Electronic Toilet Paper Tracker for Public Facilities

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Abstract

Most customers would hesitate to return to businesses without enough toilet paper, so it is important to design a system that helps employees in bigger businesses to refill the toilet paper in time. When addressing the issue of toilet paper shortage, the previous group placed their focus on a home environment, and their design had the potential problems of personal data leakage, sanitary concerns, losing login keys, and relatively expensive cost for a private household setting. Our project will instead focus on a public or commercial setting, solving all the problems the previous group had by designing a hands-free automatic system with no login key, helping businesses improve their restroom environment with relatively low cost.

Contents

1 Second Project Motivation

In this chapter, we summarize the work we have done to refine our project based on the feedback from our design review.

1.1 Updated Problem Statement

In many public areas, keeping restrooms fully-stocked is usually very low on employees' priority list, behind other duties. This can render some bathroom stalls unusable for customers needing to use the facilities. Referencing two relatively recent telephone surveys by Harris Interactive, the website nearsay.com states that 94% of customers would never return to a business with a dirty restroom. Of that 94%, two out of three classify a restroom with a lack of toilet paper as dirty [1]. Additional studies show that having clean public restrooms is of significant importance for companies such as malls and big box stores. Of those polled in a survey by Kimberly-Clark Professional, 43% of respondents said that the most "unsanitary" experience in a public restroom was a lack of toilet paper. Additionally, when asked what the most "unpleasant" experience the most common answer was also a lack of toilet paper [2].

While it is difficult to quantify business lost due to conditions described above, the benefits of investing in our toilet paper tracking system will quickly compensate for the costs involving labor and maintenance, as our calculation shows in Section 2.6. Our design will save employees valuable time and potentially increase profits for the business.

1.2 Updated Solution

1. **Our solution & Existing Alternatives**

   Researching into product alternatives, we found a potential niche for such a mechanism as our project provides. There is an application called Restroom Alert, which allows customers to notify staff about issues in restrooms, and also reminds employees if a certain amount of time has passed between inspection [3]. However, this solution relies on the customer to discover the problems in the restroom and does not contain the sensors or automation in our proposal.

   Therefore, We propose an automatic toilet paper monitoring system with minimal cost, targeting public or commercial settings, which can remind employees when the toilet paper stock is low. This system, saving employees' time in restocking toilet paper, will help businesses to save money by allowing the employees to focus on other parts of their jobs and still maintain adequately-stocked restroom facilities. Due to the relatively low price, it will take a very short amount of time for businesses to break-even after investing in this system.

2. **Project Differences**

   - **Overview:** When addressing the issue of toilet paper shortage, the previous group placed their focus on a home environment. We will instead focus on a public or commercial setting, where bathrooms are in practice cleaned and restocked on an as-needed basis. There is no widespread implementation of this kind of solution in any public restrooms that we have experienced. We also differentiate our solution with the previous project by adding a second sensor for stalls with multiple rolls, so that when the combined amount of toilet paper reaches a minimum threshold, the system will alert janitorial staff.

- **Analysis:** On the surface, a $70 toilet paper dispenser would attract little attention in private household settings. As described in Table 1, for less than $30, we can build a stall module which is scalable in practice to any number of connected components. The Design Document for the previous project states a desire to market towards businesses as well, although business logic and models are not discussed. It is logical to assume that, in a business environment, individual users would have less control over how their data is used than in a residential setting. For this reason, we will focus on the application to businesses and our improvements to the previous model from a business perspective.

  As justification for their device, the previous group cites that China is implementing systems similar in design to their project in public places and tourist sites. However, the previous design would very likely not find as much success in the United States. This would be due to the reliance upon personal data, and laws protecting and governing the use of such data in the rest of the world. Surveys have shown a growing wariness among American adults regarding the abundant collection of personal data in everyday life. The previous project's design, especially in a public business setting, would rely on personal login and interaction in order to serve any purpose at all above that of a standard toilet paper holder. At the same time, according to a November 2019 article by Pew Research Center, 79% of American adults have "concerns over data use," while 81% feel that the "risks outweigh [the] benefits" regarding commercial personal data collection [4]. Figure 1 shows these and further statistics presented in the article.

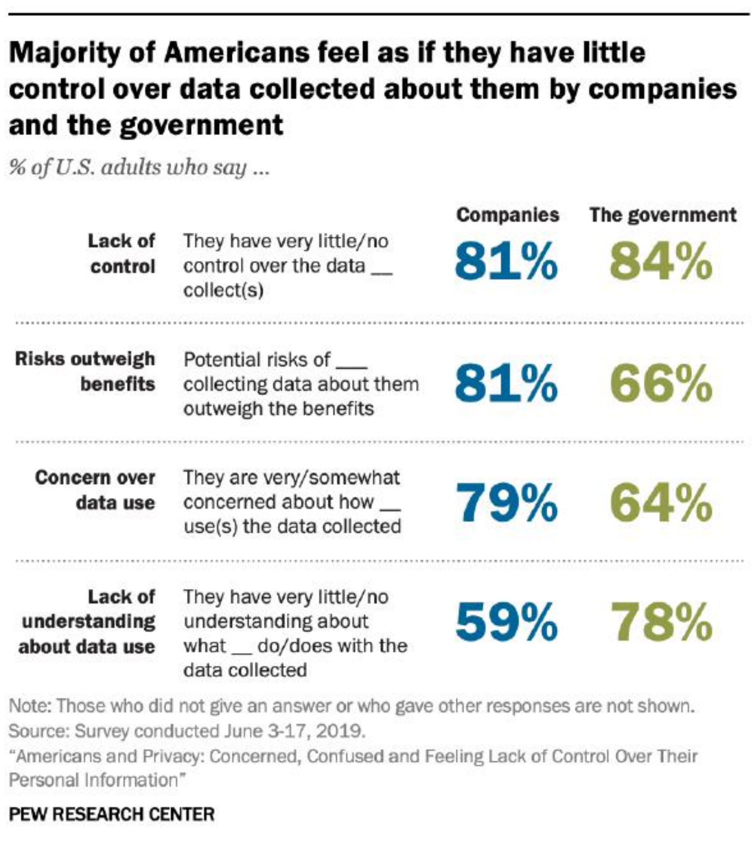

Figure 1: Privacy concerns among American adults. [4]

Our project alleviates these concerns about personal data collection by shifting to a passive model, monitoring paper supply intermittently, and notifying janitorial staff when stalls are low on paper. Along with shifting away from a focus on personal tracking, we also augment the previous design with WiFi capability and communication algorithms between the individual tracker modules, a central tracking server, and a cell phone application. This helps increase the usefulness of such a project from a maintenance and management point of view. Based on gathered evidence, these alterations to the design and business models will greatly improve product viability and expand its applications.

1.3 Updated High-Level Requirements

Our project needs to meet several criteria to address our problem adequately. These requirements ensure our design's purpose is fulfilled, the product functions fully, and the mechanism is usable for our intended target customers.

- The toilet paper tracker must be able to sense whether the total amount of toilet paper between the rolls is below 10% of full supply (low).
- When the total toilet paper is low, the user should be informed before he/she sits down, by illuminating red and green LEDs.
- When the total toilet paper is detected as low, the system must automatically inform the employee for replacement within one minute of detection.

1.4 Updated Visual Aid

Our project will be focused on first measuring and interpreting sensor readings, then acting on those readings through communication protocols. Figure 2 illustrates the information flow between the various components of our project. The stall module will inform the control server of low toilet paper via WiFi, and the server will notify employees or managers over WiFi as well. The final channel of communication will be from the employees' mobile devices to the server, which will pass a toggle on whether the employee is on-duty at the current moment, and thus whether the server should send notifications. Alternatively, employees could keep this toggle stored locally, and only let server notifications through if they have a shift. However, keeping this information on the server will help with enforcement of keeping this toggle updated accurately, and a potential feature of the server software could be to log whenever an employee switches their toggle, serving as documentation for management.

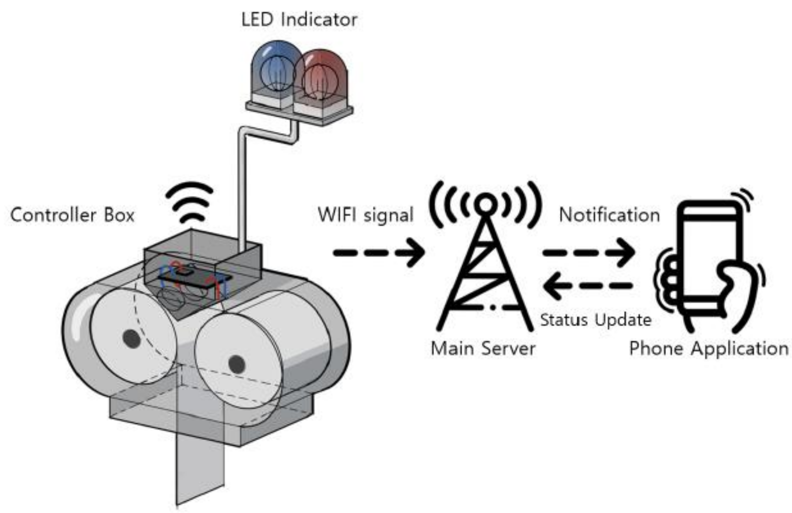

Figure 2: Information flow for toilet paper tracker.

1.5 Updated Block Diagram

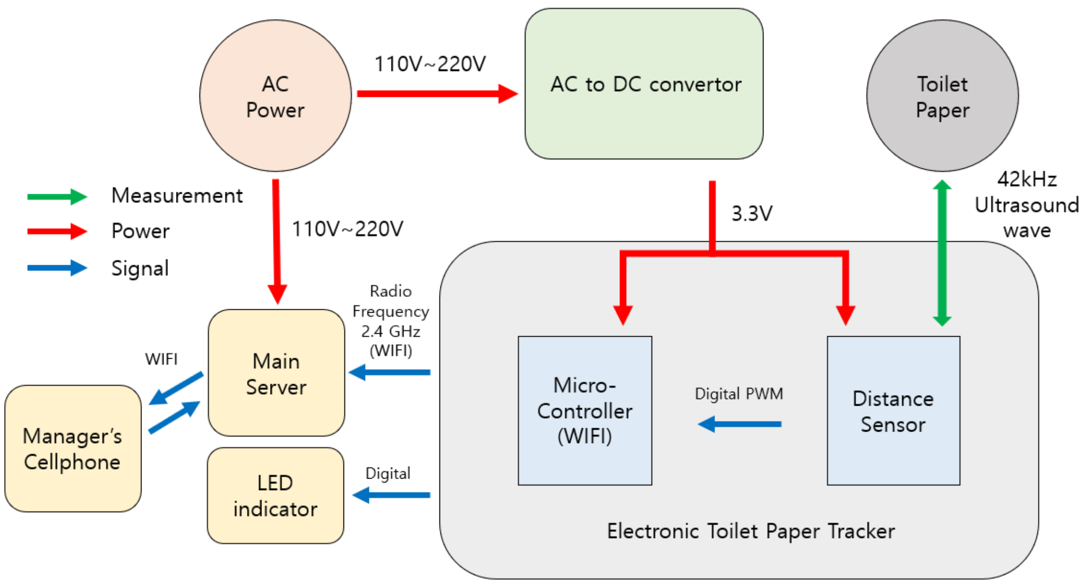

Figure 3: Block Diagram of the Electronic Toilet Paper Tracker

2 Second Project Implementation

This chapter includes the improvements we made to the physical design, schematics, PCB layouts of our project, and also mathematical calculations based on feedback from our design review.

