Automatic Toothpaste Dispenser

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1. Introduction

1.1 Objective

Toothpaste is an indispensable household item in people’s lives. Although the development of technology exceeded most people’s expectation in the last 20 years, our method of using toothpaste didn’t evolve a lot. Most people still manually squeeze toothpaste, which is effort consuming, wasteful and lack of methods of tracking the used amount of toothpaste.

In recent years, many toothpaste dispenser products entered the market, but almost all of them have significant flaws including messy dispensing mechanism, not automatic and bad compatibility.

We propose to design and implement a new automatic toothpaste dispenser supported with a smartphone app, based on the BLE Pioneer Baseboard, sensor programming, Radio Frequency Identification, and Android development, to provide a solution for the current situation. Our product would have the following distinct features from current products:

User Recognition: The RFID reader embedded in our automatic toothpaste dispenser is able to identify the toothbrush labeled with RFID and it can dispense a pre-set amount of toothpaste on the toothbrush.

Automatic Dispensing Mechanism: Our improved squeezing mechanism can accurately dispense toothpaste on toothbrush without leaking any. The diameter of toothpaste coming out from our device will be small enough that any toothbrush regardless of size can easily collect it.

Smartphone Interaction: Our outstanding Android application allows users to choose several different amounts of toothpaste matching with RFID and to store their choices. It can also record the amount of toothpaste used by certain RFID so that parents could use it to monitor the children daily brushing teeth behavior. In general, our product records long-term data on users’ daily toothpaste usage and provides a visualization of data.

1.2 Background

Several kinds of manually operated toothpaste dispensers have been designed by different manufacturers such as iLife Tech and ECOCO. In general, the mechanism applied is based on the action that the user pushes the trigger inside the dispenser with the toothbrush. This mechanism seems simple and user-friendly at the first look. Unfortunately, the trigger will soon be covered with dry toothpaste, which was
unintentionally dropped when the user was trying to hold toothpaste coming out of the tube. This major problem is widely reflected in customer reviews. For example, a user named “William J Leep” said that “the dispenser itself is fairly well made and easy to use. But, it dispenses too much and misses the brush 1/2 of the time”[1].

By making our dispenser automatic, the squeezing process can be standardized and thus the problem stated above can be mostly avoided. Since we are sponsored by Cypress Semiconductor Co., we plan to use BLE Pioneer Baseboard, which is supported by Cypress, to be the core of programming, controlling and communicating during the whole process.

### 1.3 High-Level Requirements
1. The dispenser must be able to identify at least three different users through different RFID tags on toothbrushes.
2. The dispenser must be able to dispense 0.30ml/0.40ml/0.50ml of toothpaste automatically and the amount coming out of the tube should be controllable.
3. The dispenser must be able to communicate with the APP on the user’s smartphone, providing data necessary to show usage.

### 2. Design
#### 2.1 Block Diagram
2.2 Physical Design Draft

We only need to control the open line of gear motor to dispense desired amount of toothpaste.

A syringe used for container.

A cover to close the exit of syringe when we need it.

When the plunger move from bottom to top, toothpaste in tube will be suck into the container.

Front view:
A rubber cover with "t" cross in middle of it. It can prevent toothpaste leak due to gravity and will open with enough force apply to it.
2.3 Smartphone

Smartphone with Android Operating System will serve as the platform to support the APP and will provide the base of Bluetooth connection.

2.3.1 APP

Mobile App is the interface between the user and the device. Users could control the amount of toothpaste dispensed and RFID tag matching through the APP. The APP also could display the visualization of users’ data on using toothpaste. The APP connects with the BLE Pioneer Baseboard by Bluetooth through the BLE protocol.

<table>
<thead>
<tr>
<th>Requirement</th>
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<tbody>
<tr>
<td>The APP runs fluently, loading time shorter than 5 seconds.</td>
<td>Measure the average duration of system loading lags when testing, by using the stopwatch function on phones.</td>
</tr>
</tbody>
</table>

2.3.2 WCDB

WCDB is a mobile database solution, which would allow the APP to perform Database CRUD (Create, Read, Update, and Delete) operation according to the users’ operation [2]. The users’ data logged by the BLE Pioneer Baseboard would be stored in WCDB by date partition.

