Toothbrush Alarm
ECE 445 Final Report - Spring 2024

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Abstract

This report details all the decisions our group made throughout the semester in the effort to produce the best quality version of our project, the toothbrush alarm, as we can accomplish. In this report, the basic functionality is described, the reasoning behind each of the design choices, the requirements of the project and how to verify them, our own results produced by our final design, and further modifications that can be made.

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1 Introduction

The problem our project aimed to solve was the difficulties some people have in waking up on time. People who set multiple alarms and then snooze all of them will wake up two hours later and end up being late. The solution we devised is the toothbrush alarm, incorporating something that people do every morning, which forces the user out of their bed and brush their teeth to deactivate the alarm. The project was divided into five subsystems spread across three physical devices, as seen in figure 1. The dock physical device holds the dock subsystem with a motion sensor to monitor whether a person is within 3 m of the device and the clock and display subsystem keeps and stores time with an accuracy of one second as well as take button inputs to modify internally held values. The toothbrush physical device contains the toothbrush subsystem which detects if the user applies equal to or greater than 0.2 mN on the toothbrush to consider it in use, and the alarm physical device contains the alarm subsystem which wakes up the user within one second of the set alarm time. Each of these devices has their own power and recharge subsystem to supply energy in the form of 3.3 V and 5 V to the other subsystems. The final implementation of the design is seen in figure 2.

One key change made through the project’s development was the removal of a pressure sensor from the dock subsystem. Originally, it was there to detect if the toothbrush was placed on the stand and could have been used to trigger the charging of the toothbrush or as another method to detect if the user is in the bathroom and has the toothbrush in hand. We decided to remove it from the final implementation since it was redundant with the motion sensor already in place so it would not add anything significant to the project's main function.

Another major change is that the transceiver and RTC could be implemented in the microcontroller alone. There were several microcontrollers and transceivers that we went through until we arrived on the final design of an ESP32-WROOM dev board. This was beneficial on the hardware side since it contained functionally for some of the components, reducing the parts required, however this does add complexity to the software side of things in return.