2.1 Functional Overview

For our second project, our design will focus heavily on communication, whereas our first project was focused more on sensory input (see Section 4 for more details). Our project needs to measure reliably how much paper is on two rolls of toilet paper, and then utilize WiFi communication to notify employees that maintenance is needed. We will accomplish this by using reliable sensors and minimizing circuit complexity, while also planning for the ability to unit test various aspects of the project's operation.

2.1.1 Stall Module

1. Sensors

    - Distance sensor: Two distance sensors will be needed for each device (one for each roll of toilet paper, assuming two rolls in one container). They will be placed in a control box, which sits on top of the toilet paper dispenser. The sensors will face towards the sides of the toilet paper rolls, to measure the amount of toilet paper left. For the sensors to work properly, they cannot be less than 3 cm away from the outer radius of a full toilet paper roll, nor more than 20 cm away from the shell of the toilet paper tube, due to the measurement range in the specifications document [5].

2. Control Unit and Indicator

    - Micro-controller: Each stall module requires a micro-controller to read sensors periodically and establish a connection to the collector receiver. This sensor reading does not need to be particularly frequent, and we have decided to measure once in every two minutes. We will be using an ultrasonic library, which is compatible with the distance sensors we have selected. The library will perform a calculation based on pulse-width modulation (PWM) readings from the distance sensors, to calculate the total amount of toilet paper supply between the two rolls. A message will be sent to the store staff through a WiFi connection once the toilet paper is lower than 10%.
    - LED: A red LED light will activate if the toilet paper is lower than 10%, so customers would know when there is not enough toilet paper before they use the stall, or to carefully arrange the usage of the rest if they are already on the stall. If the toilet paper is empty, the red LED will flash. Otherwise, a green LED will declare that the stall is properly supplied. Section 2.5.1 provides further details on this functionality.

3. Power Supply: We will utilize a wall plug-in for a stable power supply and convenience. This power will run through an AC-to-DC converter, to provide the stall module with a direct current at a safe voltage.

4. Toilet Paper Container: This may house one or two rolls of toilet paper, and allow a control box to sit on top of it. Specific electronic parts may also need to fit inside the container, which will require additional measurements and configuration.

5. Control Box: A sealed box will be fixed on top of the toilet paper container, with sensors, micro-controllers, and other electronic parts included inside. A sealed control box provides more safety for the customers and allows the device to be installed easily, as shown in Section 2.2.

2.1.2 Server Module

Control Server: The control server gathers the data from each stall module through WiFi and sends the notification to employees when it is necessary. For future project development and testing, we plan to use a laptop to host a simple implementation of the server module. See section 2.5.2 for implementation details.

2.1.3 Cellular Phone Application

Each employee will install a simple, streamlined app onto their device, through which they can toggle whether they are on-duty, and also receive notifications from the server. The security risks of such an app are very low, because it will only have access to sending notifications and connecting to the internet, but none of the user's data. Details for potential future design can be found in Section 2.5.3, and additional mock-ups can be found in Appendix C.

2.2 Actual Mounting

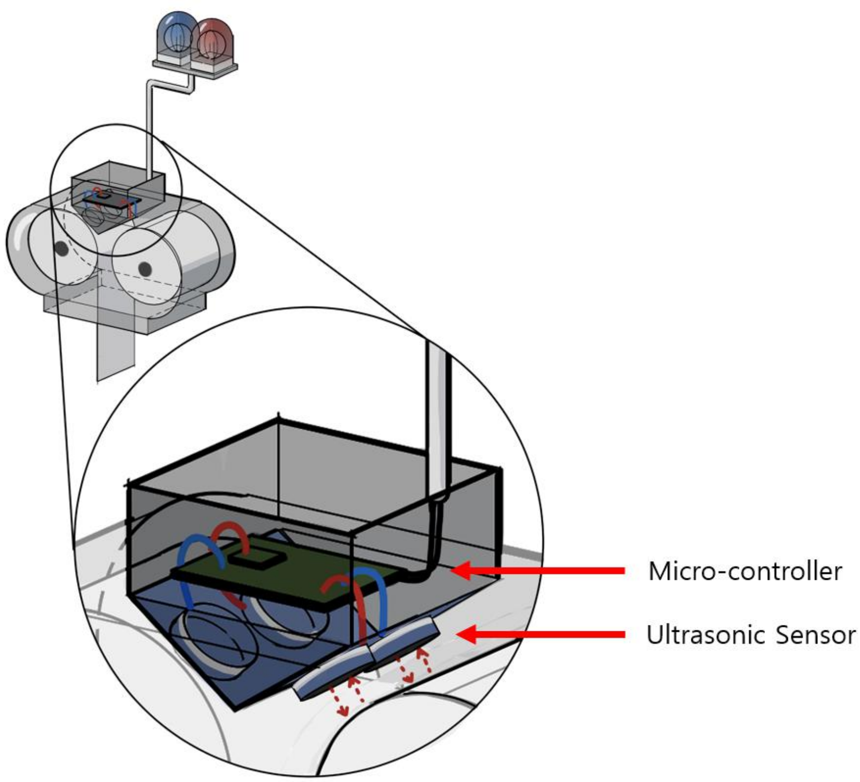

Figure 4: Detailed view of main controller box

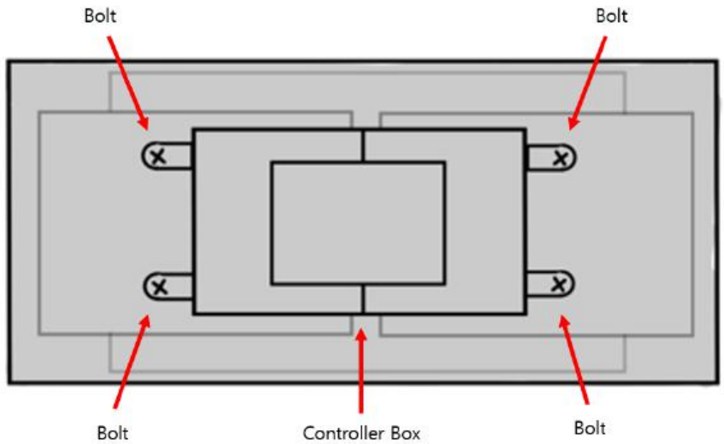

Figure 5: Top side view of the toilet paper case

2.3 Updated Schematic

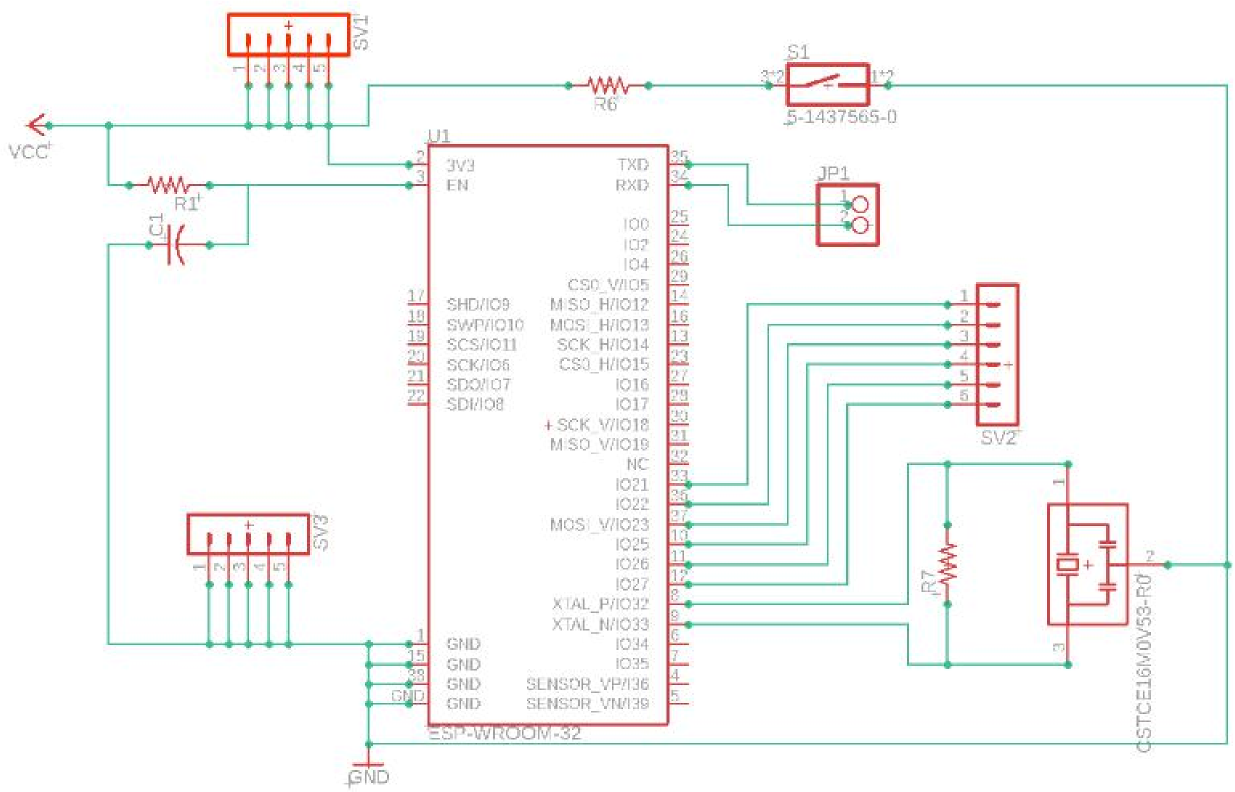

Figure 6: Body Part Schematic (ESP-WROOM-32)

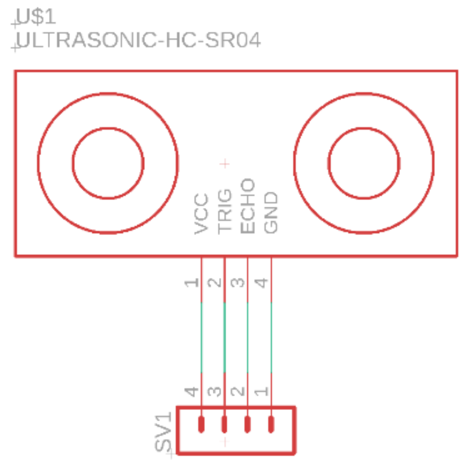

Figure 7: Sensor Part Schematic (Distance Sensor)