<table>
<thead>
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<tbody>
<tr>
<td>Performance (Batch Write Test) achieves above 20,000 ops/second.</td>
<td>Log the performance of the database through Android embedded system-monitoring methods, and calculate average performance.</td>
</tr>
</tbody>
</table>
2.4 Bluetooth Module

Bluetooth module provides fast connection and data transfer between the mobile APP and the BLE Pioneer Baseboard. All user operations and logged data are transferred through the Bluetooth module using BLE Protocol. The BLE Protocol Stack consists of three parts: Application, Host, and Controller.

![Diagram of BLE Stack](image_url)

**Figure 1**[3].

Application part refers to a use case that uses the software stack and the controller to implement a particular functionality [3].

Controller part, containing Link Layer (LL) and Physical Layer (PHY), refers to the physical device that encodes the packet and transmits it as radio signals while it decodes the radio signals and reconstructs the packet on reception. PHY transmits and receives digital data. LL defines the timing and packet format for PHY [3].

Host Control Interface (HCI) links the hardware controller (PHY + LL) layer with the firmware host layer of the stack [3].

Host part, containing Generic Access Profile (GAP), Generic Attribute Profile (GATT), Attribute Protocol (ATT), Security Manager (SM), and Logical Link Control and Adaptation Protocol (L2CAP), is mainly responsible for the connection between the Application part and the Controller part. In the Host part, the two main protocols used to complete communication are GAP and GATT.
### Requirement

<table>
<thead>
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<tbody>
<tr>
<td>The Bluetooth connection provided by the module should enable user smartphone to connect in 30 seconds after the Bluetooth module on BLE Pioneer Baseboard starts working. After the connection is established, the data can be transferred between the board and the smartphone.</td>
<td>User smartphone can send instructions to the board and receive data from the board.</td>
</tr>
</tbody>
</table>

#### 2.4.1 Generic Access Profile (GAP)

GAP controls and defines the connection between two devices. According to GAP, a device that advertises its presence and accepts connection from a GAP Central device is called GAP Peripheral device [3]. A device that scans for advertisements from GAP Peripherals and establishes a connection with them is called GAP Central device. Specifically for the BLE Pioneer Baseboard, there are two advertising mode: fast advertising mode and slow advertising mode.

#### 2.4.2 Generic Attribute Profile (GATT)

GATT is the abbreviation for. After the Central device establishes a connection with the Peripheral, both devices are said to be connected over a BLE link. On a connected BLE link, independent of the GAP role, GATT defines two profile roles based on the source and destination of data [3]. In our project, the BLE Pioneer Baseboard will be the GATT server that will send data to the GATT client, which is our smartphone.

#### 2.5 Control Unit

Control unit consists of the BLE Pioneer Baseboard and the RFID reader. The unit mainly manipulates the toothpaste dispensing mechanism and data interchange with the smartphone APP.

#### 2.5.1 BLE Pioneer Baseboard

We will use the CYBLE-214015 BLE Pioneer Baseboard provided by Cypress as the central control unit of our project. The board is powered by coin battery. For the user side, the BLE Pioneer Baseboard connects with the smartphone APP through Bluetooth to receive users’ instruction and upload users’ data. For the toothpaste dispensing part, the BLE Pioneer Baseboard receives hexadecimal identification from the RFID reader and controls the operation of the motor through an encoder.
### 2.5.2 RFID Reader

We are going to use a product named Y13R RFID Reader Component. The RFID Reader is powered by the BLE Pioneer Baseboard through a USB wire. The reader could sense any RFID tag with wireless frequency about 13.56MHz within 50mm range. It could read ID numbers inside RFID tags, transform them as a hexadecimal number and output them to the BLE Pioneer Baseboard. Its output interface is UART(TTL) and IIC so we can directly connect it with our BLE Pioneer Baseboard.

