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. Moreover, users are lack of techniques to track the used amount of toothpaste.

In recent years, many toothpaste dispenser products entered the market, but almost all of them had significant flaws including messy dispensing mechanism, manual operation, 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. 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 used amount 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 by dry toothpaste. 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].

With our automatic dispensing mechanism, the squeezing process is systematically 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 automatically dispense from 0.25ml to 0.5ml of toothpaste and the error is within 0.02ml.
3. The dispenser must be able to receive commands from and upload data to the smartphone APP.

2. Design

2.1 Block Diagram

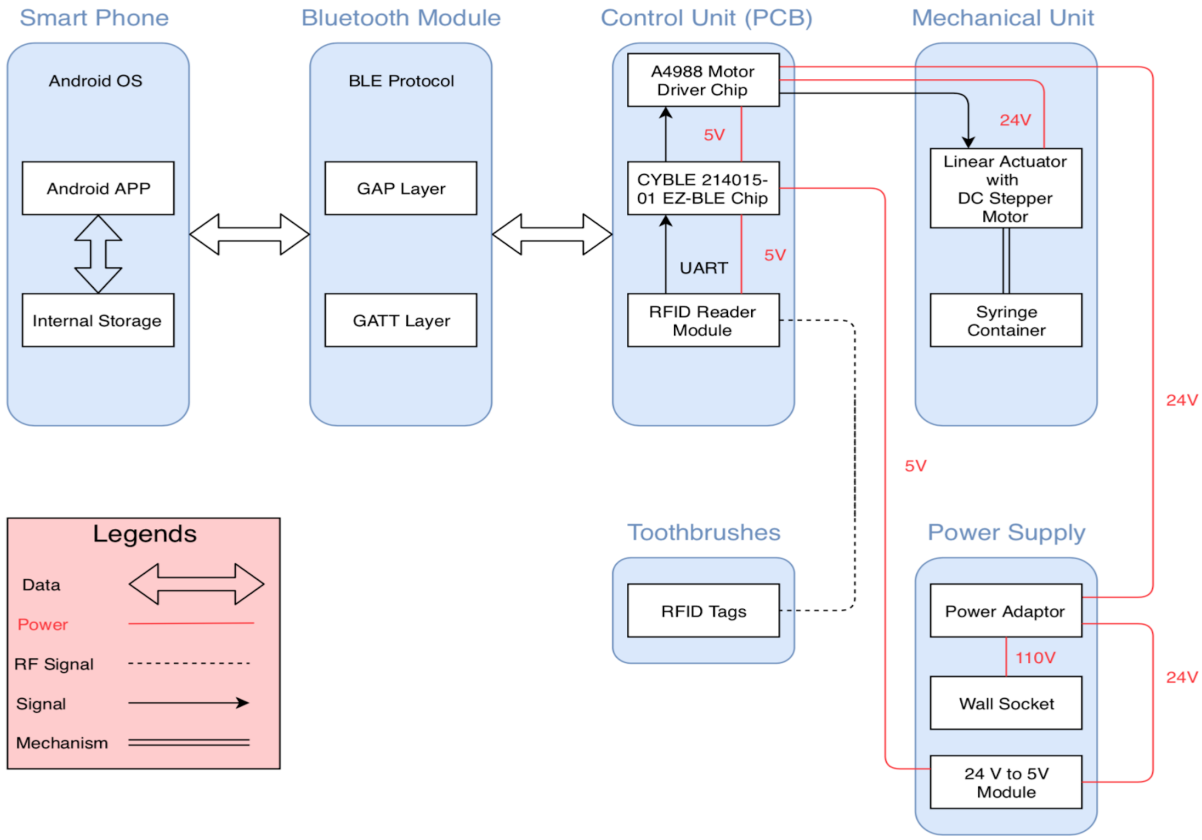

Figure 1: Block Diagram

2.2 Physical Design Draft

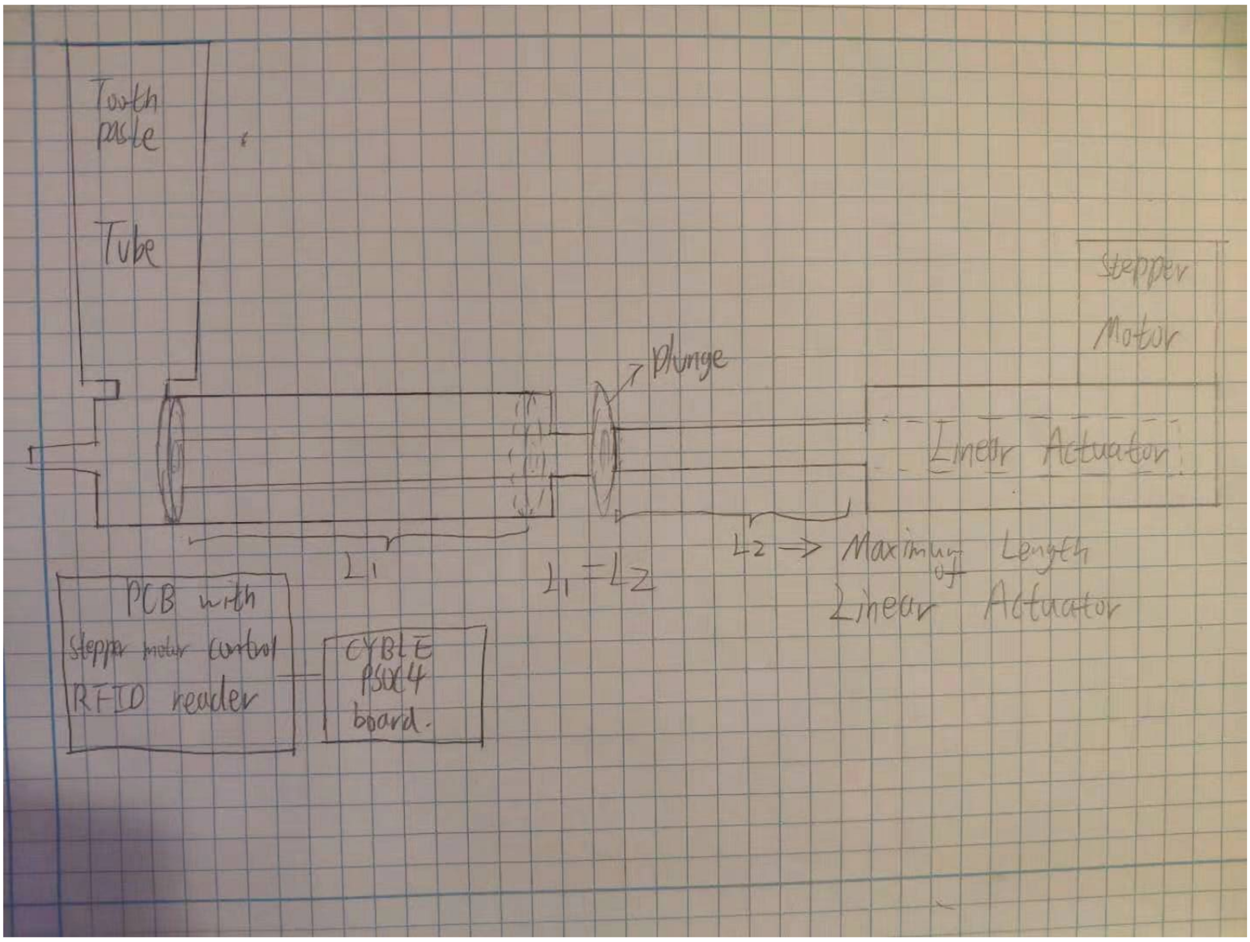

Figure 2: Mechanical Component Design

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. All user settings and toothpaste use data will be stored in the APP's internal storage.

Requirement	***Verification***
The APP's loading time is about 3±0.5 seconds.	*Start the APP ten times (kill its background process each time before*

	starting it). Calculate the average time spent on loading by using an electronic stopwatch.

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.