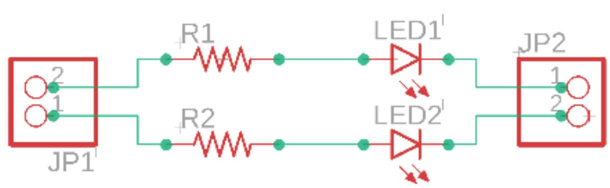

Figure 8: LED Part Schematic

2.4 Updated Circuit Board Layout

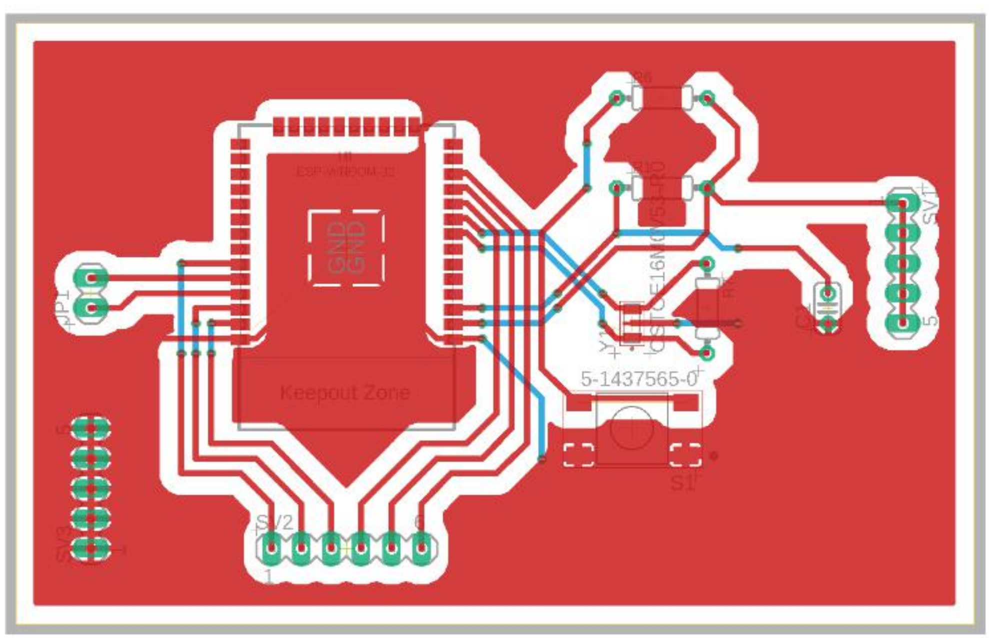

Figure 9: Body Part PCB Design (ESP-WROOM-32)

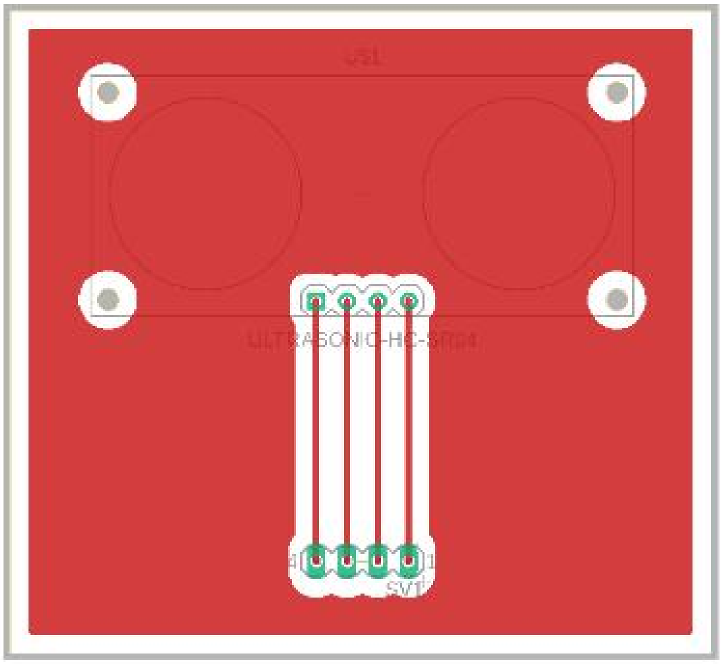

Figure 10: Sensor Part PCB Design (Distance Sensor)

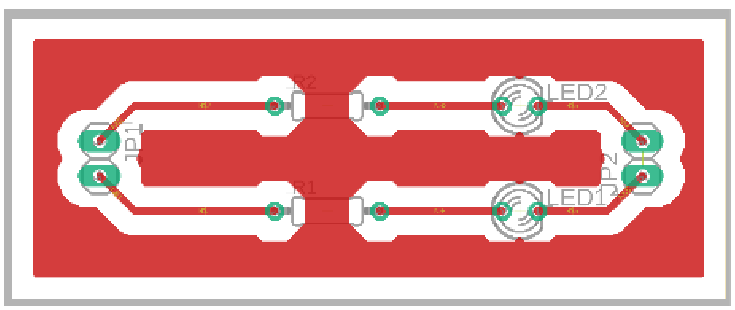

Figure 11: LED Part PCB Design

2.5 Algorithms Overview

Our second project will be computationally heavy, and each major segment of our design will require a separate algorithm to function. In all algorithm descriptions, the possibility is left open to send acknowledgment messages back to message sources. For example, an acknowledgment from the server to the microcontroller as part of a handshake, although not shown in Figure 12 will increase the robustness of the communication protocols.

2.5.1 Stall Module Algorithm

The stall module will periodically check the toilet paper level. If the paper is low, we will notify the server and update the LEDs' status. The microcontroller will need to perform basic calculations to interpret the readings of the distance sensor. Unfortunately, the documentation for our distance sensor is sparse on simulation data, and as such, physical experimentation will be required to determine specifics on any readings from the sensor. However, setting aside currently-unknown constants, the microcontroller will convert the pulse-width reading into a meaningful distance measurement, and use the combination of both sensor reading to calculate the total amount of toilet paper shared between the two rolls. Figure 12 shows the algorithmic responsibilities of the stall module.

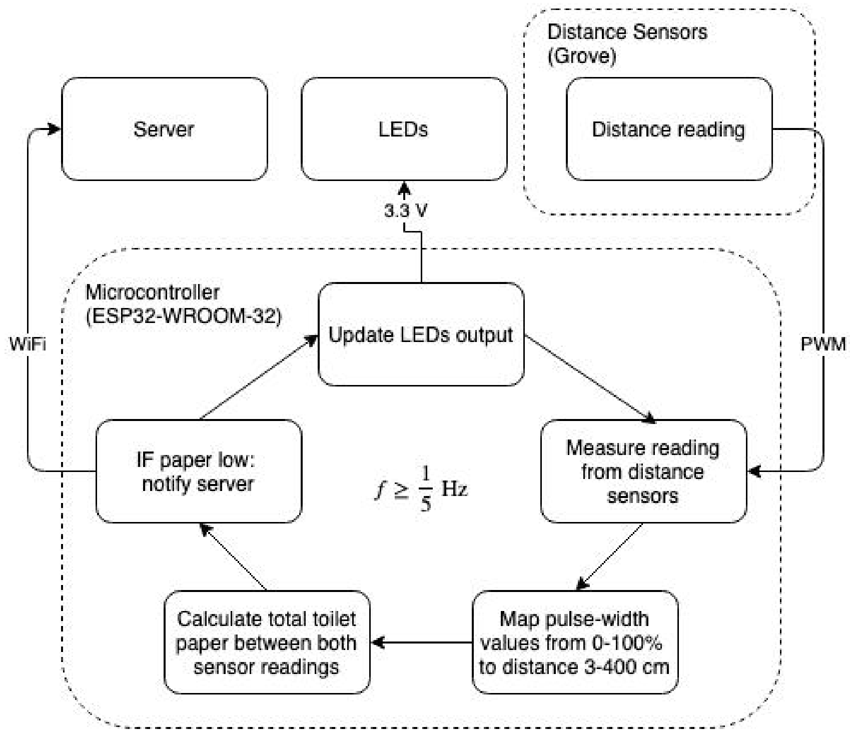

Figure 12: Basic algorithm for the stall module controller.

2.5.2 Server Algorithm

The server will need to accept connections, maintain employee login information, and send data to employees' cell phone applications. Figure 13 shows the functionalities of the central server, which bears the most procedural responsibility of the three modules. In Appendix B, Algorithms 2, 3, and 4 provide an example skeleton of implementation.

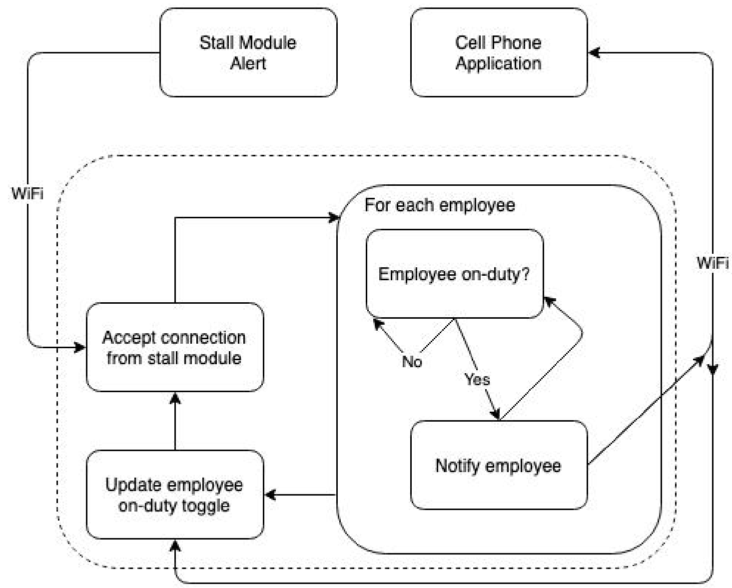

Figure 13: Basic algorithm for the server module.

2.5.3 Phone Application Algorithm

The cell phone application must reliably receive notifications from the server. Figure 14 shows the algorithm of the cell phone application. Additionally, Algorithms 5 and 6 in Appendix B show a skeleton implementation for the phone application's algorithm.

In a real-life implementation, we will use a cross-platform phone application development framework, such as React or Adobe PhoneGap to produce a usable interface. An example mock-up of this interface is shown in Figure 15, and Appendix C provides some additional views.

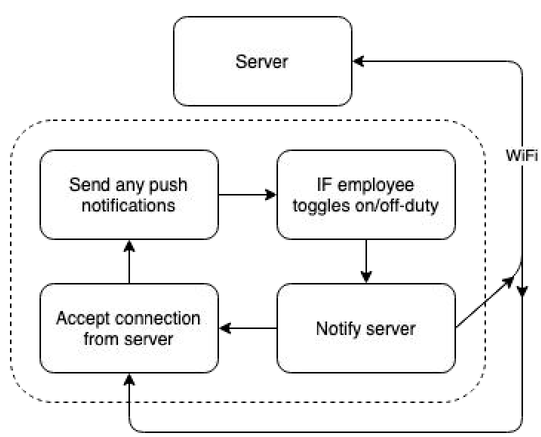

Figure 14: Basic algorithm for the phone application.