<table>
<thead>
<tr>
<th>Requirement</th>
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<tbody>
<tr>
<td>Operating voltage between 1.9V and 5.5V.</td>
<td>Measure the output voltage of the coin battery in advance, and ensure that the output voltage is within the required range.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
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<tbody>
<tr>
<td>1. Operating voltage between 3.3V and 5V.</td>
<td>1. The voltage output of the USB port is fixed at 5V.</td>
</tr>
<tr>
<td>2. Operating temperature between -13 °F and 176 °F.</td>
<td>2. Use a thermometer to measure the temperature of the RFID Reader when the device is running, because heat generated by motor running could potentially affect the temperature of the RFID Reader.</td>
</tr>
<tr>
<td>3. It can read the value of RFID within 6 cm and output the corresponding ID.</td>
<td>3. We will use a USB to TTL cable to connect this RFID reader directly to our computer. The company provides software for us to test the operation of this Y13R reader. We can just put the RFID close to the Y13R chip and the ID will show on our computer screen.</td>
</tr>
</tbody>
</table>
2.5.3 Motor Driver Component

We choose to use a PWM motor controller made by Telesky. The module can supply 9V to 36V voltage to the motor, and the maximum load current is 12A which means that it can supply any motor less than 288W power consumption. The chip is using L298 H bridge design, and by changing the input to the control pins IN1, IN2 and PWM we can control the motion of the motor. Instead of controlling the speed of the motor, we will control the motor by setting PWM to 1 and switching IN1 and IN2 between 0 and 1.

![Motor Controller Diagram]

Figure 2

<table>
<thead>
<tr>
<th>IN1</th>
<th>IN2</th>
<th>PWM</th>
<th>Motor motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>X</td>
<td>Break</td>
</tr>
<tr>
<td>*1</td>
<td>*1</td>
<td>*X</td>
<td>*X</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>Forward with full speed</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>Reverse with full speed</td>
</tr>
<tr>
<td>*1</td>
<td>*0</td>
<td>*PWM</td>
<td>*Forward with adjustable speed</td>
</tr>
<tr>
<td>*0</td>
<td>*1</td>
<td>*PWM</td>
<td>*Reverse with adjustable speed</td>
</tr>
</tbody>
</table>
### Requirement

1. **Output voltage should be 24 V to match the voltage required by our chosen motor.**

2. **The motor can rotate forward and reverse with different input.**

### Verification

1. **We connect the power adaptor to the chip power input and connect VCC to 5V, GND, PWM to 1, set IN1 to 1 and IN2 to 0. After that, we use a multimeter to measure voltage and current at the motor part to see if it satisfies our requirement.**

2. **We first connect the motor to the chip and then connect the power adaptor to the chip power input and connect VCC to 5V, GND, PWM to 1, and change the value of IN1, IN2 to see if the motor can rotate at correct direction.**

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### 2.6 Mechanism

#### 2.6.1 Motor

We plan to use the GPG120W DC Gearmotor, which is controlled by the motor driver component. In this design, we do not need an encoder to measure the detail of the motor. Because we always let the motor run with full speed and the motor is run with very low speed after using a gearbox, we only need to measure how many toothpastes can be dispensed in each second. Using this data, we can set how many time we will open the motor to get the desired amount of toothpaste. Because our motor has break component, we can dispense this value very precisely. After visiting the machine shop, we were told that we need a motor to provide a force that is equal to the weight of 10 pounds. That means we need a very powerful motor and 10 Nm torque will be a good choice.
The above is the parameter for the motor itself without using the gearbox.

This is the torque provided by gearbox with our choosing motor using different gear ratio. We decide to use gear ratio 50 which means we could have about 12.6 Nm torque.
1. The motor can provide enough torque to lift a 10 pounds staff.

<table>
<thead>
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<tbody>
<tr>
<td>1. The motor can provide enough torque to lift a 10 pounds staff.</td>
<td>1. We will take the motor to the machine shop and the staff in has the tools to measure the actual torque of the gearbox motor. (HIOS)</td>
</tr>
</tbody>
</table>

2.6.2 Mechanical Components

The main mechanical component is a syringe, which functions as the buffer between the toothpaste tube and the users’ toothbrushes. We will drill a hole on the side of the syringe to plunge the toothpaste tube. The plunger of the syringe is controlled by the motor through gears and a screw. To dispense toothpaste, the motor rotates and push the plunger down. To reload toothpaste, the motor rotates inversely and the barometric pressure squeezes the toothpaste from the tube into the syringe.