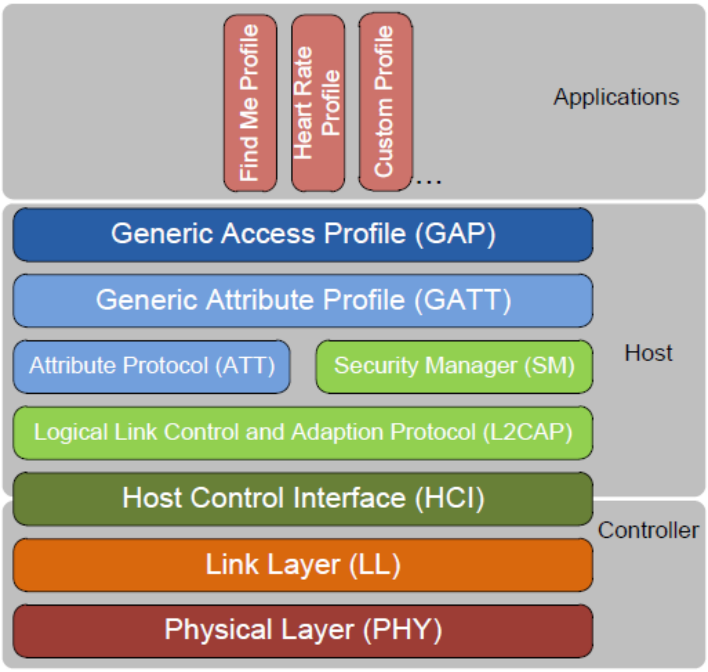

Figure 3: Bluetooth Protocol Schematic [3]

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	***Verification***
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.	*If the connection between the smartphone and the board is successfully established, the smartphone should display "Connected". If the board is then turned off, the smartphone should display "Disconnected".*

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 CYBLE-214015-01 EZ-BLE™ Creator Module

Figure 4: CYBLE-214015-01 EZ-BLE chip

According to Cypress, 'The Cypress CYBLE-214015-01 is a fully certified and qualified module supporting Bluetooth Low Energy (BLE) 4.2 wireless communication. The CYBLE-214015-01 is a turnkey solution and includes onboard crystal oscillators, trace antenna, passive components, and the Cypress PSoC® 4 BLE.' We will use the PSoC 4 Pioneer board and CYBLE-214015-EVAL board to test our circuit at first and then directly solder this chip on our PCB board.