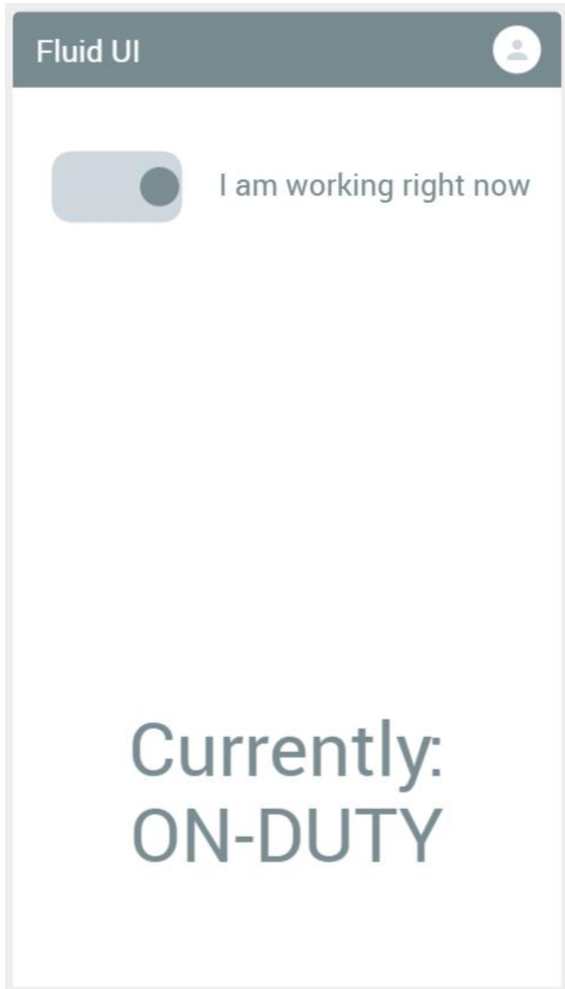

Figure 15: Work status toggle for the phone application.

2.6 Cost Analysis

For our cost analysis calculation, we used the Mall of America in Minneapolis, Minnesota as an example setting ideal for our toilet paper tracker. At the Mall of America, a housekeeping supervisor makes between \$16 and \$28 per hour [6]. We will take the average of these values at \$22 per hour. Counting men's and women's restrooms as separate, we discern 28 public facilities in the Mall from the directory [7]. A 2016 document entitled "Public Bathroom Management Report" by the city of SeoCheon, South Korea, explains that it takes about 10 min to move from one bathroom to another. Additionally, a graphic in the report implies that it takes about 30 min to clean the bathroom, and 10 min to check the stock [8]. Translating these estimations to the Mall of America setting, a worker must spend 50 minutes to take care of 1 bathroom in the mall. Applying this result to an average 8 hour workday, we find that a worker can clean

$$8\frac{\text{hrs.}}{\text{day}} \times 60\frac{\text{mins.}}{\text{hr.}} \times \frac{1}{50\frac{\text{min}}{\text{bath}}} = 9.5 \text{ bathrooms per day.}$$

In order to clean 28 restrooms, three workers are required, and as such, paying these workers will cost

$$3 \text{ employees} \times 8\frac{\text{hrs.}}{\text{day}} \times \$22/\text{hr.} = \$528/\text{day.}$$

Now, consider the time that these workers will save by using our product. The allotment of 50 minutes to check one public bathroom is reduced to 40. Now, we have

$$8\frac{\text{hrs.}}{\text{day}} \times 60\frac{\text{mins.}}{\text{hr.}} \times \frac{1}{40\frac{\text{min}}{\text{bath}}} = 12 \text{ bathrooms per day.}$$

In order to clean 28 restrooms, $2.\bar{3}$ workers are now required, and as such, paying these workers will be reduced to

$$2.\bar{3} \text{ employees} \times 8\frac{\text{hrs.}}{\text{day}} \times \$22/\text{hr.} = \$411/\text{day.}$$

These results subtract to render a daily cost savings of \$117/day by using our design. Now, let us calculate how long it will take to "break-even" after purchasing our product. Generously assuming 12 stalls in every bathroom (the more stalls, the more units to purchase), we arrive at 336 stalls in the Mall of America. As shown in Table 1, one stall module will cost approximately \$29, and thus installing toilet paper trackers in every mall stall will bring an upfront cost of

$$336 \text{ stalls} \times \$29/\text{stall} = \$9,744.$$

Dividing the total by our daily savings of \$117, we find that less than 84 workdays are required to pay off the costs of our system, making our product a phenomenal investment. [1]

[1] The metric claiming it takes 10 minutes to check the stock in each restroom may appear slightly surprising, but repeating the calculations with a more believable time of five minutes still results in the mall breaking even in about 250 workdays.

Table 1: Cost & Parts for One Toilet Paper Tracker Device

Part/Link	Mft	Desc	Price	Qty	Total
CSTCE16M0V53-R0 	Murata Electronics	CERAMIC RES 16.0000MHZ 15PF SMD	$0.76	1	$0.76
ESP32-WROOM-32 	Espressif Systems	Bluetooth, WiFi Transceiver Module 2.4GHz 2.5GHz Surface Mount	$3.80	1	$3.80
101020010 	Seeed Studio	3.3 V/5 V, Ultrasonic Distance Sensor	$3.90	2	$7.80
B07V811RPY 	HiLetgo	85-264V AC To 3.3V DC Isolated switching Module	$4.59	1	$4.59
L6LAC004-DT-R 	Amazon Basics	18 AWG (American wire gauge) universal power cord	$8.57	1	$8.57
CP2102 	TZT	USB to TTL serial UART STC download cable PL2303 Super Brush line upgrade	$1.09	1	$1.09
Resistors, Capacitors, LEDs, Connectors, Press Button	.	.	.	.	~$2.00
Total Price	.	.	.	.	~$29.00

3 Second Project Conclusions

This chapter contains our reflections on the redesigns we made to our project, and potential improvements we can make in the future to perfect our design.

3.1 Implementation Summary

3.1.1 Accomplishments and Significance

- **Physical Design:** We redesigned the physical mounting of our project, so instead of having two sensors at the sides of the dispenser, we now combine all the electronic components into one controller box and have it sitting on top of the toilet paper dispenser. This design allows us to save space by combining all the electronic parts. It is also much safer, since all the parts are protected by the sealed controller box. The redesign makes our device easier to install, and theoretically able to fit onto toilet paper dispenser of many types and shapes.

- **Schematics:** There are three main parts in our project, the body part (stall module), the sensor part, and the LED part. The schematics show the connection between each of the electronic components, as indicated in Chapter 2.

- **PCB Designs:** Three PCB boards are designed according to the schematics. Those circuit board layouts show how the electronic components are connected, as shown in Chapter 2.

- **Algorithms:** The three algorithm charts in Chapter 2 indicate the general idea of the implementation of our project. The Algorithms include the stall module part, server part, and phone application part. Our project is computation-heavy and the implementation of algorithms provides a clearer idea of how our project functions. Skeleton pseudo-code outlines are provided in Appendix B.

- **Cost Analysis:** We did a mathematical analysis of the benefits our project can bring to businesses like shopping malls, and the time needed to break-even if the business purchases our system. By using our device, the employees in the shopping mall can spend less time checking the bathroom, and spend more time on other tasks to provide better customer services. On the other hand, the business can hire less people doing bathroom checking routine and save money accordingly. Due to the relatively low cost of our device, it only take up to three months for the business to break-even the price if purchases our system. Therefore, our project can provide big improvements to the bathroom environment for bigger businesses with little cost.

3.1.2 Teamwork

- **Marshall Shriner:** Implementation (Algorithm, Cost Analysis), Previous Project (CAD Models, PCB Designs), Appendix (Phone Application Mock-Up).

- **Seongje Jung:** Implementation (Physical Mounting, Block Diagrams, Schematics, PCB Designs, Cost Analysis), Previous Project (PCB Designs).

- **Yaning Lan:** Second Project Motivation, Implementation (Cost Analysis), Second Project Conclusion, Previous Project (PCB Designs).

3.2 Unknowns, Uncertainties, Testing Needed

1. **Distance Sensor Accuracy:** We will use a distance sensor to determine the amount of toilet paper left – by measuring the distance between the sensor and the edge of toilet paper. The distance sensor we are using is an ultrasonic transducer that generates a 40KHz ultrasonic wave, which encounters the object, and reflects back to the receiver. Figure 16 shows the distance calculations, using the speed of sound in air as 340 m/s.

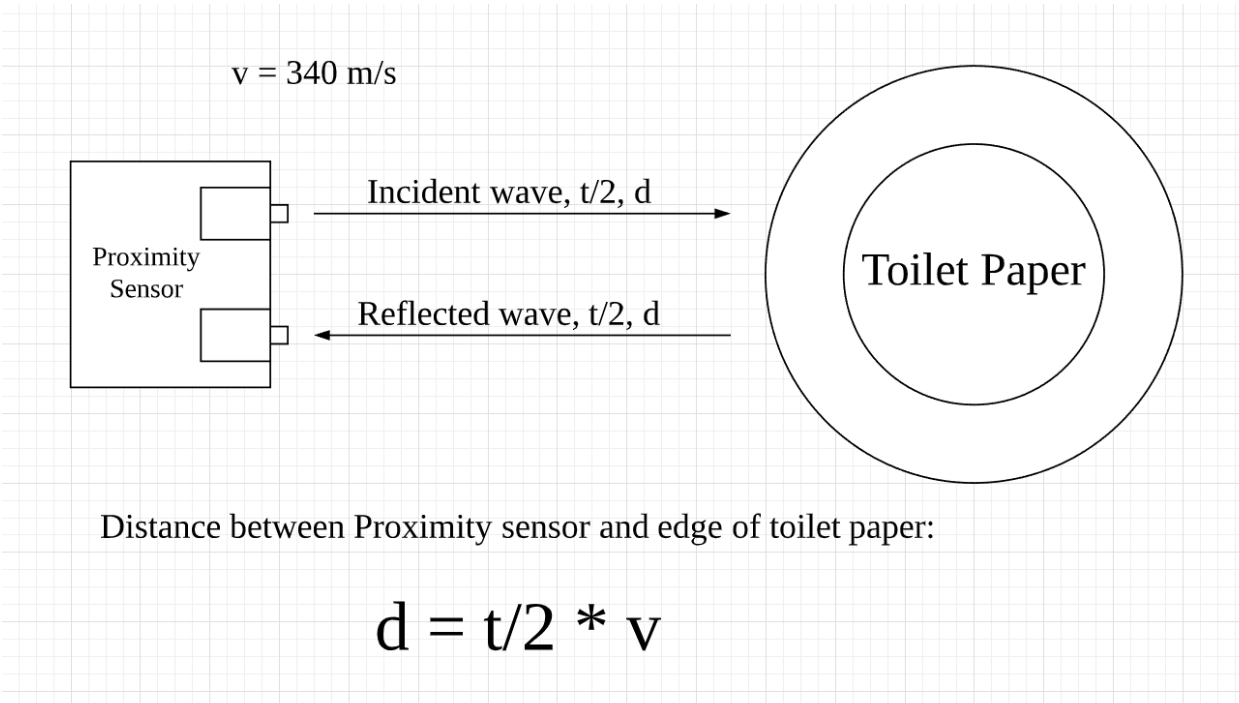

Figure 16: Distance Measured by Proximity Sensor

The distance sensors will need to discern its distance to the roll with high accuracy. However, the accuracy of the distance sensor would need further testing. Since we do not have an ultrasonic sensor in our hands, we propose the following testings we like to do to the ultrasonic sensor in the future:

   (a) Whether different types of toilet paper (texture, softness, number of layers) affect the accuracy of the distance sensor;

   (b) How the installation of the distance sensor (perturbations of the angular and distance from the sensor to the toilet paper) would affect the measurements.

