HABIT-FORMING TOOTHBRUSH STAND

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1 INTRODUCTION

1.1 PROBLEM

There are few habits as impactful as good dental hygiene. Brushing your teeth in the morning and night can significantly improve health outcomes. Many struggle with forming and maintaining this habit. At times, a small nudge is needed to keep kids, teenagers, and adults of all ages aware and mindful about their brushing habits. Additionally, many tend to zone out while brushing their teeth because they are half asleep or have no idea how long they are brushing. Parents might have a difficult time getting children to brush in the morning and before sleep.

For homeless shelter staff, rehab facility staff, patients, or anyone else looking to develop and track this habit, they may want a non-intrusive, privacy-preserving method [1] to develop and maintain the practice of brushing their teeth in the morning [2]. Keeping track of this information but not storing it permanently through a mobile application is something that does not exist on the market.

1.2 SOLUTION

Our solution works by adapting electric toothbrushes to meet user needs. Unlike specific toothbrush brands that come with mobile applications, our solution can be applied to all electric toothbrushes, preserves privacy, and reduces screen time. We will implement a habit-forming toothbrush stand with a microcontroller, sensors, and LED display that will work as a central hub for storing our toothbrush. A band of sensors will be wrapped around the base of the toothbrush, providing data to the central hub. Lifting the toothbrush from the stand, turning it on, and starting the brushing process will display a timer that counts in seconds up to ten minutes. Dentists recommend brushing twice a day for at least two minutes at a time [3], so our device solves the problem of brushing too quickly or losing track of time and brushing for too long.

Additionally, the display will provide an auto-adjusting calendar for brushing, with 14 graphical values coming from brushing your teeth in the morning or night during the current 7-day period. This will augment the user's awareness of any new trends, and potentially help parents, their children, and other use cases outlined above. We specifically store just one week of data as the goal is habit formation, not permanent storage of potentially sensitive health information in the cloud. The timer will display red numbers until the user has brushed for at least two minutes, after which the timer will turn green, and the current day and time period marker will turn from red to green (Figure 1).