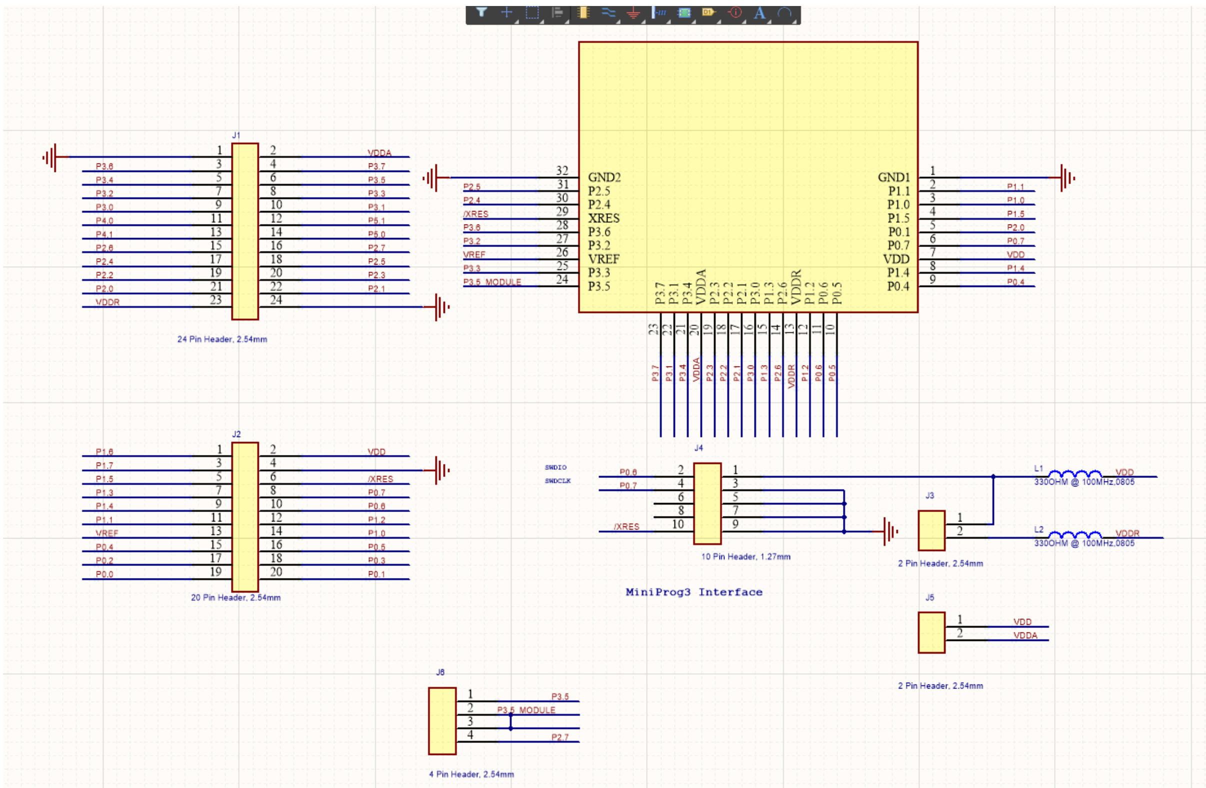

Figure 5: Schematic for CYBLE-214015-01 chip

Requirement	***Verification***
1. The input voltage to the VDD is about 4.7±0.5V.	1. *Use a multimeter to measure the voltage supply of the VDD input of the PCB to see if it falls in 4.7±0.5v.*

2.5.2 RFID Reader

We are going to build our own RFID reader on PCB. The RFID Reader is powered by the BLE Pioneer Baseboard with 5V. 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.

Requirement	***Verification***
1. Operating voltage between 4.7±0.5V. *2. It can read the RFID tag within 6±2 cm and output the corresponding ID.*	*1. Use a multimeter to measure the voltage supply of the VDD input of the PCB to see if it falls about 4.7v.* *2. We have software to test the function of the RFID reader. The RFID reader part on PCB can be directly connected to our computer with USB wire (TTL). Put the RFID tag close to our PCB and see if the ID is displayed on our computer.*

2.5.3 A4988 Stepper Motor Driver

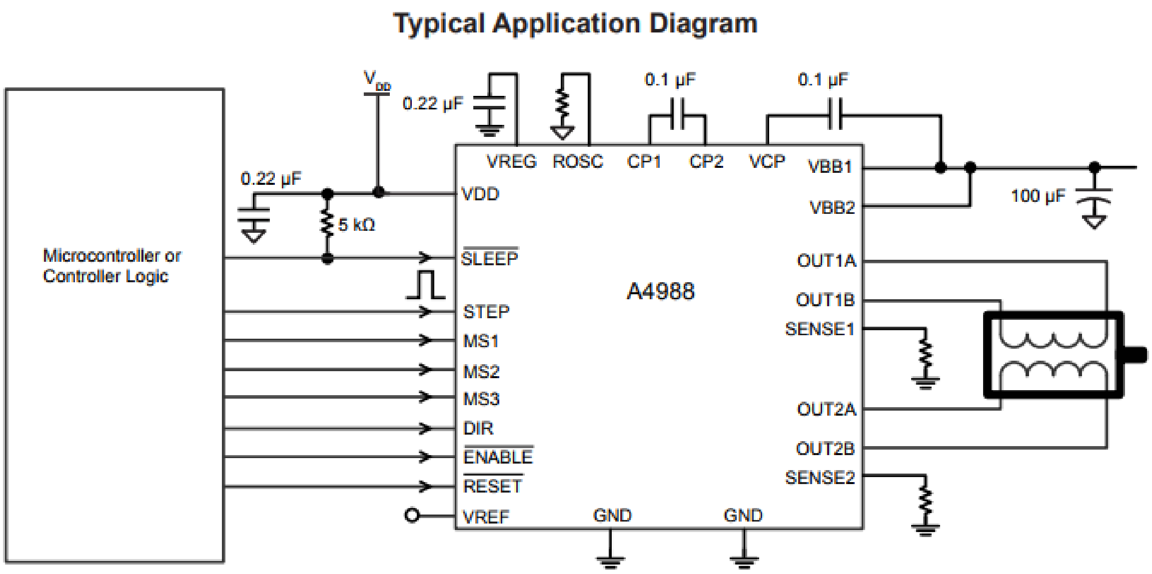

Figure 6: Typical application Diagram of the A4988 chip[8]