2. **PCB Design Based on Control Box:** A control box will contain all the sensors and PCBs and sit on top of the toilet paper dispenser. Due to the relatively small size of the control box, we need to make further measurements and designs, so our PCB can fit properly inside. We may also need to design our PCBs with a specific shape for them to fit in such a narrow space. Since we do not have access to any public restroom toilet paper dispensers right now, we have not yet made actual designs for the control box. Therefore, we need to save the measurements and testing for the future.

3. **Installation:** Without access to a toilet paper dispenser or the electronic components we need, we cannot perform any assembly or installation tests. We will need to install the sensors and PCBs in such a way that:

   (a) They can fit properly in a variety types of toilet paper dispensers, while keeping sufficient distance between the sensors and the toilet paper.

   (b) They are inaccessible to customers (for safety reasons).

   (c) They are easy to dissemble for the employees if anything goes wrong.

   Specific parts may need to be 3D-printed, and we would require further discussion with the ECE machine shop for the installation and design of those parts.

3.3 Ethics and Safety

3.3.1 Ethical Considerations

- People need privacy while using the restroom, so they probably do not want other people to know that they are short on toilet paper. The reminding module would use an LED light to tell the user that the toilet paper is low, without making any sound to allow others to hear it. Very loosely, this corresponds to the guidelines of IEEE Policy 7.8.9 [9].
- We would not want customers' privacy to be invaded, so shop staff should not receive the message and try to refill the toilet paper while the customer is still sitting on the stall. We can ensure this by reminding the employee to go change the toilet paper several minutes later in the notification text, so employees would arrive after the customer has already left. (IEEE Policy 7.8.9)[9].

3.3.2 Safety Considerations

- The devices will be plugged in, so the plugin and the device should be tightly sealed to protect the users from getting shocked. Following IEEE Policy 7.8.1 [9], we will make sure the wires and plugin are inaccessible from the customers, by adding a layer of protection to the wires and making the plugin out of reach.
- The opening of the device should be designed so kids cannot put their hands inside and get stuck. We will make sure the only opening of the toilet paper container is small enough so hands cannot reach in, following IEEE Policy 7.8.1 [9].
- The device should be firm enough to handle some physical damage, so it does not break and harm the users. We will use hard plastic for the container, which is both hard to break and does not shatter when broken. (IEEE Policy 7.8.9)[9].
- The electronic parts need to be somewhat waterproof, to work safely in the humid environment in the bathroom. We will make sure the plastic container has no holes besides at the bottom, so water cannot leak in. The electronic components will be protected by a plastic or rubber container, so it endures the humid environment. (IEEE Policy 7.8.1)[9].

3.4 Project Improvements

Due to the limited amount of time we had to finish this project, we can only have simple implementations and models for our project. If we had a whole semester to finish this project, we could have made several improvements to our design. These changes would not only provide more functionality but also make the product easier to use. The following are three improvements we would like to add to our project:

1. **More Detailed Phone Application**
   If we have more time to develop our system, we would like to make a phone application with more functionalities. Right now the phone application can only send a notification, check internet status, and allow employees to indicate whether they are on duty. We would like to make the system capable of detecting employees' GPS locations, so the system can send a message to the nearest employee possible when the toilet paper is low. If the employee is currently busy, he or she can check the related button on the phone app, and the notification will be sent to another employee.

2. **Total Toilet Paper Amount Tracking**
   We would like to develop the function for our system to track the total amount of toilet paper used by the business in a certain time interval (a year, etc). With this function, the business will be able to know exactly how much toilet paper they should prepare for the customer at any time of the year, so there is no shortage nor waste of the toilet paper. Also, knowing the amount of toilet paper used each year can call for awareness from the businesses and customers to save the toilet paper and protect the environment.

3. **Fully Automatic Toilet Paper Restocking Mechanism**
   Another function we may consider adding to our project is an automatic toilet paper restocking mechanism. The employees need only to refill the toilet paper containers once a day, and the rest of the day the device can replace used toilet paper rolls with new rolls by itself. This mechanism can make our device fully automatic, without the need for employees to check the bathroom regularly, but it may be costly and the mechanism can be complicated. Therefore, we will consider this for one possible improvement we can make to our project, but not the highest priority. Such an additional feature could be found on a "premium" version of our product.

There are also a few changes we would like to make to the project, in the event we have more time to develop our design.

1. **Better Document for Ultrasonic Sensor**
   The document we found online for the ultrasonic sensor is very general. The document only indicates how to use the sensor, but provides limited testing data. We would like to find a more detailed document or do more actual testing to the ultrasonic sensor if no such documents are available. We could also look for an ultrasonic sensor with better documentation or one with discounts for buying in bulk.

2. **Better Protection for the Components**
   Right now the controller box is designed to sit on top of the toilet paper dispenser. However, customers can easily access the controller box and potentially damage the components. In a premium redesign of

our product, we would like to produce a CAD for the entire toilet paper dispenser, so both the toilet paper and electronic components are safely included inside. This will help shield internal components from touch and damage from customers.

3. **Modulating Our Design**
The design we have now is only for tracking two rolls of toilet paper at the same time. We should make our design more modulated, so we can use one such device to track a single roll of toilet paper, and also able to easily assemble multiple devices together to track multiple rolls of toilet paper in the same dispenser, in the event there were more than two rolls per dispenser.

4 Progress Made on First Project

Our project for the first half of this semester took the form of a single-handed video game controller, as shown in Figure 17. We had been in correspondence with the ECE machine shop regarding fabricated parts and had placed PCB orders before being shut down. Though we could not finish our first project, we made follow-up PCB designs and CAD drafts, which can be used for future implementation, should we decide to continue the project. Appendix D shows our progress on mechanical and electrical modeling for the first project.

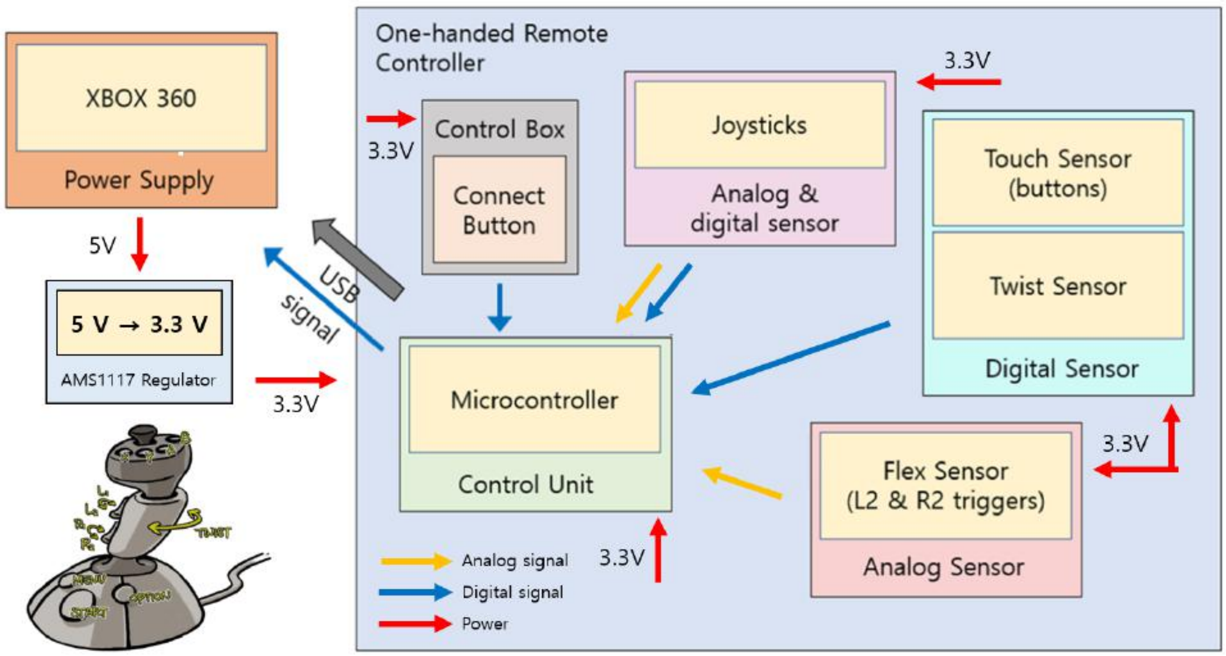

Figure 17: Illustration and block diagram for the single-handed video game controller.

The PCB Designs include 3 separate layouts, the top, middle, and bottom PCB boards.

- **Top PCB:** Press buttons (X, Y, A, B), thumb joystick;
- **Middle PCB:** Twisting mechanism, bumper buttons;
- **Bottom PCB:** Main joystick, main power button, menu buttons, USB (Power supply).

Appendix D includes the models for the twisting cylinder, bottom cylinder cap, the assembly of both parts, and the top cylinder cap. The purpose of the twisting mechanism was to combine two directional controls on a standard Xbox controller via a toggle. Depending on whether the stick was twisted, the reading of the base joystick would correspond to different controls. This mechanism would have been the most challenging part, and so to construct the controller, we will need to 3D print specific parts to make the twisting work as intended.

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Appendix A Sensors

This section provides a few links to sensors we are using in our project.

