the microcontroller. B. Insert a toothbrush inside the dispensing slot. C. Check if the microcontroller can detect the toothbrush by the output pin voltage.

3. Parts and Cost

3.1 Prototyping Cost

Item	Cost/$
PSOC Micro-controller	0 (sponsored)
Peristaltic Pump	12
Toothpaste Tube Connector	
Device Shell	15*
LCD Screen	10*
IR Sensor	8*
3S Li-Po Battery	12*
110VAC/12VDC Converter	11*
PCB Power Distribution Board	
Connectors, wires and miscellaneous	5*
Labor	15*8*3*12=4320

*Item cost is estimated based on available parts

3.2 Mass Production Cost Estimation

Item	Cost/$
Micro-controller	100
Peristaltic Pump	10
Toothpaste Tube Connector	1
Device Shell	5
LCD Screen	10
IR Sensor	7
3S Li-Po Battery	10
110VAC/12VDC Converter	10
PCB Power Distribution Board	
Connectors, wires and miscellaneous	2
Labor	10h/week * 12 week *3 *40/h=14400

4. Time schedule and Task Assignment

Date from	Date to	Mechanical (Jianqiao Xiao)	Sensor and hardware	Control (Zhaoying Du)

			(Yusheng Wei)	
2/18	2/24			
2/25	3/3	Pump functionality test with dried toothpaste and sealed tube	Sensor Functionality test	Design interaction between microcontroller, DC motor, LCD, sensors, and buttons.
3/4	3/10	Design Document revised	Design Document revised	Design Document revised
3/11	3/17	3D printing shell	Power Distribution Board, motor control board Design	LCD drive installed, control logic for LCD screen, sensors and buttons
3/18	3/24	General assembly and adjustments	Sensor installation	control logic for DC motor
3/25	3/31	Pumping system improvement	PCB optimization	firmware optimization
4/1	4/7	3D Printing updated shell design	PCB optimization	additional improvement added
4/8	4/14	Second-round integration	second round integration	second round integration
4/15	4/21	Work on report		
4/22	4/28	TBA		
4/29	5/5	TBA		

5. Ethics and Safety

In our project the 110VAC wall plug is used and is a potential high voltage hazard. For the high-voltage module, we will exclusively use commercially available and certified product for safety purpose. Besides the 110VAC high voltage, there are still several safety concerns with our project. First of all, since this dispenser is designed to be used in bathrooms, sealing up the casing for the power supply unit, sensors and peristaltic pump is necessary to prevent shorting the circuits and electric shocks to the users. Secondly, considering we are expecting children to use the device, it must not contain small easily disassembled small components or sharp edges that may hurt children. In addition, because toothpaste goes into people's mouth, we must carefully choose those components that contact the toothpaste directly so that the user will not accidentally consume any toxic substance. According to IEEE Code of Ethics [5], it is important to be aware of and to inform the potential damage to people or the environment caused by our design. We will be constantly aware of our effect to the surroundings and the user at every step to obey the Code of Ethics.

6. Tolerance Analysis

The pumping rate of the peristaltic pump is the primary error sources that may affect the performance of our toothpaste dispenser. The following paragraphs analyze the extent of the error and the possible effects on the overall performance.

The peristaltic pump that pumps the toothpaste out of the tube determines the dispensing accuracy. Here the impact of voltage variation on the pump is mainly discussed.

Our peristaltic pump consists of a DC motor and three rollers with 11mm diameter. The shaft of the DC motor has a diameter of 2.25mm and drives the roller by friction through direct contact.

Since the voltage driving the motor is provided directly by the battery, which has a voltage between 12.7V (fully charged) and 9.7V (fully discharged). It is also known that at 12V rated voltage, the no-load speed of the motor is 5000RPM. With the provided information, the following calculation is performed.

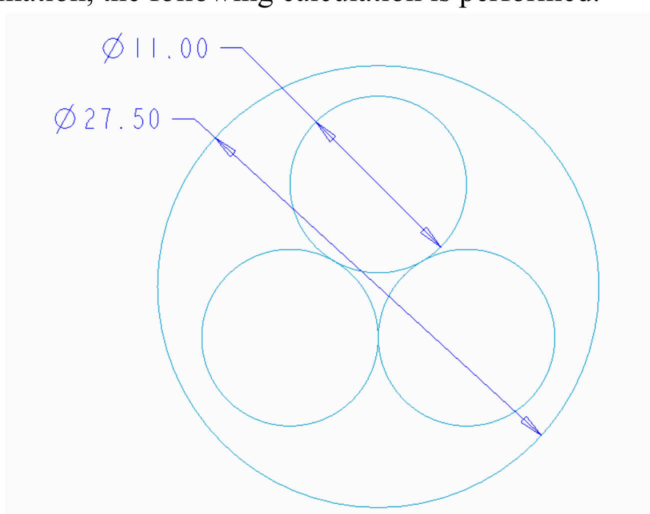


Figure 2: Peristaltic Pump Roller Configuration

For a DC brushed motor: $e_a = K_a \phi_d \omega_m$, meaning the rotation speed varies proportionally with the voltage applied, assuming the torque is constant under different speed.

The pumping tube we used has 2mm inner diameter and 4mm outer diameter. Assuming the tube is fully squeezed during pumping, the volume between rollers inside the tube is

$$V_{\frac{1}{3}rotation} = 1^2\pi \times 27.5\pi \times \frac{1}{3} = 90.47mm^3$$

Then the roller rotation speed is computed below given the dimensions of the shaft and the roller and the RPM of the shaft.

$$\omega_r = \frac{2000}{11}\frac{11}{27.5} = 72.7RPM = 1.2\frac{rotation}{s}$$

Dispensing rate is:

$$V = 90.47 * 1.2 = 108.6\frac{mm^3}{s}$$

At 12.7V, the theoretical dispensing rate is

$$V = 108.6 \times 12.7/12 = 114.93\frac{mm^3}{s}$$

At 9.7V, the dispensing rate is

$$V = 108.6 \times 9.7/12 = 87.78\frac{mm^3}{s}$$

If we use open loop control for the peristaltic pump assuming the dispensing rate is 101.35 (half way between the maximum and minimum value) the result error is $13.6\frac{mm^3}{s}$. Assuming a toothpaste has density of $1.33\frac{g}{cm^3}$, if we want to dispense 5 second of toothpaste, the max error we can get is:

$$13.6 * 5 * 1.33 * 10^{-3} = 0.09g$$

This result is smaller than the 0.1 gram error we proposed.

Works Cited

[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.

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[3] Cypress, "PSoC® 4 BLE (Bluetooth Smart)," Cypress, 2019. [Online]. Available: https://www.cypress.com/products/psoc-4-ble-bluetooth-smart.

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

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