Absolute Maximum Ratings

Characteristic	Symbol	Notes	Rating	Units
Load Supply Voltage	V_{BB}		35	V
Output Current	I_{OUT}		±2	A
Logic Input Voltage	V_{IN}		–0.3 to 5.5	V
Logic Supply Voltage	V_{DD}		–0.3 to 5.5	V
Motor Outputs Voltage			–2.0 to 37	V
Sense Voltage	V_{SENSE}		–0.5 to 0.5	V
Reference Voltage	V_{REF}		5.5	V
Operating Ambient Temperature	T_A	Range S	–20 to 85	ºC
Maximum Junction	T_J(max)		150	ºC
Storage Temperature	T_{stg}		–55 to 150	ºC

Figure 7: Maximum Ratings about A4988 chip[8]

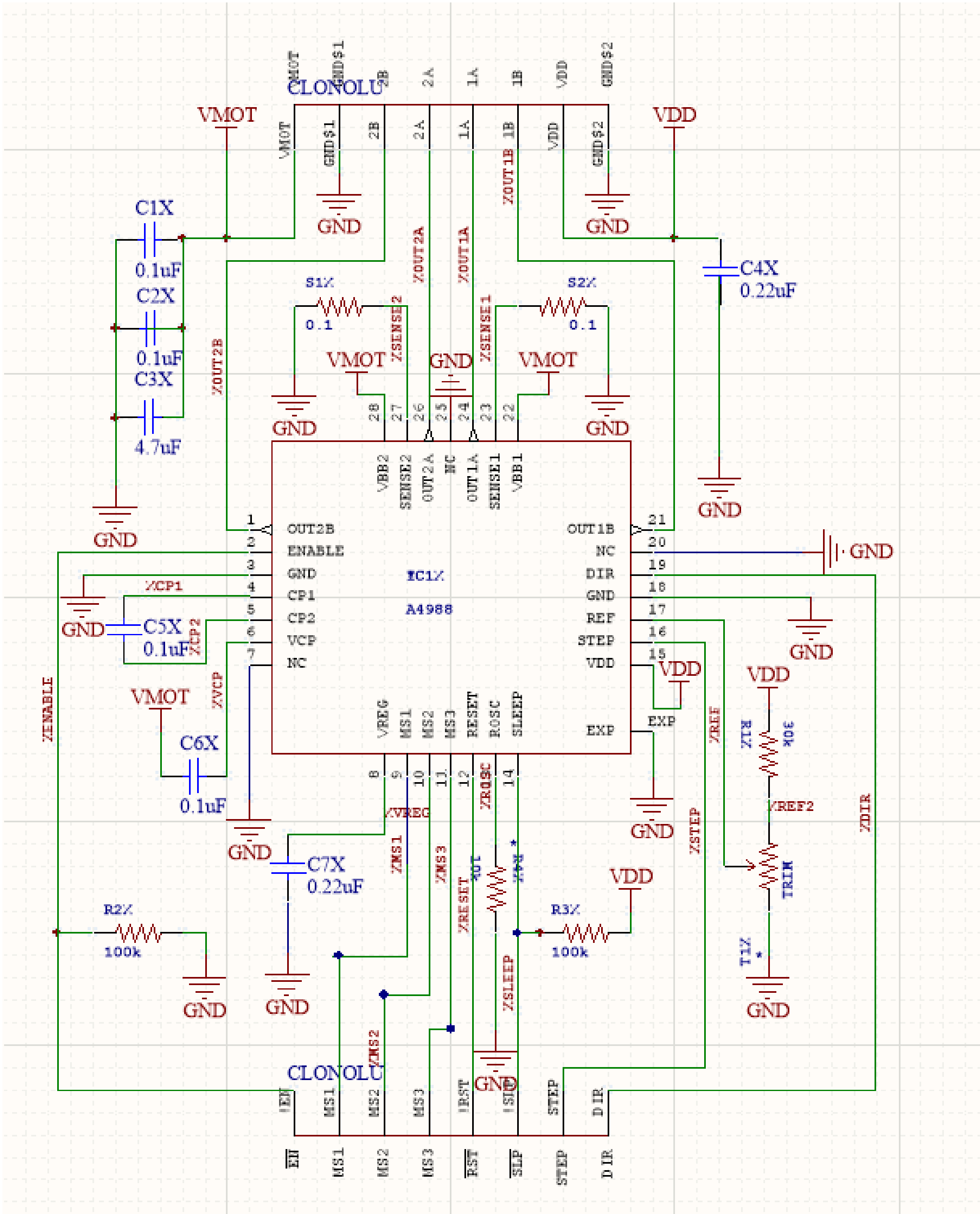

Figure 8: Schematic for our A4988 Control

We will use A4988 to build our own step motor control on PCB. Our step motor is 24 V and this chip can supply up to 35V. The power of our motor is 30 W so its required current is about 1.2 A and this chip can supply up to 2 A current. By connect step motor to OUT1,2AB and then every impulse we send to the STEP pin of the chip will make the step motor move about 1/200 turns and by this we can very precisely control the step motor. We should make sure the capacitor we buy can have at least 24V voltage rating so it will not be destroyed by the input voltage for the motor.

Requirement	***Verification***
1. The input Voltage to the VDD pin should be about 5±0.5V.	*1. Use a multimeter to measure the input voltage of this A4988 module. Also, we can directly connect this a 4988 part of our PCB to a stepper motor and send a signal to STEP pin to see if the motor can move correctly.*