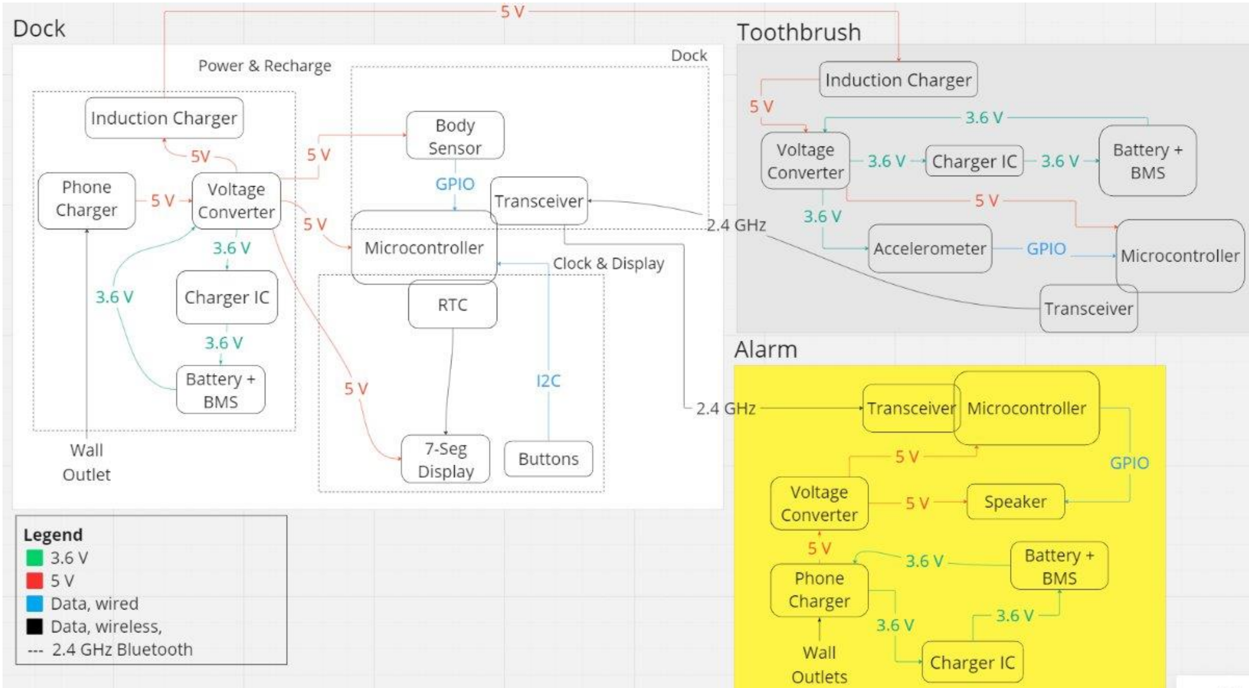


Figure 1

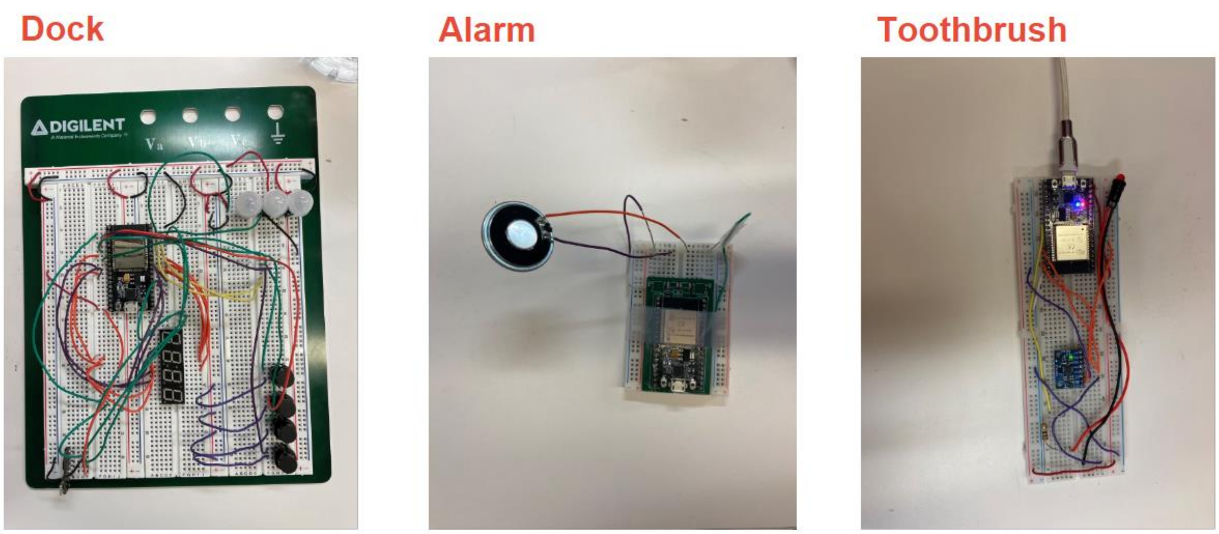


Figure 2

2 Design

2.1 Design procedure

The dock subsystem, shown in figure 3, is composed of an IR motion sensor to detect the presence of the user within 3 m of the dock and a microcontroller to register the output signal. There were no alternatives considered for the IR motion sensor as it accomplishes its purpose sufficiently. There were other microcontrollers considered, such as the PIC16F886, ATMega32, and ESP32-C3. In the final design, the ESP32-WROOM was used, as it functions as a microcontroller, transceiver, and Real Time Clock (RTC), which reduces necessary parts and is simpler to program compared to the other candidates.

The clock and display subsystem, shown in figure 4, is composed of a seven-segment display to show the user the current time and time left to brush teeth, buttons to modify the time, an RTC to generate the clock signal, and a microcontroller to receive inputs, store alarm time, and output signal for the seven-segment display. A different seven-segment display was considered, but rejected as it did not have the colon used in time displays. There could have been a separate microcontroller and RTC, but it would not have been as efficient as using the ESP32-WROOM which could do both, and it shares the microcontroller with the dock subsystem since they are both on the dock physical device.

The toothbrush subsystem is composed of an accelerometer, shown in figure 5, to detect the angular velocity of the brush, a microcontroller to interpret the signal from the accelerometer, and transceivers here and on the dock to remotely communicate. With some internal calculations by the microcontroller, the force applied to the brush can be estimated. An acceleration threshold is set in the programming, so that when the brush is used with equal or greater force, the microcontroller outputs a signal that the brush is in use. Other accelerometers were considered, but rejected when their physical dimensions made them too small to work with them. The microcontroller and transceiver could have been implemented separately, but it was more efficient to implement them both in the ESP32-WROOM.

The alarm subsystem is composed of a speaker, shown in figure 6, to awaken the user once the alarm time has been reached, a microcontroller to activate the speaker, and transceivers here and on the dock to remotely communicate. Several other speakers were considered for the final design, until the speaker from Soberton was selected due it is larger size to make it easier to work with and loudest volume of all candidates. The transceiver and microcontroller are implemented together for the same reasons as the toothbrush subsystem.

The power and recharge subsystems are composed of a recharging IC, shown in figure 7, rechargeable batteries and battery management systems, shown in figure 8, and 3.3 V and 5 V regulators. No alternative designs were considered, as each of their datasheets specified the chips would operate at the designed specifications.

