Electronic Toilet Paper Tracker for Public Facilities

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Contents

1 Introduction

1.1 Objective

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 unfit for use for customers and people needing to use the facilities. We propose a toilet paper supply monitor and notification system and backup roll, so that employees can focus on other parts of their jobs and still maintain adequately-stocked restroom facilities.

1.2 Background and Alterations from Basis Project

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 those 94%, two out of three classify a restroom with a lack of toilet paper as dirty [1]. This provides substantial incentive for establishments to keep on top of restroom maintenance, including stocking toilet paper.

Research into product alternatives indicates 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 remind employees if a certain amount of time has passed between inspection [2]. 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. Based on the survey information supplied above, at that point, it might already be too late to save the business's reputation with that customer.

1.3 Visual Aid

Our project will be focused on measuring and interpreting sensor readings, and acting on those readings through communication protocols. Figure 1 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.

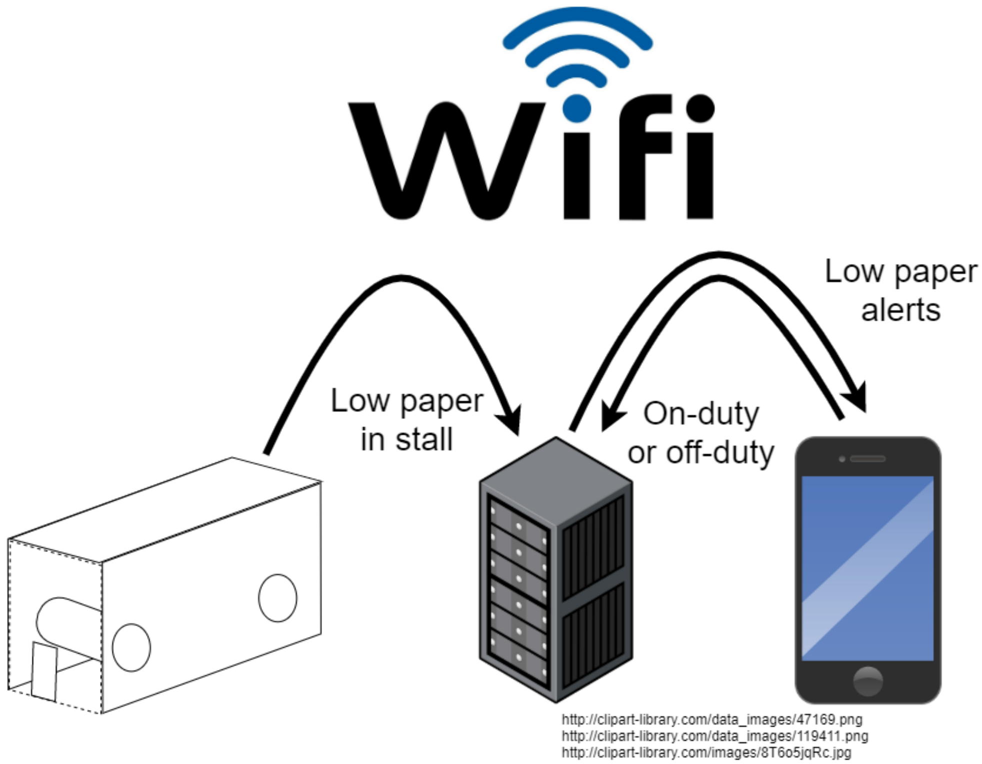


Figure 1: Information flow for toilet paper tracker.

1.4 High-Level Requirement List

Our project needs to meet several criteria in order 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 to be low, the system must automatically inform the employee for replacement within one minute of detection.

2 Design

When designing a toilet paper tracker, we need to take into account several functionalities that are needed. Figure 2 shows the overview block diagram for our design, and Figure 3 shows some concept illustrations.

2.1 Functional Overview

Contrary to our previous project this semester, our design will contain far fewer sensors and instead focus on communication. 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 the complexity of the circuits, 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 on the side of the container to measure the distance between themselves and the roll of toilet paper, to determine the amount of toilet paper still in the container overall. The sensors 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 [3].