2. The chip can keep working for 300±20 seconds without burning the a4988 chip.	*2. Also, we can directly connect this a 4988 part of our PCB to a stepper motor and keep send a signal to STEP pin for 5 minutes to see if it will burn*

2.6 Mechanical Part

2.6.1 Linear Actuator with Linear Actuator

Figure 9: 30W Linear Actuator with Step Motor [6]

We plan to use the Linear Actuator to push and pull the plunger of the syringe. The length of the actuator is about 80mm and this is the same number as the maximum moving length of the plunge. The step motor on this Linear Actuator is 24V and the maximum moving speed is 7 mm/s because there is a gearbox inside the Actuator. This speed is big enough for our design because our desired speed during the fill process is about 1 mm/s. The maximum staff it can push is 50kg while we test in the machine shop the force we require is about 10 kg so it is much more than enough. We can easily control the turns of step motor through our A4988 motor control PCB so we can precisely control the output toothpaste.

Requirement	***Verification***
1. The Actuator can provide about 200 N (+ infinite / -10N) torque to lift things up.	*1.A. Connect the motor to our a4988 motor control PCB and send a signal to the step input and see if the linear actuator can start moving.* *B. Put a 20 kg stuff on top of the actuator and see if it can push up. If it does, then it can provide about 200N torque.*
2. The pushing length of the actuator should be about 80±2 mm.	*2. We use motor control to move the push rod inside the actuator to its maximum position and measure the length of it. The error of this number will only affect the capacity of our syringe.*