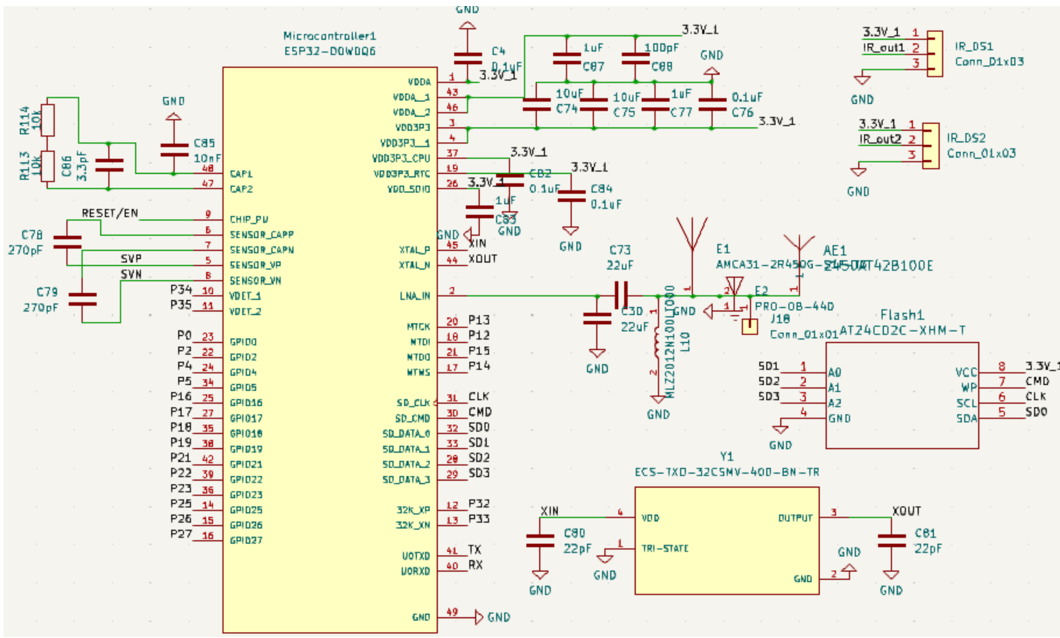


Figure 3

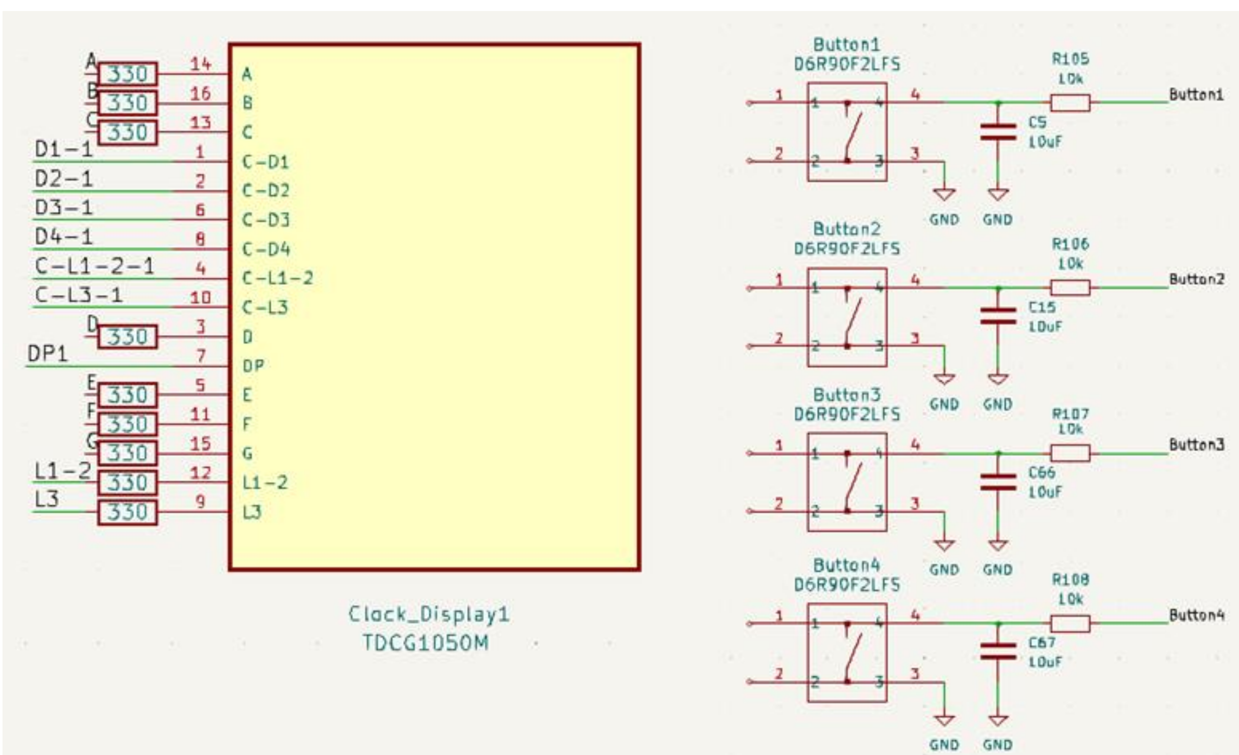


Figure 4

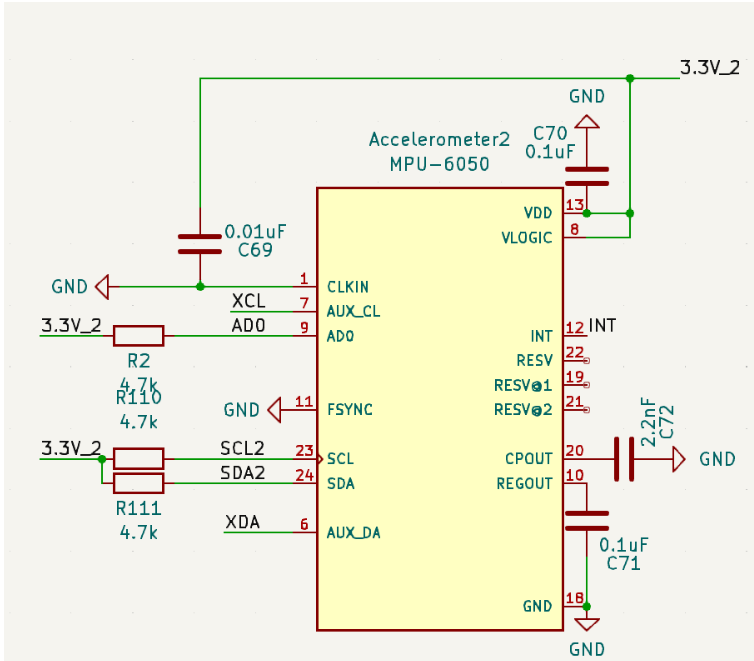


Figure 5