2. Control Unit and Indicator

   - Micro-controller: Each stall module requires a microcontroller to read sensors periodically and establish a connection to the collector receiver. This sensor reading does not need to be particularly frequent, perhaps once every 10 seconds to a few minutes. The micro-controller will also 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 would be sent to the store staff after several minutes through a WiFi connection once the toilet paper is lower than 10%. This is so that staff can restock the toilet paper after the customer has left the stall, ensuring the customer's privacy.
   - 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. Otherwise, a green LED will declare that the stall is properly supplied.

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

4. Toilet Paper Container: This may house one or two rolls of toilet paper, as well as the electronic components. Specific parts can be 3D printed to fit in the sensors and mechanisms. Our sensors could also be retro-fit onto existing consoles housing the toilet paper within stalls, to reduce the cost of installation of our product. This would require measurements and configuration.

2.1.2 Server Module

Control Server: The control server should be able to gather the data from each electronic toilet paper tracker stall module through WiFi and send the notification to employees when it is necessary. For demonstration purposes, we plan to use a laptop to host the server module.

2.1.3 Cellular Phone Application

Each employee will install a simple, streamlined app onto their personal 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 give notifications, and the internet, but none of the user's personal data.

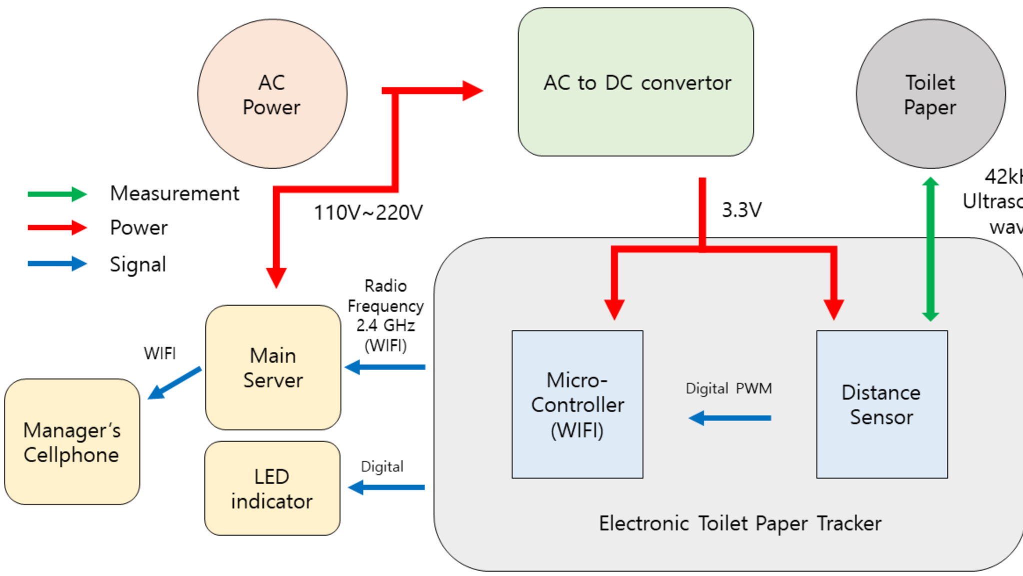


Figure 2: Block Diagram of the Electronic Toilet Paper Tracker

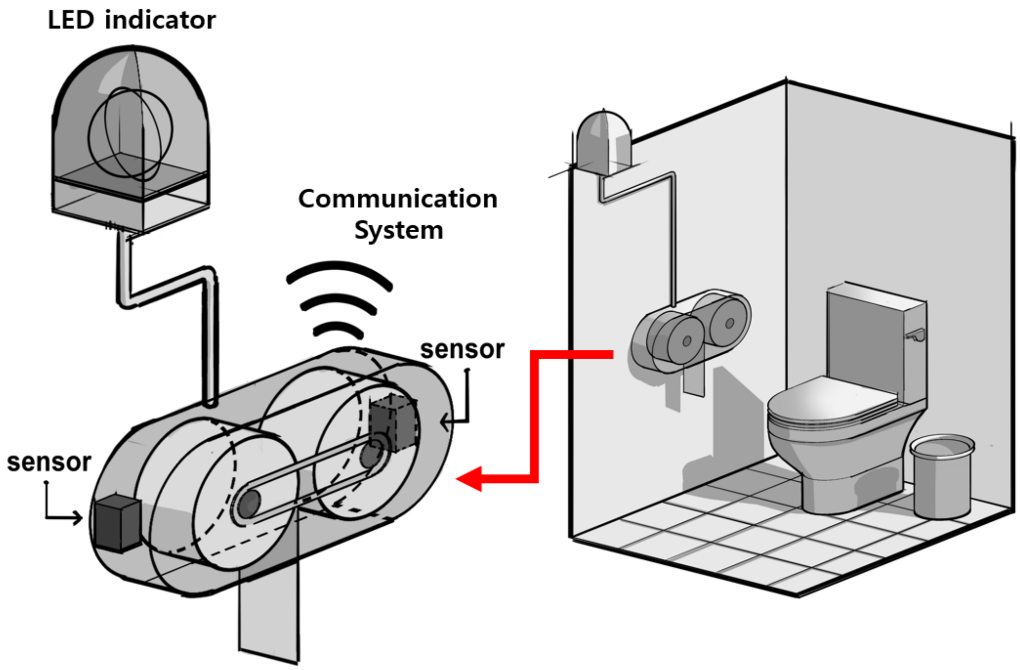


Figure 3: Concept art for electronic toilet paper tracker

2.2 Block Requirements

This section describes the functionality requirements of each major component within the toilet paper tracker system. Each component is critical to a different section of the information flow between the facilities and maintenance employees.

2.2.1 Control Unit and Indicator

The microcontroller must have the capacity for wireless communication, accept three digital inputs (two as PWM, and one for a reset button), and power two digital outputs for the indicator lights. We refine these requirements in Table 1. We will include a JTAG debugger in order to monitor the internal workings of our microcontroller during development (see Table 6 for more information).