1.3 VISUAL AID

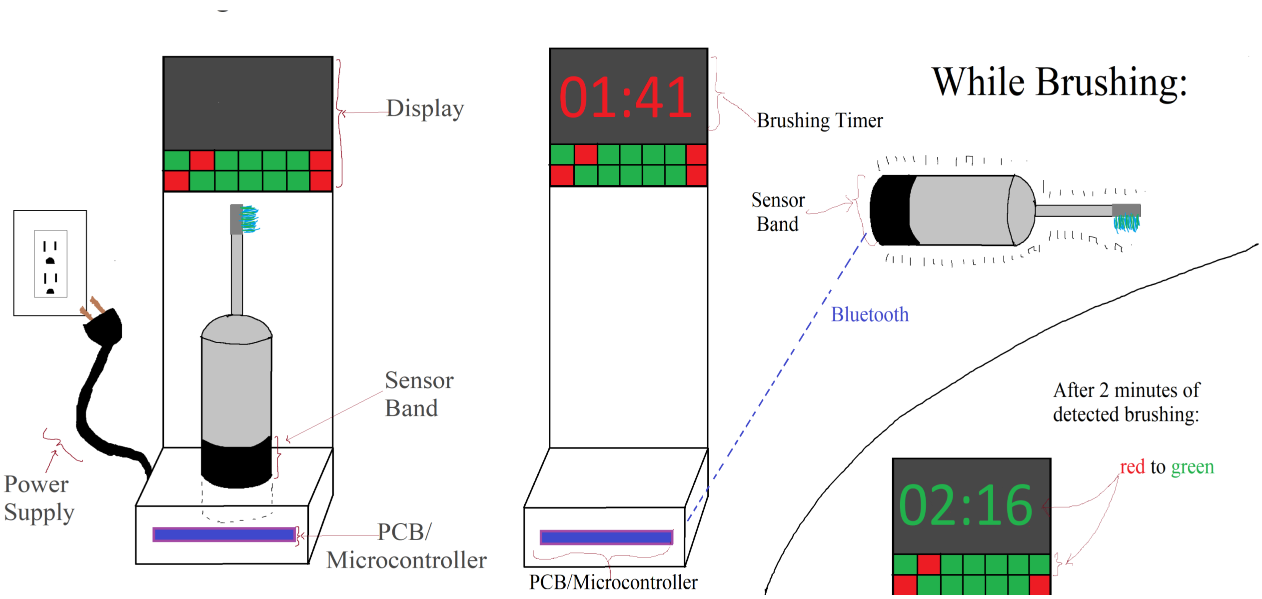

Figure 1: Device Physical Design

1.4 HIGH LEVEL REQUIREMENTS LIST

- After the user lifts the toothbrush **and** begins brushing, the sensor band accurately detects legitimate brushing activity and the brushing timer begins with the LED display showing a timer with red numbers.
- After at least two minutes of brushing have passed, the timer turns green, and when the toothbrush (with the sensor band) is set back on the stand, the display correctly marks the current day and period (morning or evening) green. If the user does not brush during the morning or night, the display will categorize the current period as “missed” (red).
- Track record over current and last six days, is accurately maintained, and at the start of a new day, the record is shifted appropriately.

