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).
3 High-level Requirements

- The toothbrush stand will start tracking time after brushing activity has started for a minimum of two seconds, and stop tracking within 1 second after brushing activity has ceased.

- The Habit-Forming Toothbrush stand can determine whether a user is underbrushing (brushing less than two minutes), over-brushing (brushing longer than four minutes), or brushing the dentist recommended two minutes (but no longer than four minutes).

- The display on the toothbrush stand shows, in the specified format, whether the user brushed their teeth in the morning and in the evening for the past 7 days.
4 Block Diagram

Figure 2: Block Diagram
5 Requirements & Verification Tables

5.1 Remote Sensor Band Subsystem

The remote sensor band subsystem will be tracking the user’s motions during the toothbrushing process, utilizing sensor data by putting it through our algorithm to determine display instructions, and sending data to our board microcontroller in the toothbrush stand. By using a lithium ion battery to power our sensor band we will be able to take the provided voltage of 3.7V and send it through a linear voltage regulator to bring the voltage down to 3.3V to properly power our ESP32 microcontroller and accelerometer sensor.

Additionally, the remote sensor band microcontroller will act as our access point such that the board microcontroller will request instructions based on the amount of time elapsed as well as the data from our dual accelerometer and gyroscope sensor. By doing so, the boards will be able to communicate and request data from each other through HTTP.

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| 1. Provide 3.3V +/- 0.5% from a 3.7V-4.2V source at an operating current of 500mA. | 1A. Measure the output voltage using an oscilloscope, ensuring that regulated voltage stays within 0.5% of 3.3V.  
   1B. Connect a variable resistor to the output of the regulated voltage as well as to ground; measure the output current using an oscilloscope and verify that it is at 500mA. |
| 2. The position data must be acquired from the accelerometer at a scale of 16g and 0.488 mg/LSB (16 bit) sensitivity with +/- 10% variance. | 2A. Connect the accelerometer to the ESP32 MCU through I2C.  
   2B. Move the accelerometer at a fixed speed on the X, Y, and Z axes over five trials.  
   2C. Compare the data from each of the five trials and ensure that the readings are within 10% of each other. |
| 3. The microcontroller can be recognized as a “soft access point” over WiFi and receive sensor data with an average latency of around 10ms +/- 10%. | 3A. After running the code to set up the MCU, use a separate WiFi enabled device to test the connection to our access point over the 2.4 GHz RF band.  
   3B. Using request URLs for acceleration data, ensure that our MCU is properly receiving acceleration values.  
   3C. In unison with the board MCU, verify the latency of display requests through the output in the Arduino serial monitor. |
An important part of our project is using acceleration data to determine when the user is brushing their teeth. We will be using the LSM6DSL inertial measurement unit from STMicroelectronics to capture the acceleration data on the sensor band. Two important considerations are how sensitive the sensor should be and how to recognize brushing activity with the acceleration data.

The accelerometer can be set to several different measurement ranges, which determines the largest acceleration that the sensor can measure. In order to read usable data, the range must be larger than the magnitude of acceleration that we expect to encounter. Although it may seem reasonable to select the largest measurement
range, using a more narrow range increases the sensitivity of the sensor, so it is ideal to choose the narrowest range that can handle the largest expected acceleration.

We expect that a brushing motion will have a travel distance of less than 10cm, and the brushing frequency will be less than 8 times per second. Assuming a linear sinusoidal motion, we can model the displacement as:

\[ d(t) = 5\text{cm} \times \cos(2\pi \times 8s^{-1} t) \]

We can calculate the acceleration by taking the second derivative of the displacement:

\[ a(t) = 5\text{cm} \times 4\pi^2 \times 64s^{-2} \times \cos(2\pi \times 8s^{-1} t) \]
\[ a(t) = 126 \text{m/s}^2 \times \cos(2\pi \times 8s^{-1} t) \]

We observe that the maximum expected acceleration is 126m/s\(^2\), or 12.9g (where g is the acceleration due to gravity). The LSM6DSL has a measurement ranges of ±2g, ±4g, ±8g, and ±16g, so we will use the ±16g setting for our project.

Concerning the detection of whether the user is brushing their teeth, we expect that the magnitude of acceleration will be sufficient for identifying brushing activity. However, we will need real-life tests to determine the threshold magnitude and to confirm whether the acceleration magnitude provides sufficient information on its own. We will also implement a buffer time of one or two seconds in order to prevent accidentally miscategorizing non-brushing activity as brushing activity.

9 Safety & Ethics

*We need to include OSHA/other type of standard, it's in grading pdf for DD (not DDC)*

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.
10 Citations