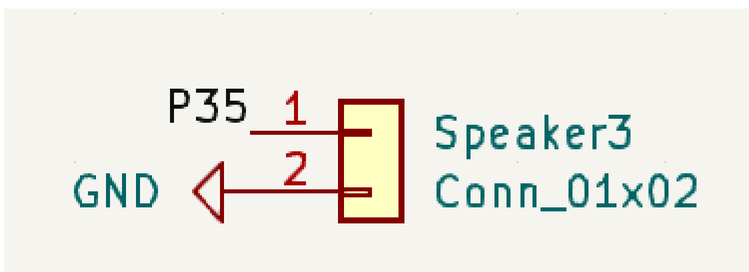
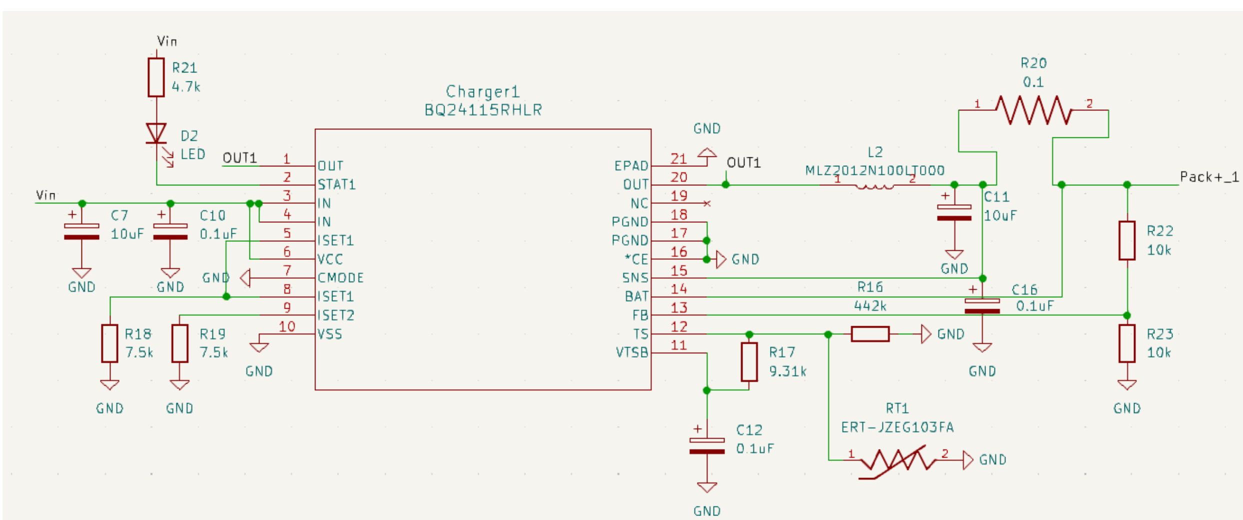


Figure 6



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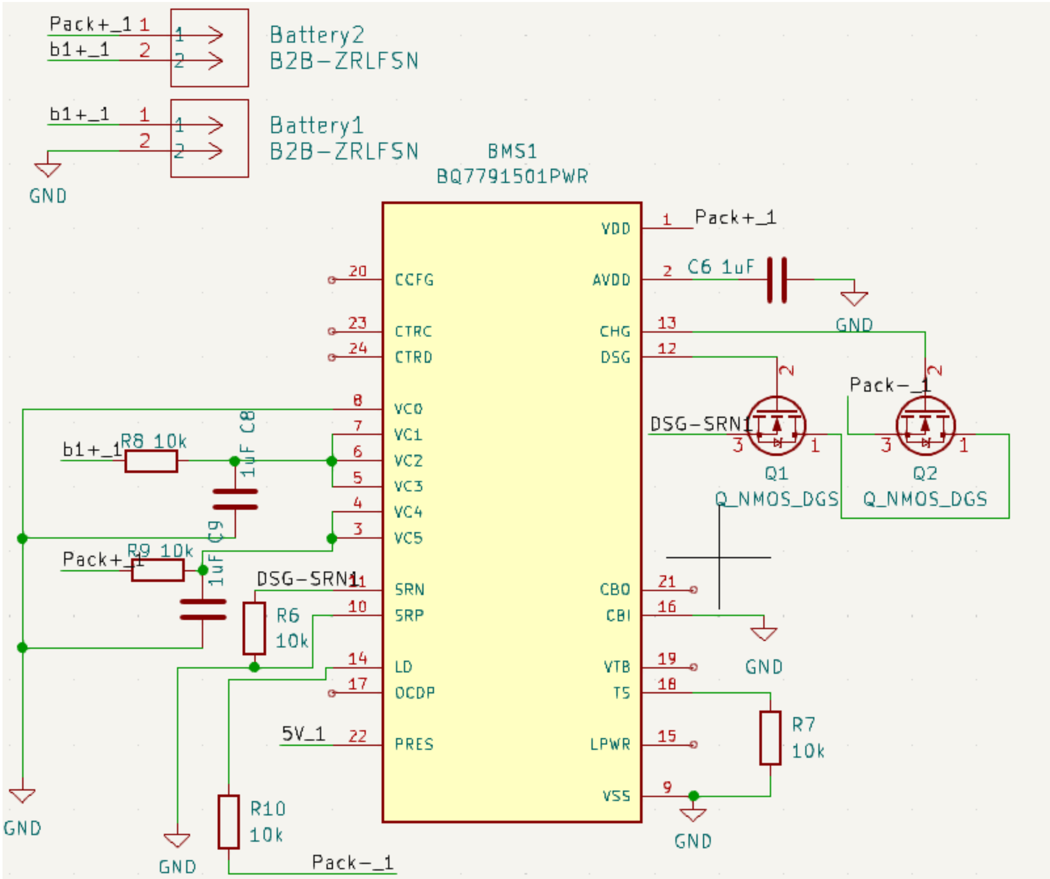