2 DESIGN

2.1 BLOCK DIAGRAM

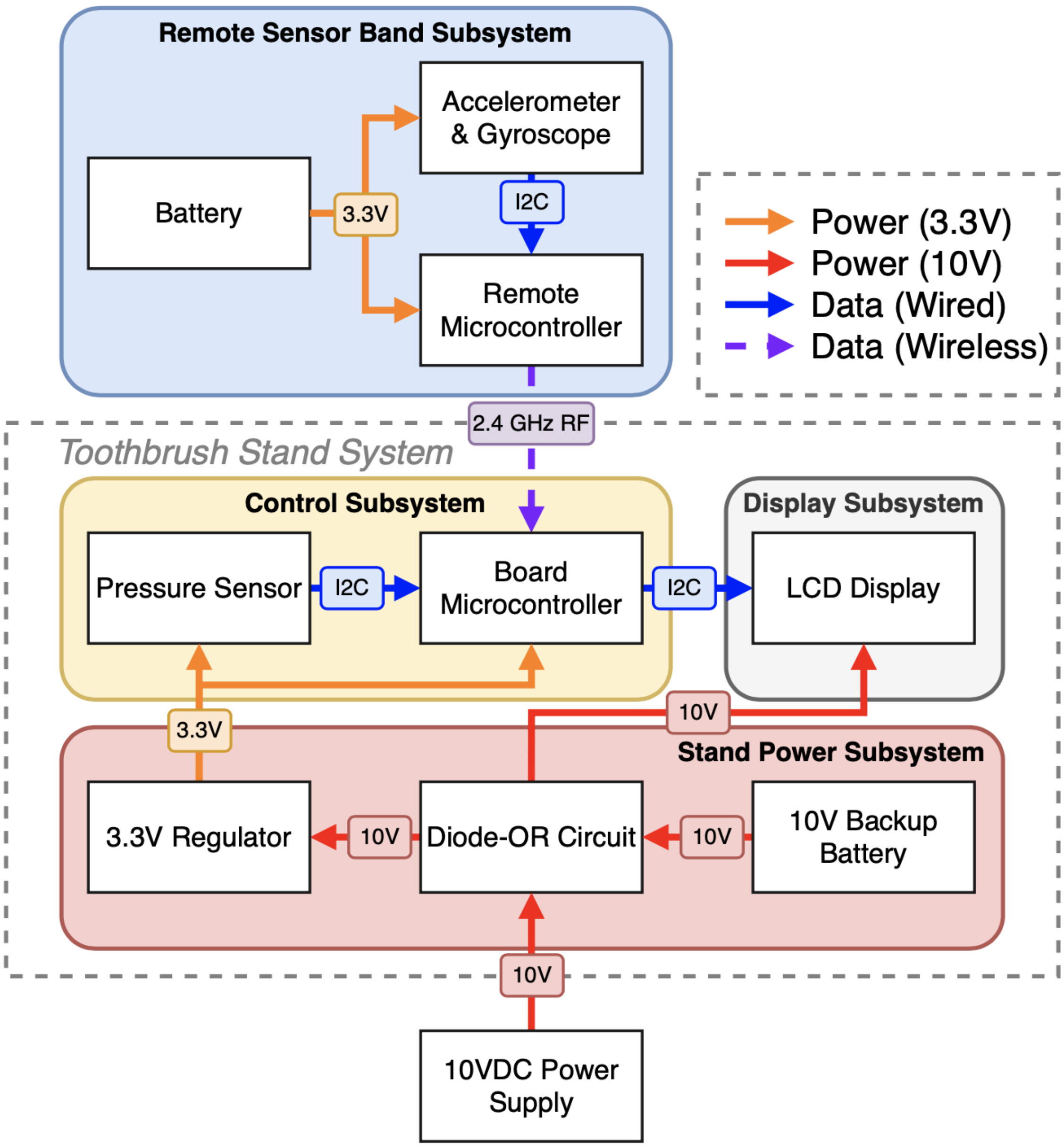

Figure 2: Block Diagram

2.2 Functional Overview

2.2.1 Remote Sensor Band Subsystem

2.2.1.1 Battery

The sensor band will be powered by a primary battery. The battery must produce a suitable voltage and provide enough current for the sensors and microcontroller on the sensor band. According to the ESP32 datasheet [4], the microcontroller requires a minimum of 500mA of current. Since we do not need to work with any components that require an operating voltage higher than 3.3V, the battery will not need any additional components.

Requirement 1: The battery must output between 3.0 to 3.6V DC and provide at least 550 mA of current.

2.2.1.2 Accelerometer

The sensor band will contain both an accelerometer/gyroscope sensor that will capture data for our microcontroller. This will allow us to determine if the user has actually started the process of brushing their teeth, rather than a false positive. We will experiment with the overall angle, but knowing whether the toothbrush is parallel to the ground, or is accelerating back and forth will give us validation. The data will be computed on an ESP32 microcontroller attached to the sensor band which will send the instructions over HTTP to an additional ESP32 chip.

Requirement 1: The accelerometer must operate properly when the supplied voltage from our battery is within the acceptable range (1.62V - 3.6V).
Requirement 2: The sensor must send acceleration data (I2C) to our ESP32 microcontroller so the data can be processed and analyzed for microcontroller instructions.

2.2.1.3 ESP32 Microcontroller (remote)

The ESP32 microcontroller on the remote sensor band will constantly be receiving the data provided from our accelerometer sensor. With built-in WiFi and Bluetooth Low Energy capabilities, we will be able to send our display data through HTTP communication to the board microcontroller that is housed in our toothbrush stand. By using this remote microcontroller we can perform any calculations remotely before sending the less time sensitive display data to our board microcontroller. Since we are using HTTP for communication, we will set up this microcontroller as a “soft access point” so the other microcontroller can request the display data [5].

Requirement 1: The microcontroller should receive the data from our accelerometer and use the information to determine success or failure.
Requirement 2: The microcontroller must be recognizable as a soft access point and respond to requests from clients connected to the “server”.

2.2.2 Stand Power Subsystem

2.2.2.1 10V DC Power Supply

The primary source of power for our toothbrush stand will be a 10V DC power supply that is plugged into an outlet. Since the display requires a different voltage than the sensor and microcontroller, we will use the voltage from the power supply to run the LCD/OLED display, and a 3.3V regulator will be used for the other components. This ensures that the voltage that we are supplying to our overall device will never be more than the specified voltage.

Requirement 1: The AC to DC power supply must output 10V ± 5% V and provide at least 750mA of current [4, 6].

2.2.2.2 Backup Battery

In order to retain data in the event of external power loss, a backup battery pack will also be used to provide 10V power to our system. Similar to our power supply, it will be providing the maximum voltage to our display as that requires the most regulated voltage, whereas the control subsystem will still need to use a 3.3V regulator to keep within operating voltages for the sensor and microcontroller.

Requirement 1: The backup battery must output 10V ± 5% V and provide this at 750mA of current, the same operating conditions as our power supply.
Requirement 2: The backup battery should automatically be used once the power supply has been disconnected from an outlet.

2.2.2.3 3.3V Regulator

Since we are working with a power supply that is providing a voltage above the operating voltage of our ESP32 microcontroller as well as our pressure sensor, the voltage regulator will bring our 10V ± 5% V supply voltage down to a stable 3.3V operating voltage. Additionally, since we have specific requirements on the current delivered by the external power supply on the microcontroller [4] and the LCD/OLED display [6], we will ensure that the current delivered will be at minimum 750mA to accommodate.

Requirement 1: The 3.3V regulator must be capable of providing a maximum of 3.3V ± 0.3V at 750mA current.

2.2.3 Control

2.2.3.1 Pressure Sensor

A pressure sensor will be used to detect if the toothbrush is placed in the stand cavity. The sensor will be powered by the 3.3V regulator and communicate with the microcontroller via I2C. It acts as the first step in our teeth brushing process as we will begin to start our polling of the sensor band's progress when the user lifts the toothbrush from the stand.

Requirement 1: The sensor should be able to provide pressure data to our microcontroller such that it can detect whether the toothbrush is placed in the stand.