- Microcontroller: ESP32-WROOM-32 – https://www.digikey.com/short/zj0d9d
- Distance Sensor: Distance Sensor Development Tool Grove - Ultrasonic Distance Sensor 101020010 – https://www.mouser.com/ProductDetail/Seeed-Studio/101020010?qs=1%252B9yuXKSi8D6aN06jq6dCQ%3D%3D&gclid=EAIaIQobChMI0o_P_6XK6AIVAo9bCh2D5wg7EAQYAiABEgKjivD_BwE
  - NOTE: this will give PWM

Appendix B Algorithms

B.1 Stall Module

Algorithm 1 Stall Module Operations

```
const SCALE_ERROR, OFFSET_ERROR {Determined by trial-and-error}
int low_thresh, empty_thresh {Determined case-by-case per installation}
LEDs ← solid green
w ← new WiFiConnection()
u1 ← new Ultrasonic()
u2 ← new Ultrasonic()
while true do
  if 2 minutes have passed then
    d1 ← u1.MeasureInCentimeters()
    d1 ← (d1 + OFFSET_ERROR) × SCALE_ERROR
    d2 ← u2.MeasureInCentimeters()
    d2 ← (d2 + OFFSET_ERROR) × SCALE_ERROR
    if isBelowThresh(d1, d2, low_thresh) then
      w.notifyServer(”low”) {there is not enough paper}
      if isEmpty(d1, d2, empty_thresh) then
        LEDs ← flashing red
      else
        LEDs ← solid red
      end if
    else
      w.notifyServer(”good”) {there is enough paper}
      LEDs ← solid green
    end if
    reset timer
  end if
end while
```

Note: Notice the library call, `MeasureInCentimeters()`. While this library does handle the step in our diagram where we deal with PWM, it is unlikely to give us accurate, meaningful readings out of the box. For this reason, we will still need to adjust the values returned, and we plan to accomplish this with a linear transformation, as seen immediately after the library call.

B.2 Server Module

Algorithm 2 Server Module – Stall Incoming (Sample Thread)

```
u ← ∅ {set of stalls, about which employees have NOT been notified, shared with Algorithm 4}
q ← ∅ {set of stalls, about which employees have been notified, shared with Algorithm 4}
while true do
  c ← acceptConnection() {poll incoming connections}
  s ← c.getStallName()
  m ← c.getStatus()
  if m == "good" then
    remove s from q and u
  else
    add s to u
  end if
end while
```

Algorithm 3 Server Module – Phone Incoming (Sample Thread)

```
e ← dictionary {key = employee name and IP, value = work status, shared with Algorithm 4}
while true do
  c ← acceptConnection() {poll incoming connections}
  n ← c.getEmployeeInfo()
  d ← c.getStatus() {on-duty or off-duty}
  if d == "on-duty" then
    e[n] ← true
  else
    e[n] ← false
  end if
end while
```

Algorithm 4 Server Module – Phone Outgoing (Sample Thread)

```
Ensure: Employees are notified of new shortages within 1 min of detection, and reminded every 5 mins.
  w ← new WiFiConnection()
  e ← dictionary {key = employee name, value = work status, shared with Algorithm 3}
  u ← ∅ {set of stalls, about which employees have NOT been notified, shared with Algorithm 2}
  q ← ∅ {set of stalls, about which employees have been notified, shared with Algorithm 2}
  reset timer1 {timer for new stall shortages}
  reset timer2 {timer for reminders}
  while true do
    if 30 seconds have passed (timer1) then
      reset timer1
      if u ≠ ∅ then
        add all values of u to q
        clear u
        for k in e.keys() do
          if e[k] == true then
            w.notifyEmployee(k, q) {send employee list of low stalls}
          end if
        end for
      else if 5 minutes have passed (timer2) then
        reset timer2
        for k in e.keys() do
          if e[k] == true then
            w.notifyEmployee(k, q) {send employee list of low stalls}
          end if
        end for
      end if
    end if
  end while
```

B.3 Phone Module

Algorithm 5 Phone Module – Server Incoming (Sample Thread)

```
while true do
  c ← acceptConnection() {poll incoming connections}
  deliverNotification(c.getStalls()) {display stall information from server}
end while
```

Algorithm 6 Phone Module – Server Outgoing (Sample Thread)

```
w ← new WiFiConnection()
while true do
  if toggle switched on then
    w.updateServer(true)
  else if toggle switched off then
    w.updateServer(false)
  end if
end while
```

Appendix C Phone Application Mock-Ups

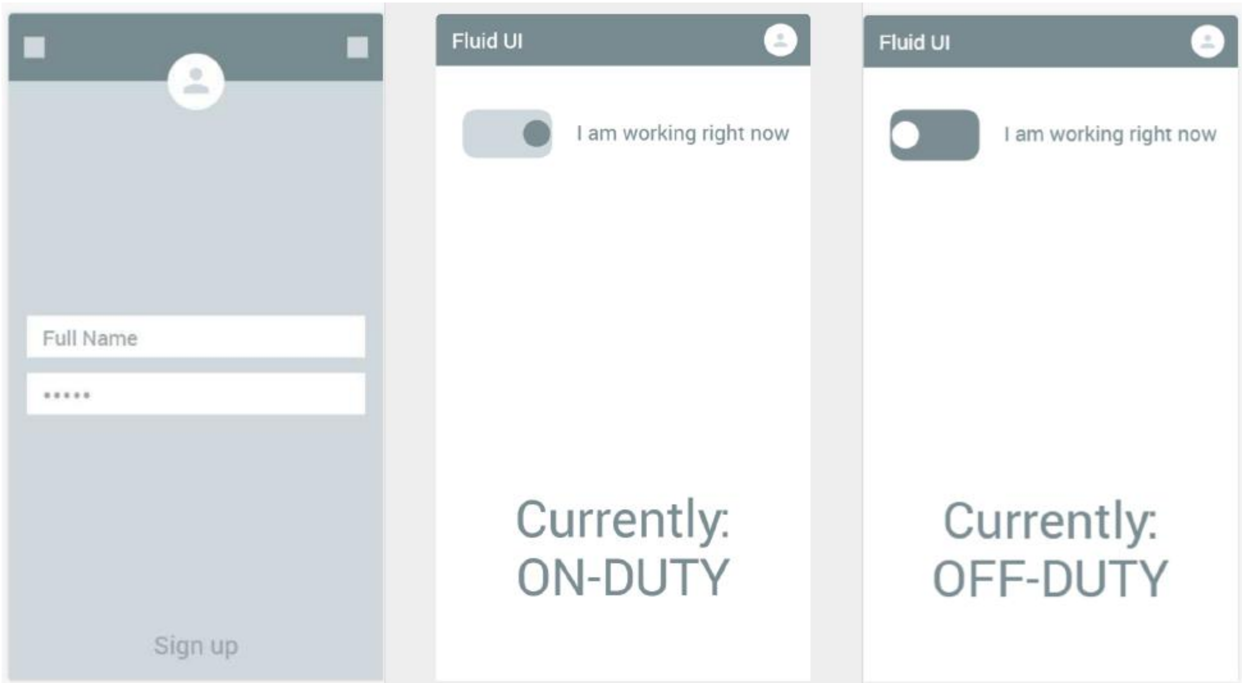

Figure 18: Phone application login and status toggle.

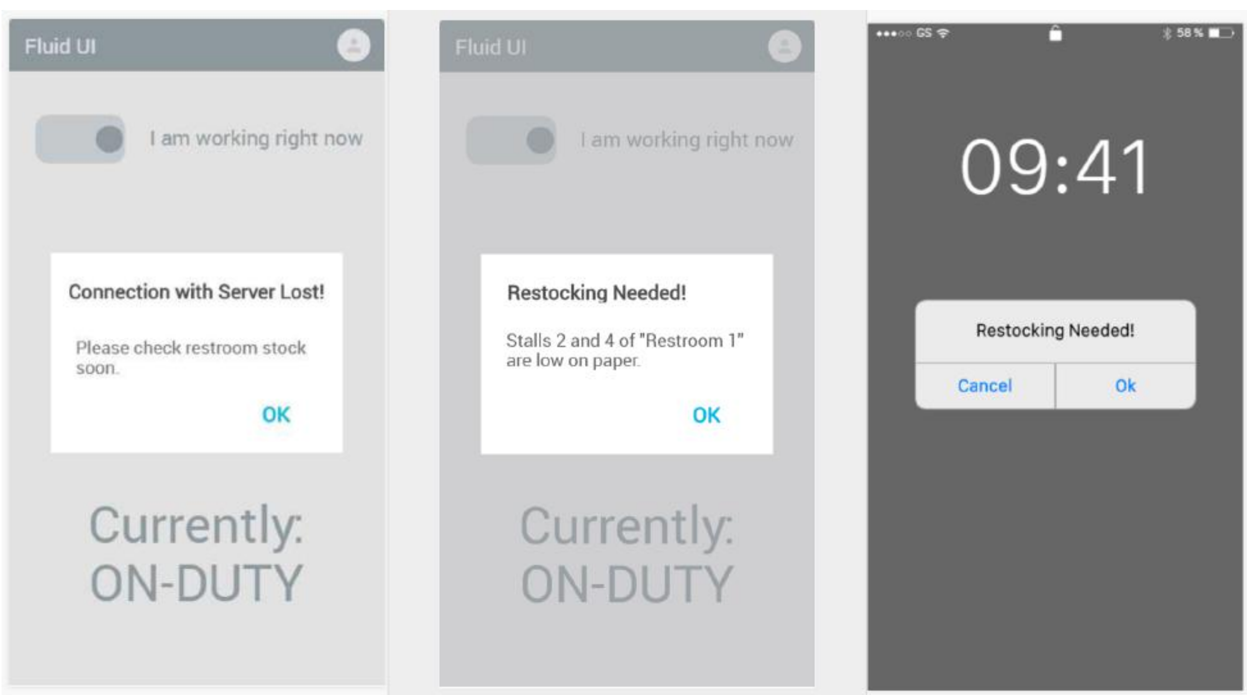

Figure 19: Additional phone application mock-up examples.