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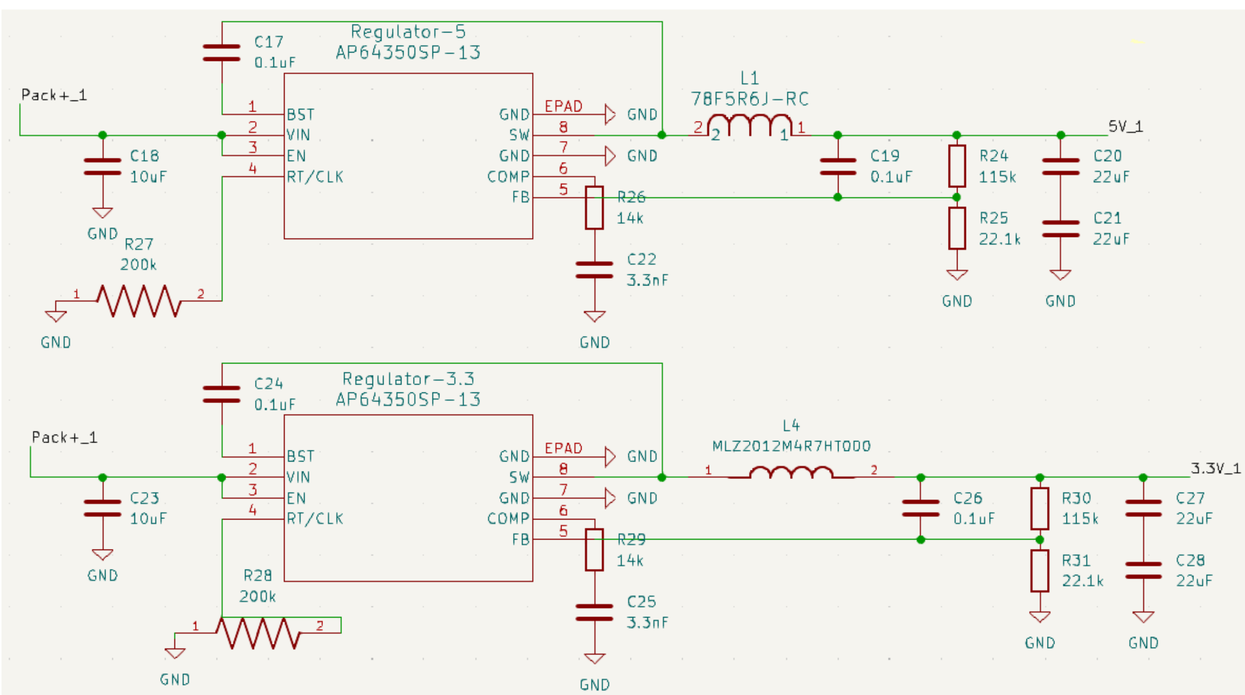

Figure 9

2.2 Design details

All the subsystem circuits were designed based off the typical application shown in their respective datasheets.

Figure 10 is the state diagram for the dock subsystem. The dock subsystem programming to interpret the IR motion sensor is straight forward as the sensors output a digital 0 or 1. The dock checks the time, and if it matches the set alarm time, the microcontroller sends a signal to the alarm subsystem to activate and wake up the user. The microcontroller reads the value of the pins connected to the motion sensors and if any of them are 1, the microcontroller knows a person is within 3 m of the dock and shuts off the alarm. If two buttons from the clock and display system are pressed and held, the user can turn off the alarm in case of emergency. If the dock both senses a person in front of it and the toothbrush subsystem sends a signal that it is in use, the teeth brushing timer will countdown.

Figure 11 is the state diagram for the button inputs of the clock and display subsystem. There are a total of four buttons, and from left to right, the buttons will be referred to as 1, 2, 3, and 4. Not pushing any buttons sets the display to the current time. Pushing button 1 once sets the display to modify the current time, where button 2 increments the hour and button 3 increments the minute. Pushing button 4 confirms the selection and brings the display back to the current time. Pushing button 1 twice sets the display to modify the alarm time, where buttons 2 and 3 increment hour and minute respectively, and button 4 confirms and brings the display back to current time.

Figure 12 is the state diagram for the toothbrush subsystem programming. The accelerometer takes a measurement of its current angular velocity, sends it to the microcontroller, and the microcontroller stores the value. Then another measurement is taken at another time, it is compared to the stored value, and now the microcontroller has an estimate of the angular acceleration in that time frame. Using equation 1 from section 3.3, the force applied can be estimated, and if it is higher than the programmed threshold, the toothbrush sends the dock a signal to indicate it is in use.

Figure 13 is the state diagram for the alarm subsystem programming. Once the signal to activate is received from the dock, the alarm will sound and wake up the user. Otherwise, it does nothing.