<table>
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<tr>
<td>Air leaked into the syringe in the reloading process is less than 5ml.</td>
<td>Visual check through the scale on the syringe.</td>
</tr>
</tbody>
</table>
2.7 Toothbrushes
In order to identify different toothbrush users, a unique RFID tag will be attached to each toothbrush. The RFID tag is a sticker form and it will be pasted on the handle of toothbrushes. Ideally, the RFID reader’s sensing range is within 50mm, which is short enough to avoid to sense more than one toothbrushes at the same time.

<table>
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<tr>
<td>Operating frequency about 13.56 MHz.</td>
<td>The RFID reader is able to distinguish different RFID tags.</td>
</tr>
</tbody>
</table>

2.8 Power supply
The motor circuit is powered by a wall socket that connected with a big power adapter designed for large power consumption. This adapter can provide a stable 24V voltage to the motor and its load current can be up to 10 A. The BLE Pioneer Baseboard is powered by a 3V coin-battery. The RFID Reader is powered by the BLE Pioneer Baseboard via a USB wire.

<table>
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<tbody>
<tr>
<td>1. The power adapter supplies 24V voltage for the motor.</td>
<td>1. Use a voltmeter to measure the output voltage of the power adapter.</td>
</tr>
<tr>
<td>2. The power adapter can supply more than 7A current (our 120W motor requires 7A).</td>
<td>2. Use the multimeter to measure the output current of the power adapter to make sure it is higher than 7A. We can also directly connect the power adapter to the motor to see if the motor can work correctly.</td>
</tr>
<tr>
<td>3. The coin Battery supplies 3V voltage for the BLE Pioneer Baseboard.</td>
<td>3. Use a voltmeter to measure the output voltage of the coin battery.</td>
</tr>
</tbody>
</table>

2.9 Tolerance Analysis
(The mechanical components part is the most challenging task in our project, as we are lack of experience in Mechanical Engineering. Our mechanism requires high accuracy and high synchronization between the electrical part and the mechanical part, which would be time-consuming to test and moderate. If we cannot achieve the ideal level of automatically dispensing a pre-set amount of toothpaste, we wish to implement the automatically dispensing function at least. The bottom line of the
mechanism is that the dispensing system should be activated by the approach of toothbrush attached by an RFID tag.

3. Ethics & Safety

3.1 Ethics

Our design of mechanical components might refer to the mechanical design of manual dispenser on the Internet. Therefore, this would potentially be a violation of #2 of the IEEE code of ethics - to avoid real or perceived conflicts of interest whenever possible [4]. We currently come up with a mechanism that is significantly different from those manual dispensers. In the following modifications of our design, we will try to avoid using the ideas that appeared in the existing products.

Keeping the data safety and privacy should be our first concern, however, the data we collect about the daily usage of toothpaste is important for any toothpaste company (our potential cooperative partner) and they could pay us for analyzing our data and advertising specific targets through our APP. This would be a violation of #4 IEEE code of ethics - to reject bribery in all its forms [4].

3.2 Safety

We are using a lithium-ion battery so it might explode when we overcharge the battery. We will make sure that our charging circuit design for this battery has the protection code, which will automatically disconnect when the charging voltage exceeds the designed level.

The RFID tags we can get are only made for appropriate environmental conditions. However, attaching it on the toothbrush might violate its original design purposes because we cannot avoid washing our toothbrushes with water. We plan on using waterproof material such as waterproof tapes to cover the tags but it might potentially influence the reading process.

We are using RFID in the toilet and this is the place that people could stay for about 1 hour each day. However, there potential radiation risk in high-frequency RFID. However, there is a small distance between the toothbrush and Human in the toilet so this is not a vital risk.

4. Cost & Schedule

4.1 Cost

4.2 Schedule
5. References