2.2.3.2 Microcontroller (Board)

The toothbrush stand microcontroller is responsible for communicating with the pressure sensor, display, and sensor band. The microcontroller will use I2C to communicate with the pressure sensor, and based on the data received from the sensor, the microcontroller will determine whether the toothbrush is placed in the stand. Once the toothbrush is removed from the stand, the microcontroller will initiate communication with the sensor band and constantly check if the user has started brushing their teeth. By sending HTTP requests to our "soft access point" on the sensor band's ESP32 microcontroller, it will receive the instruction on whether or not the user has brushed their teeth in the acceptable time range for the time of day [4]. The microcontroller will also render the graphics for the display. The microcontroller will communicate with the display via I2C, and will operate on a regulated voltage of 3.3V similar to the pressure sensor [4].

Requirement 1: The I2C from the microcontroller must meet the timing specifications for the pressure sensor and display.
Requirement 2: The microcontroller must be able to send HTTP requests to our sensor band "soft access point" and receive the success or failure decision for the specified time of day.
Requirement 3: The microcontroller should properly update the display in real time.

2.2.4 LCD/OLED DISPLAY

The display will show the user how much time they spent brushing as well as the brushing history for the past week. The calendar must be properly adjusted according to the current day of the week. The display will receive the graphical data from the microcontroller using I2C communication and run on 10V from the power supply [6].

Requirement 1: The display's I2C connection must be working properly and allow control over every pixel.
Requirement 2: The display must update the proper graphics in real time.

2.3 Tolerance Analysis

A challenging component of our design is ensuring that the sensor band can withstand water. Our sensor band will be transmitting the user data when the actual tooth brushing process is being conducted; therefore, we must account for any possibility of water coming in contact with our sensors or voltage supply. In order to achieve success in eliminating this risk, our group went to the machine shop for guidance on waterproofing these components. After speaking with machine shop staff, their suggested methods were to have everything sealed in cling film, silicone sealant over the circuits/sensors, or a waterproof case; however, they noted the last solution would have additional challenges in terms of powering the sensor band. Since water damage would hinder our progress substantially, we will need to rigorously test the methods listed above to find the solution that fits our project.

3 ETHICS AND SAFETY

Privacy is an issue of great prominence and plays a central role in our design. According to sections 1.3, 1.6, and 1.7 of the ACM Code of Ethics and Professional Conduct, focusing on Privacy, “Only the minimum amount of personal information necessary should be collected in a system” [7]. Our system is optimized for user privacy, as the bare minimum data is stored for at most one week in a manner that is clear to the user and in a manner that cannot be exported or stored. The Habit-forming Toothbrush Stand preserves user privacy, a fundamental human right in a manner with the knowledge of the people affected, for legitimate ends. Sensitive user information will not be stored on-device in order to minimize data collection and prevent unauthorized access to personal data. Additionally, having a method to “reset” the toothbrush stand and the display is worth exploration for individuals in shared environments.

Section I-1 of the IEEE Code of Ethics emphasizes that striving to comply with ethical design and protecting the privacy of others is paramount [8] . Additionally, section II of the IEEE Code [8] states that it is essential to “to treat all persons fairly and with respect, to avoid harassment or discrimination, and to avoid injuring others.” Since our device uses a display we must ensure that there are no effects that could lead to photosensitive epileptic seizures for vulnerable users. Our design does not include specific animations or effects, we will only be using the display to show the calendar and timer. We have explored the possibility of different colors or unique identifiers in our numbers so that colorblind users can utilize our device with minimal disruption.

The sensor band could potentially be a choking hazard for children, so our device must be utilized by children above four. Additionally, the battery that powers our sensor band is not rechargeable so battery disposal must be done responsibly. To ensure we properly use and dispose of batteries safely, we will abide by the safety standards of the Division of Research Safety [9] at the University. Electrical hazards and improper battery or power management could pose safety risks which we will account for through our project design. In accordance with

Section I-5 of the IEEE Code of ethics [8] we will accept and implement feedback from teaching, assistants, Professors, and Machine Shop staff.

Additionally, our system comes in contact with water, therefore we need to take precautions about water damaging our circuits, or worst case potentially coming into contact with the power outlet. Bathroom sinks and outlets are already designed in a manner that would not require additional measures, however, addressing the risks of water entering the toothbrush stand or the sensor band is important. Machine shop staff recommended the following: sealant over the circuits/sensors, a waterproof plastic covering, or having everything sealed which would prevent water from damaging our system.

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