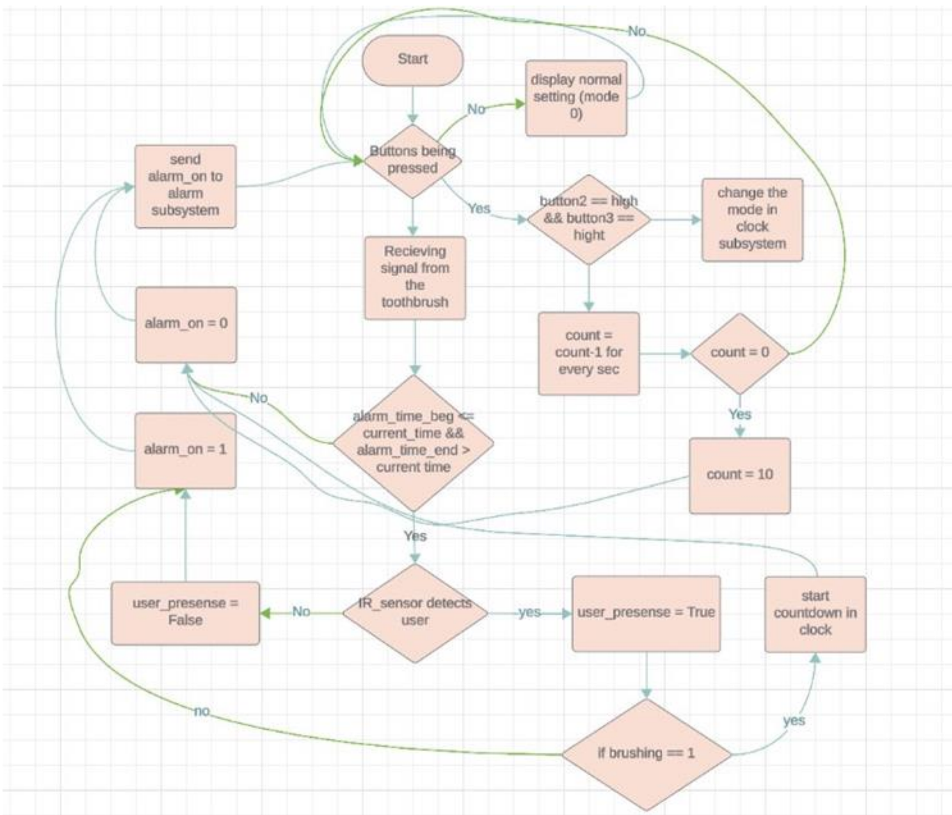

Figure 10

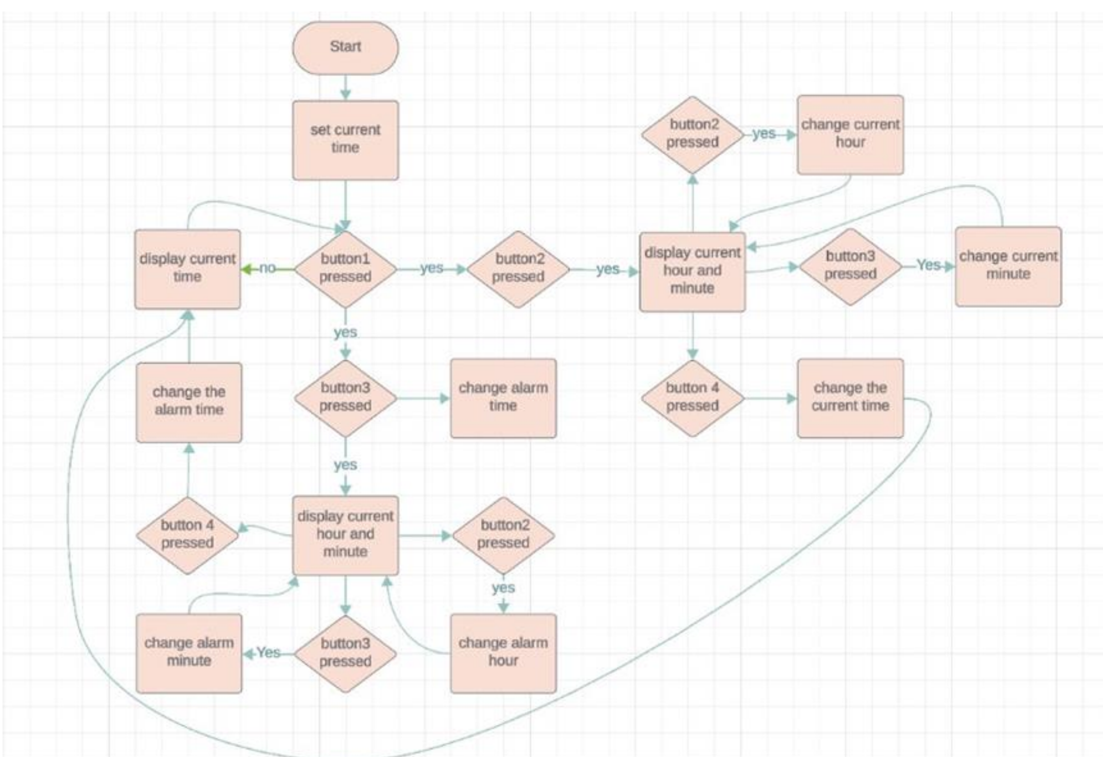

Figure 11

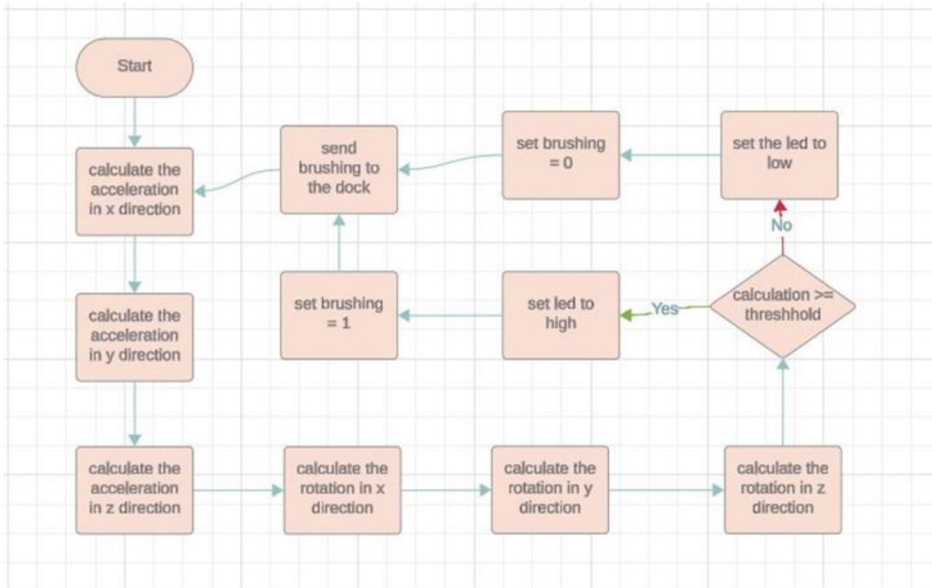

Figure 12

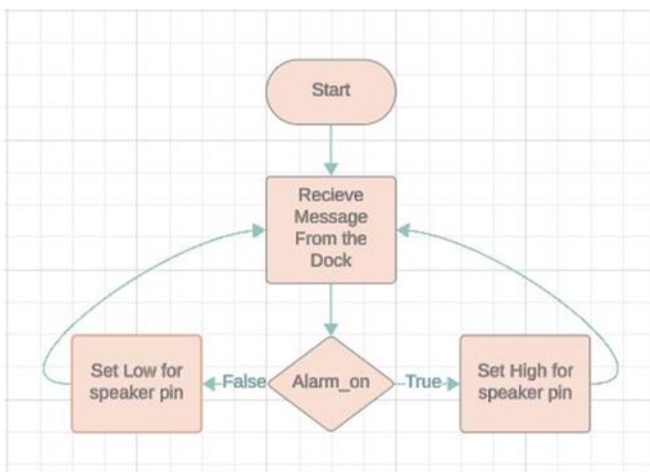

Figure 13

3 Verification

Speaker Volume:

GPIO pins	45 dB
Ground	40 dB
Power (5.5v)	60 dB

We wanted our alarm to ring as loud as possible, so we connected it to power.