Appendix D Materials for the First Project

D.1 PCB Designs

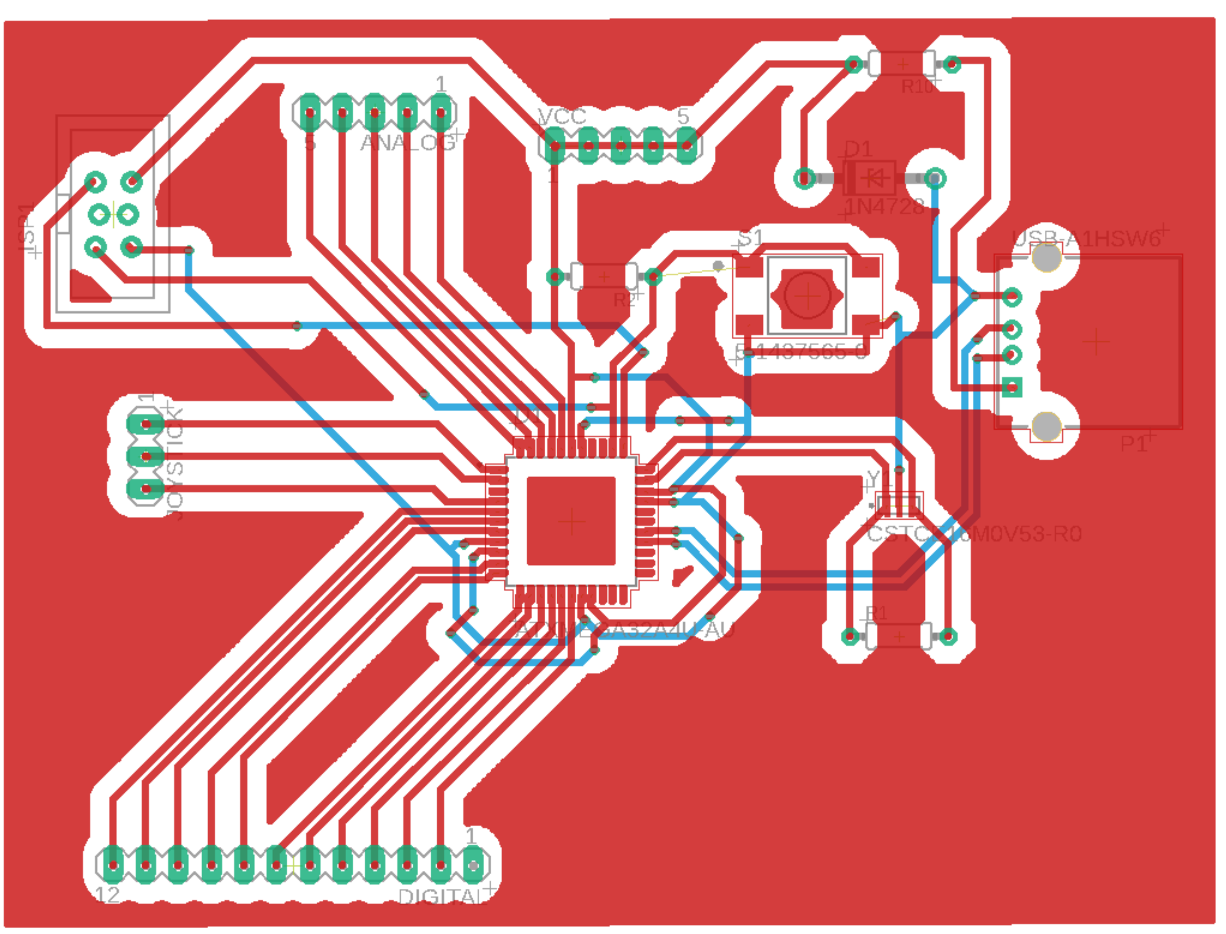

Figure 20: Bottom part PCB design for one-handed controller

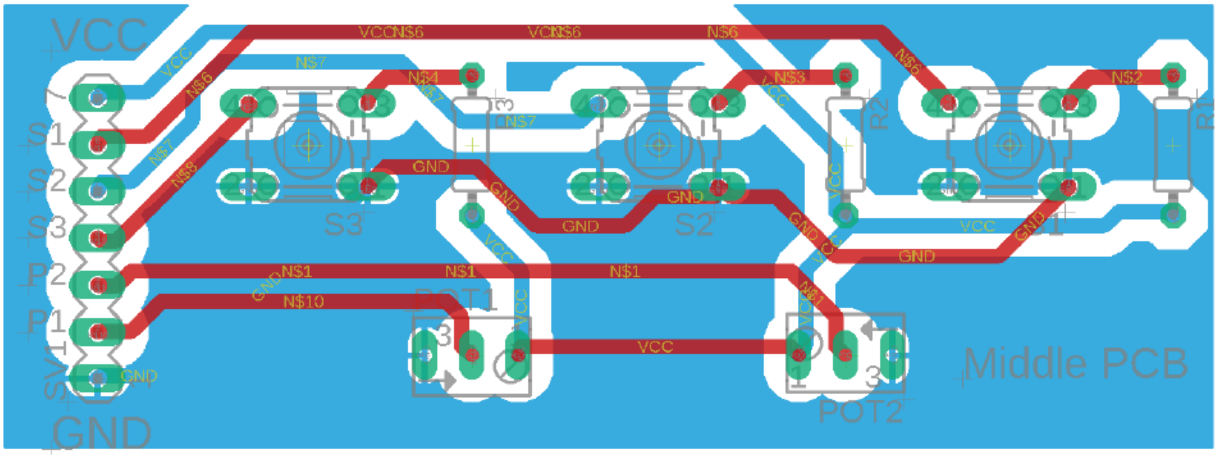

Figure 21: Middle part PCB design for one-handed controller

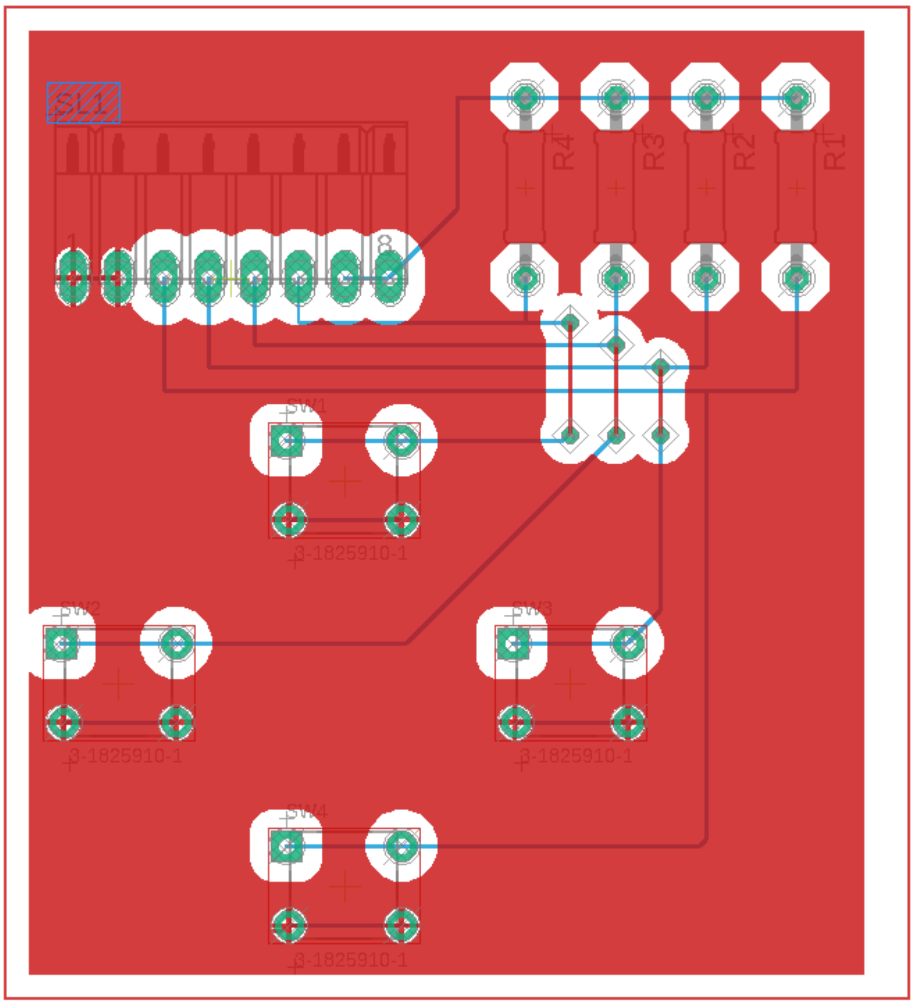

Figure 22: Top part PCB design for one-handed controller

D.2 CAD Models

Figure 23: Model of the central support rod, for attaching the joystick to the base. Note the D-shaft design and end peg, for securing into the twist mechanism and base controller stick.

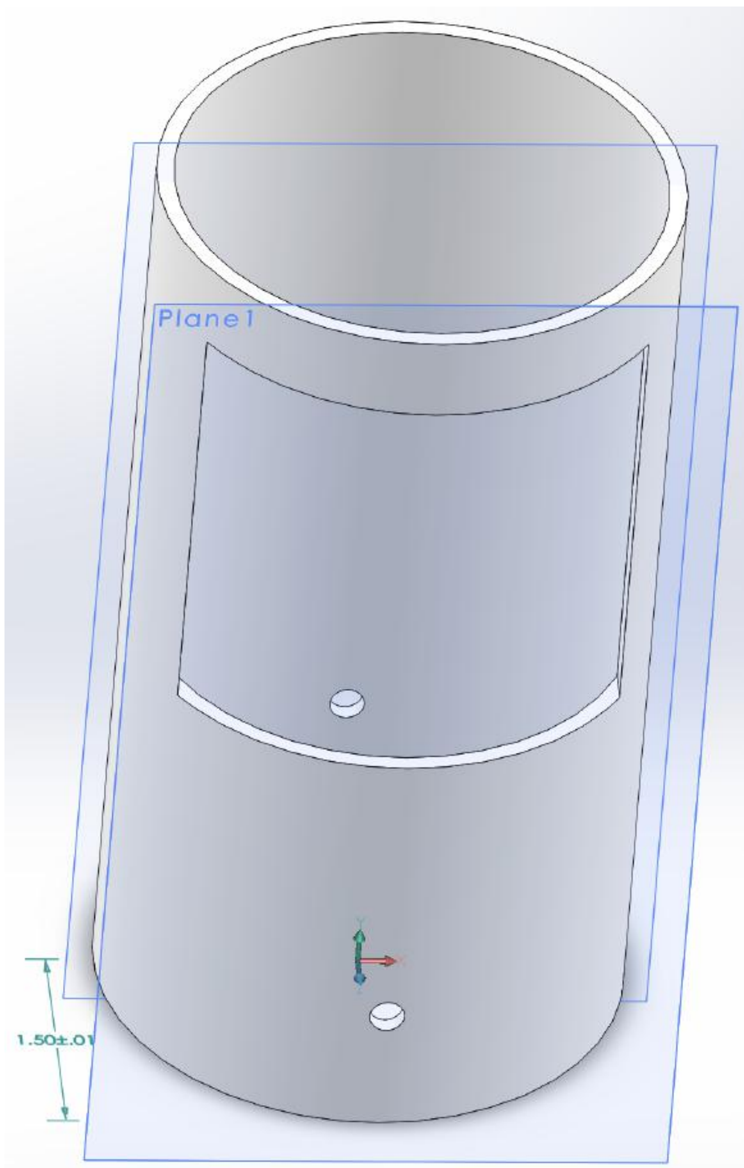

Figure 24: Model for the twisting cylinder, with a cutout for the trigger and bumper controls.