2.6.2 Mechanical Components (Syringe type container with cap)

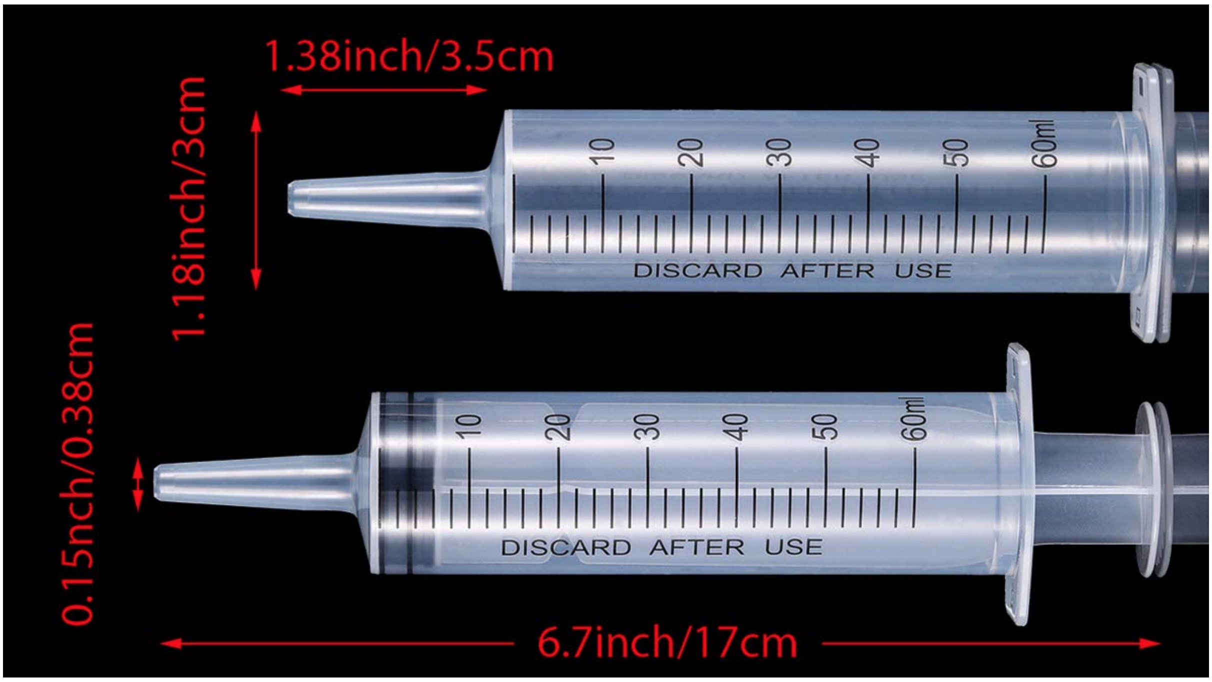

Figure 10: Frienda Plastic Syringe [5]

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. In order to do that, we will have a sealed cap for this syringe to prevent any air comes from the exit of our container during the refill process. During the normal use time, the cap will be put aside and there will be a small rubber cover on the exit of the syringe with a small cross-shaped gap on it. This rubber cover design will be easily open with high force applied by the motor but it can't open due to the pressure of toothpaste itself. It can prevent toothpaste leak when no cap is on the syringe.

Requirement	***Verification***
1. Without the control of the motor, the initial volume of air inside the syringe should be 15±2ml. *2. The syringe should be airtight when the front cap is on the syringe and the input hole is blocked.*	*1. Check the scale on the syringe to see if the volume of the air gap is about 15ml.* *2. Block the input hole of toothpaste on the syringe. Put the cap on the syringe and pull the plunger. An airtight syringe*

	should allow the plunger to bounce back to the original position after being released.
3. The small rubber cover at the top of the syringe can prevent toothpaste from leaking due to gravity.	*3. Refill the syringe, hold it at the vertical position and check if leaking occurs.*

2.7 Toothbrushes(RFID)

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.

Requirement	***Verification***
The RFID can be read within 5 cm by our RFID reader with the correct value.	*A. Connect the RFID reader to a computer and use a software (provided by seller) to read the signal from the RFID reader.* *B. Put RFID on a toothbrush and hold the toothbrush to approach the reader.* *C. Check software to identify the maximum range that the RFID reader can sense RFID tags.*

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.

Requirement	***Verification***
1. The power adapter supplies 24±0.5V voltage for the motor.	*1. Connect the power adapter to the wall socket and use a multimeter to measure the output voltage of the power adapter.*

2. The power adapter can supply 10±0.5A current.	*2. Use a multimeter to measure the output current of the power adapter. Also, directly connect the power adapter to the motor to see if the motor works correctly.*
3. The 24V to 5V voltage reduction module can supply about 5±0.5V.	*3. Use a multimeter to measure the output voltage of the voltage reduction module.*

2.9 Tolerance Analysis

The core of tolerance analysis toward our design is the air impermeability of mechanical components (syringe, syringe cap, toothpaste entry hole) and the performance of the motor.

Ideally, the syringe should be an airtight container. It should be unable to suck any air through the exit of the syringe during the toothpaste refilling process, thus preventing the inaccuracy due to the air gap. The motor should push the plunger of the syringe for a fixed distance in the dispensing process to accurately control the dispensed volume of toothpaste.

Nonetheless, the toothpaste entry hole drilled on the side of the syringe would cause the syringe to contain an initial air gap with a volume of around 15ml since the entry hole would physically obstruct the plunger to be pushed to the end. Also, the entry hole and the exit of the syringe would be potential sources of air leak. Therefore, the volume of toothpaste dispensed by the syringe each time when the plunger pushes it might not be exactly the same. This would prevent the dispenser to accurately meet our high-level requirement: 0.25ml/0.50ml.