3.1 Motion sensor range:

We have done multiple tests for its effective distance, the average we got at the end is 3.78m, and the furthest is 3.81m. It stayed very consistent, and well passed the 3m threshold in our high-level requirements. Moreover, it could detect over 180 degrees of areas in front of it that is specified in the high-level requirements.

3.2 Wi-Fi range:

All three of our components communicate with each other via Wi-Fi. Our tests came back with a range over 20m, which is sufficient for most household use. The user could grab their toothbrush and walk away from the dock, and it will continue the countdown.

3.3 Acceleration resolution:

Our accelerometer can measure angular acceleration up to hundredth place, 0.01 rad/s, so the smallest acceleration that we can measure is 0.2mN, which surpasses our high-level requirements. The 120 cm comes from an estimated distance between the floor and the user's mouth and this value represents the radius of the brush's movement. The 20 g comes from an estimation of the mass of the final design toothbrush device.

$$0.01 \text{ rad/s}^2 * 120 \text{ cm} * 20 \text{ g} = 0.2 \text{ mN} \quad (1)$$

3.4 Other:

We have also tested its long-term performance, and it holds up well. The alarm would reliably sound every time. The user could also change the time while the alarm is ringing, or set the alarm to the current time, and the alarm will ring or stop accordingly correctly.

4 Costs

4.1 Parts

Here are all the parts that we have acquired throughout our implementation. There are many components that we have bought in earlier stages that provide very significant contributions in later completion. We spent around $105.33 for all the components we used in our final design.

Description	**Manufacturer**	**Quantity**	**Total Price**	**URL**
Rechargeable Battery [2]	YDL	**5**	**$21.35**	**Link**
Battery Management IC [3]	Texas Instrument	**3**	**$5.16**	**Link**
Charger IC [10]	Texas Instrument	**3**	**$3.78**	**Link**
Induction charger (receiver) [13]	Würth Elektronik	**1**	**$8.80**	**Link**
Induction charger (transmitter) [14]	Signal Transformer	**1**	**$5.54**	**Link**
Speaker [4]	Soberton Inc.	**1**	**$1.68**	**Link**
IR distance sensor (Pack of 5) [5]	Nanyang Senba Optical and Electronic	**1**	**$9.98**	**Link**
Clock Display [6]	Vishay Semiconductor Opto Division	**2**	**$6.30**	**Link**
Real-Time Clock [7]	Texas Instruments	**1**	**$1.61**	**Link**
Tactile Switch [8]	C&K	**5**	**$7.65**	**Link**
Wall Charger Adapter (Pack of 2) [9]	AILKIN	**1**	**$11.99**	**Link**
ESP32 WROOM dev board (Pack of 3) [10]	Espressif Systems	**1**	**$15.00**	Link
MPU6050 3 Axis Accelerometer Gyroscope [11]	HiLetgo	**1**	**$6.49**	Link

The price of the PCBs, as quoted from PCBWay, are $5/5 boards for the dock physical device, $19.99/5 boards for the toothbrush physical device, and $5/5 boards for the alarm physical device.

4.2 Labor

For each one of us, the ideal salary we expect for this role is close to the TA hourly rate here at the University of Illinois at Urbana-Champaign, which is 14.00 dollars per hour. Based off this information, here is the labor cost estimate for each of our members:

Eric Lin:

$$14\ \text{(dollar/hr)} \times 80\ \text{(hr)} \times 2.5 = 2800\ \text{dollars} \tag{2}$$

Laurenz Nava:

$$14\ \text{(dollar/hr)} \times 80\ \text{(hr)} \times 2.5 = 2800\ \text{dollars} \tag{3}$$

Carl Xu:

$$14\ \text{(dollar/hr)} \times 80\ \text{(hr)} \times 2.5 = 2800\ \text{dollars} \tag{4}$$

In total, it would cost us around $111.33 to build the final design as a complete package, and we have spent $8535.32 in terms of building this prototype.

5 Conclusion

5.1 Accomplishments

We successfully implemented all the subsystems we had on breadboard, and all functioned as expected. Our implementation on the breadboard also satisfies all three high-level requirements we have set for this project.

5.2 Uncertainties

There were many uncertainties when it came to the PCB side of things. The power and recharge subsystem was not able to be tested, so it is uncertain if they were properly designed. However, everything on breadboard works as intended perfectly, and does not have any uncertainties.

5.3 Ethical considerations

Our project is committed to the highest safety standards, placing safety as our foremost priority, aligning with IEEE's Code of Ethics Section I.1, to "hold paramount the safety, health, and welfare of the public." [1]

Understanding the potential hazards associated with electrical devices, particularly those in close contact with water, though we did not finish our PCB implementation, we have planned enclosed cases for all the components to be water splash proof to prevent potential harm to the user. This design choice minimizes any risk of electric shock, making the device safe for everyday use in a bathroom environment.

Our team members have also "treat[ed] all persons fairly and with respect, to avoid harassment or discrimination, and to avoid injuring others," and supported and assisted each other as needed. [1]

5.4 Future work

If we were to continue working on this project in the future, we expect to fix the PCB implementation first. We will also swap the speaker to be a louder one, or connect multiple speakers together, since 60db is sometimes not loud enough to wake people up.

We could also implement more ways other than brushing teeth as the condition to turn off the alarm, so that it can be more flexible and fit more users' preferences.