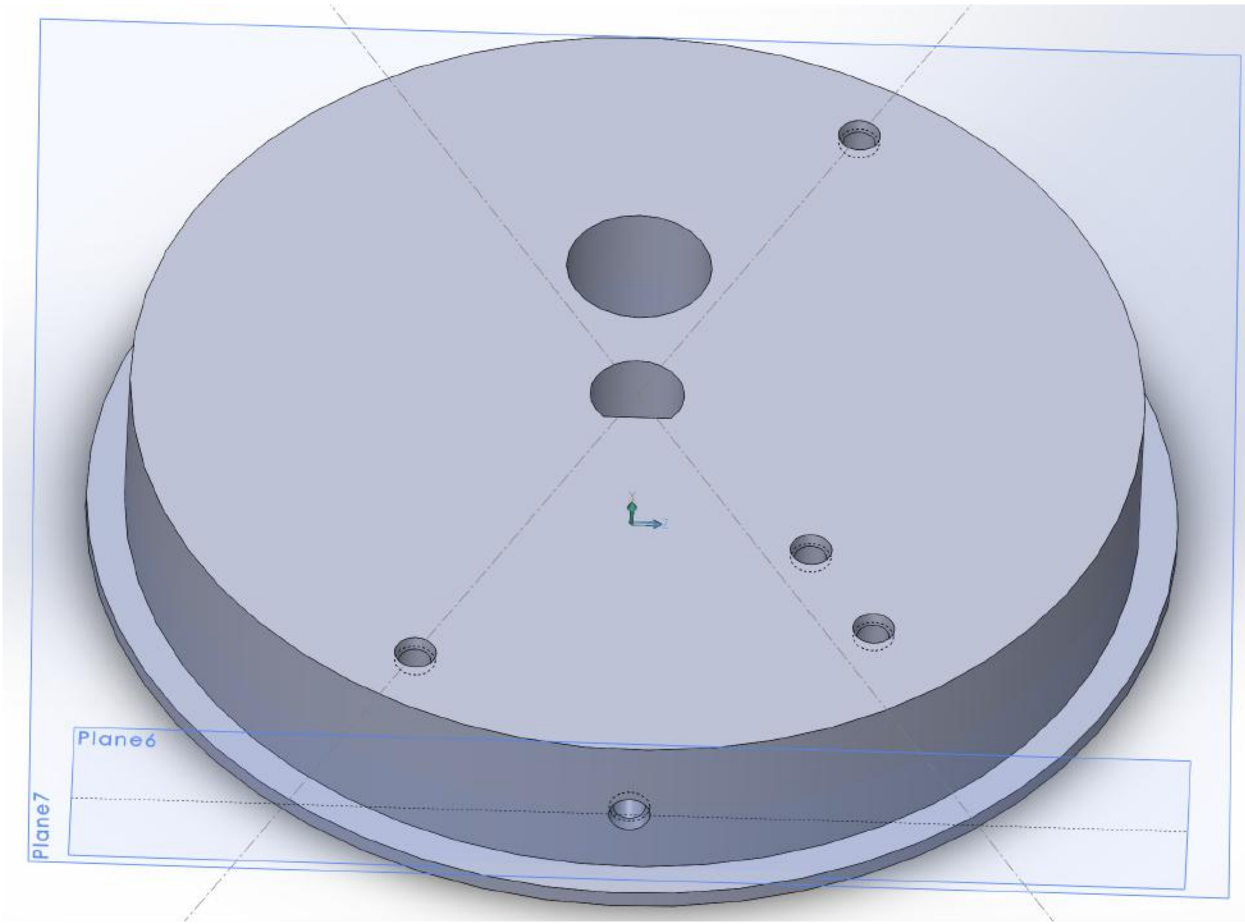

Figure 25: Model for the bottom cylinder cap, which does not rotate and houses the wist sensor buttons.

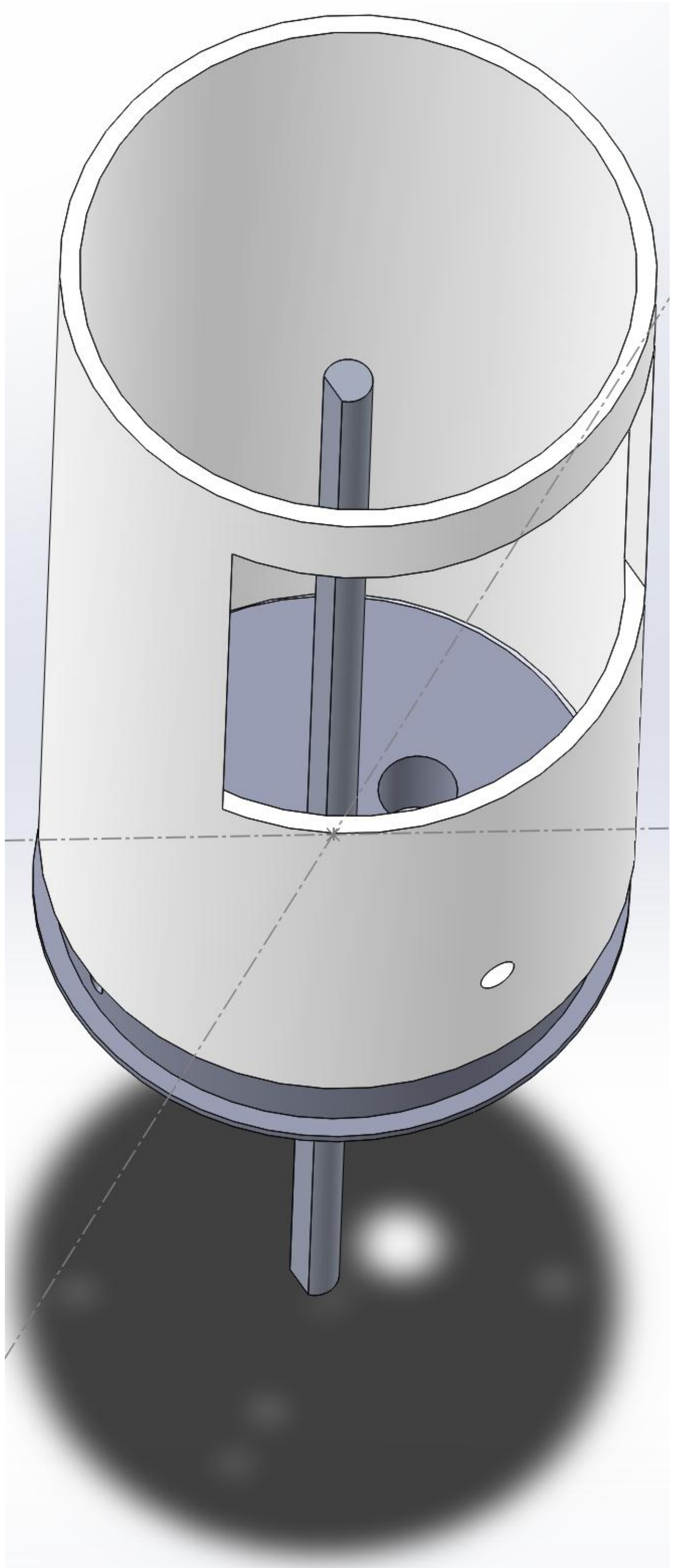

Figure 26: Composite model showing the assembly of the shaft and twisting mechanism.

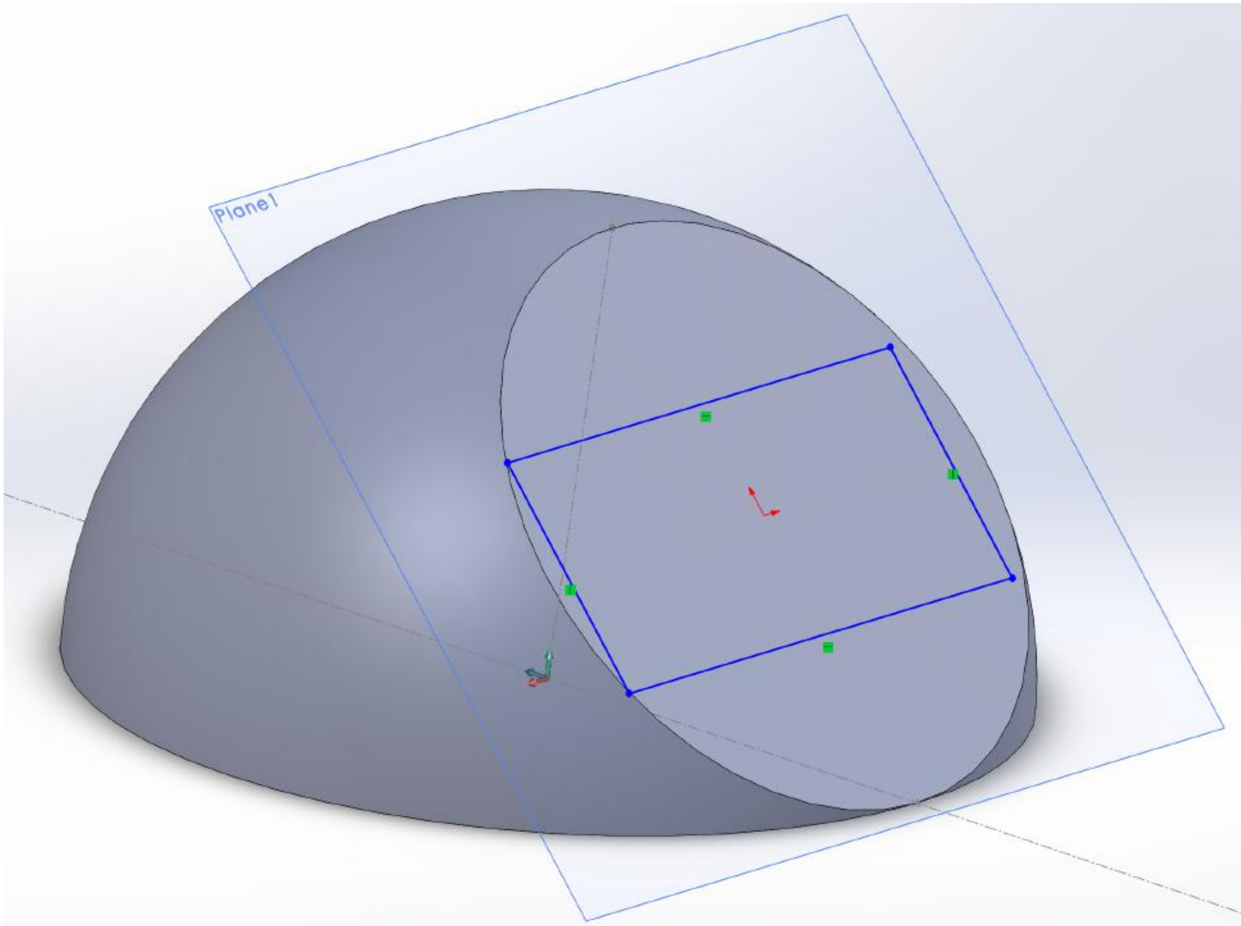

Figure 27: Unfinished model for the top cylinder cap, which rotates and houses the rest of the main controller buttons on the slanted face.