Refilling at least loads 45ml of toothpaste/air into the syringe (maximum 60ml).
Number of squeezing after refilling once = 45 / Dispensed Volume
= 90~180 times

As our tolerance range for dispensing volume is **0.10ml**, so the maximum volume of air leak allowed is **9ml~18ml** in each refilling process. Planning for the worst scenario, the tolerance range of air trap inside syringe is 9+15=**24ml**.

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 use 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

We have 3 people in our group and use **40$/ hour** as our hourly salary. We will put 10 hours/week into this project and there are about 16 weeks for us to do this project. Total labor cost: 3*(40*12*16)*2.5=**$57,600** in total.

Component	Cost
CYBLE PSoC 4 BLE pioneer board	$30*1=$30
CYBLE MiniProg3	$99*1=$99
PWM Motor control board	$8.7*1=$8.7
Sticky RFID tags	$0.24*16=$3.84
Y13R RFID reader	$6.66*1=$6.66
USB to TTL line	$1.15*1=$1.15
Power adaptor	$9.14*1=$9.14
Coin Battery	$0.99*5=$4.95
GPG 120W motor	$80*1=$80
Connection wire	$0.1*10=$1
Syringe	$2.99*2=$5.98
Colgate toothpaste (Pack of 12)	$12.99 *1 = $12.99
Labor	$57600
Total	$57863.4

4.2 Schedule

Week	Member	Task
2.11	Haoyu Tian	Start writing the design document and buy the necessary components.
	Renjie Fan	Start writing the design document and buy the necessary components.
	Yanbo Chen	Start writing the design document and buy the necessary

		components.
2.18	Haoyu Tian	Detailed Mechanical part design.
	Renjie Fan	Learn to develop with CYBLE BLE Pioneer Baseboard.
	Yanbo Chen	Learn to develop with CYBLE BLE Pioneer Baseboard.
2.25	Haoyu Tian	Finish Mechanical part design and order mechanical part prototype from the machine shop.
	Renjie Fan	Complete mobile App UI design.
	Yanbo Chen	Build a sample Bluetooth connection between smartphone and board successfully.
3.4	Haoyu Tian	Develop the connection between the CYBLE board and the motor control board.
	Renjie Fan	Develop mobile App framework.
	Yanbo Chen	Work on RFID module.
3.11	Haoyu Tian	Enable CYBLE Board to control the movement of the motor and start to develop RFID reader connection with CYBLE board.
	Renjie Fan	Develop mobile App database function and learn Android Bluetooth programming.
	Yanbo Chen	Start working on data transfer between the smartphone and the board.
3.18	Haoyu Tian	Spring break
	Renjie Fan	Spring break
	Yanbo Chen	Spring break
3.25	Haoyu Tian	Develop CYBLE board to change the configuration for the corresponding RFID.
	Renjie Fan	Build Bluetooth communication between mobile App and CYBLE board.
	Yanbo Chen	Finish data transfer function between smartphone and board
4.1	Haoyu Tian	Test and debug the whole project without the mobile App. Make sure RFID reader and mechanical part work correctly when using CYBLE board to control.

	Renjie Fan	Test mobile App's User Interface and function of users' settings.
	Yanbo Chen	Enable user to configure the amount of toothpaste dispensed through the mobile App
4.8	Haoyu Tian	Assembly all the components on a platform and improve product appearance.
	Renjie Fan	Collaborate with Yanbo on general software testing and debugging.
	Yanbo Chen	Collaborate with Renjie on general software testing and debugging.
4.15	Haoyu Tian	Collaborate with teammates on general software-hardware testing and debugging.
	Renjie Fan	Collaborate with teammates on general software-hardware testing and debugging.
	Yanbo Chen	Collaborate with teammates on general software-hardware testing and debugging.
4.22	Haoyu Tian	Write final reports and demo project
	Renjie Fan	Write final reports and demo project
	Yanbo Chen	Write final reports and demo project
4.29	Haoyu Tian	Group presentation
	Renjie Fan	Group presentation
	Yanbo Chen	Group presentation

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