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Appendix A - Requirements and Verification

Table 1: Dock Subsystem - Requirements & Verification

Requirements	Verification
• When the user enters within 3 meters of the dock, the alarm should deactivate, and the clock & display subsystem should display the remaining time left to brush teeth, or brush countdown	• Measure the user is more than 3 meters away from the dock, and check if time display is set to current time. • Then, user approaches and measure distance less than 3 meters away • The time display should now be set to the time remaining to brush teeth
• When the user enters within 3 meters of the dock, but then leaves before completing their teeth brushing, the alarm should continue, and the brush countdown should remain	• Measure the user is less than 3 meters away from the dock and check if the remaining time to brush teeth is displayed. • While the remaining time is greater than zero, have the user move further than 3 meters from the dock. • This should cause the alarm to resume, and the time remaining is still displayed
• When the user finishes brushing their teeth, the clock display reverts to showing the current time, and the alarm remains off	• Measure the user is less than 3 meters away from the dock and check if the remaining time to brush teeth is displayed. • Have the user brush their teeth until the time remaining hits zero, for 2 (± 1) seconds • The display should now show the current time, and moving 3 meters further from the device does not retrigger the alarm
• When the user overrides the alarm, the clock display reverts to showing the current time, and the alarm remains off	• Measure the user is less than 3 meters away from the dock and check if the remaining time to brush teeth is displayed. • While the remaining time is greater than zero, have the user press the left and right button at the same time for

	10 seconds to activate the override protocol. • This should force the display to show the current time, and moving 3 meters further from the device does not retrigger the alarm
• When the alarm has been on for longer than 30 minutes, the clock display reverts to showing the current time, and the alarm turns off	• The alarm is triggered, but the user does not complete brushing their teeth. • After 30 minutes since the set alarm time, the alarm will automatically shut off

Table 2: Clock & Display Subsystem - Requirements & Verification

Requirements	**Verification**
• When real time clock, RTC, matches with the time for the alarm to ring, the alarm should start ringing	• The user sets a time for their alarm. • The RTC time reaches the set time. • This should cause the alarm to start ringing
• When the user enters within 3 meters of the dock, the clock & display subsystem should display the brush countdown	• Measure the user is more than 3 meters away from the dock, and check if the time display is set to current time. • Then, user approaches and measure distance less than 3 meters away • The time display should now be set to the time remaining to brush teeth
• When the user is properly brushing their teeth, the brush countdown should be decrementing	• The user takes the toothbrush and brushes their teeth properly, which can include up and down, back and forth, and circular movements with sufficient force and frequency. For specifics, see section 2.7.1 In-Use Sensor • The displayed time should decrement until it hits zero, where it will stop, and after 2 (± 1) seconds the current time will be displayed
• When the user is not properly brushing their teeth, the brush countdown should be remain constant	• The user takes the toothbrush and brushes their teeth improperly, which can include up and down, back and forth, and circular movements with insufficient force and frequency. For specifics, see section 2.7.1 In-Use Sensor

	• The displayed time should remain the same until the user begins brushing their teeth properly
• When a button is being pressed, the clock display or the alarm time should be modified according to its function.	• Press the button and observe the displayed time or the alarm time. Verify that the display time is accurate. • The left and right buttons cycle through the numbers on the display, acting as a selector. The selected number blinks at a regular interval and stops blinking after a period of inactivity. • The up and down buttons increment and decrement the value selected. These buttons are to adjust the time. • The toggle button cycles through the three modes of the display. First is the RTC, the current time, displayed as hour-minute-second-AM/PM. Second is the alarm time, with the same display as RTC. Last is the time brush countdown, displayed as blank-blank-minute-second

Table 3: Toothbrush Subsystem - Requirements & Verification

Requirements	**Verification**
• When the toothbrush is in proper use, it should relay a signal to the dock system to start decrementing the brush countdown	• The user takes the toothbrush and brushes their teeth properly, which can include up and down, back and forth, and circular movements with sufficient force and frequency. For specifics, see section 2.7.1 In-Use Sensor • The displayed time should decrement until it hits zero, where it will stop, and after 2 (± 1) seconds the current time will be displayed
• When the toothbrush is not in proper use, it should relay a signal to the dock system to stop decrementing the brush countdown	• The user takes the toothbrush and brushes their teeth improperly, which can include up and down, back and forth, and circular movements with insufficient force and frequency. For specifics, see section 2.7.1 In-Use Sensor

	• The displayed time should remain the same until the user begins brushing their teeth properly

Table 4: Alarm Subsystem - Requirements & Verification

Requirements	**Verification**
• When real time clock, RTC, matches with the time for the alarm to ring, the alarm should start ringing	• The user sets a time for their alarm. • The RTC time reaches the set time. • This should cause the alarm to start ringing
• When the user enters within 3 meters of the dock, the alarm should stop.	• The alarm is ringing from the time set by the user. • The user then moves to be less than 3 meters away from the dock. • This should cause the alarm to stop ringing
• When the user leaves before completing their teeth brushing, the alarm should resume	• The alarm is ringing from the time set by the user. • The user then moves to be less than 3 meters away from the dock, which stops the alarm, but does not complete brushing their teeth properly. • This should cause the alarm to start ringing again
• When the alarm has been on for longer than 30 minutes, the alarm should turn off	• The alarm is ringing from the time set by the user. • The user does not complete brushing their teeth properly for 30 minutes from the time their set alarm time. • This should cause the alarm to stop ringing

Table 5: Power and Recharge Subsystem - Requirements & Verification

Requirements	**Verification**
• When the dock, alarm, or toothbrush is charging, an LED should indicate that it is charging to the user	• The user plugs in the device to charge. • A green LED will light up to indicate the device is charging, and will turn off once it is fully charged

• Each cell is recharged so that the voltage of each cell maintains the same proportions (± 0.1 V)	• With the batteries at full capacity, measure and record the voltage of each cell