Table 1: Requirements and verification for the control unit.

Requirement	Points and Verification	Verified?
The microcontroller must have WiFi capability, and accept and monitor the two distance sensor inputs as digital PWM: One distance sensor per paper roll.	(5 points) We will send a message (via 2.4 GHz WiFi protocol) to a server with code uploaded to the microcontroller, containing the readings of the PWM sensors.	.
The controller must control two LEDs (for example, red and green) to notify potential users whether a particular stall has enough toilet paper.	(5 points) We will indicate with the green and red LEDs whether the algorithm detects a high or low toilet paper supply.	.
The controller must communicate when total amount of toilet paper is below roughly 10% supply.		
The controller must operate on 3.3±0.3 V DC power.	(5 points) We will use a voltmeter to measure the input voltage to the controller chip.	.

2.2.2 Distance Sensors

The distance sensors will need to discern its distance to the roll with high accuracy, with two sensors in each stall module monitoring two rolls of paper. The distance sensors allow the microcontroller to compute the amount of toilet paper on each roll, and determine if it needs to notify staff. The distance sensors will operate on a 42 kHz ultrasound wave,and relay readings to the controller in PWM format. Table 2 shows the requirements for this module. Following the requirements and verification table, we provide additional analysis and plots for measuring distance.

Table 2: Requirements and verification for the distance sensors.

Requirement	Points and Verification	Verified?
The sensors must be able to detect changes in 1 cm between the distances of 3-20 cm. Our sensor that we have in mind accomplishes this (see Appendix A).	(5 points) We will periodically send a reading to the JTAG attachment, gradually moving the obstacle away from the sensor. This should occur with a frequency of at least once every centimeter of distance change. We will make readings every 1-2 seconds so that we exceed the requirements.	.
The sensors must be readable at least every 5 s.		
The controller must operate on 3.3±0.3 V DC power.	(2.5 points) We will use a voltmeter to measure the input voltage to the sensors.	.

Distance measured by Proximity sensor: We will use a proximity sensor to determine the amount of toilet paper left – by measuring the distance between the sensor and the edge of toilet paper. The proximity 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 4 shows the distance calculations, using the speed of sound in air as 340 m/s.

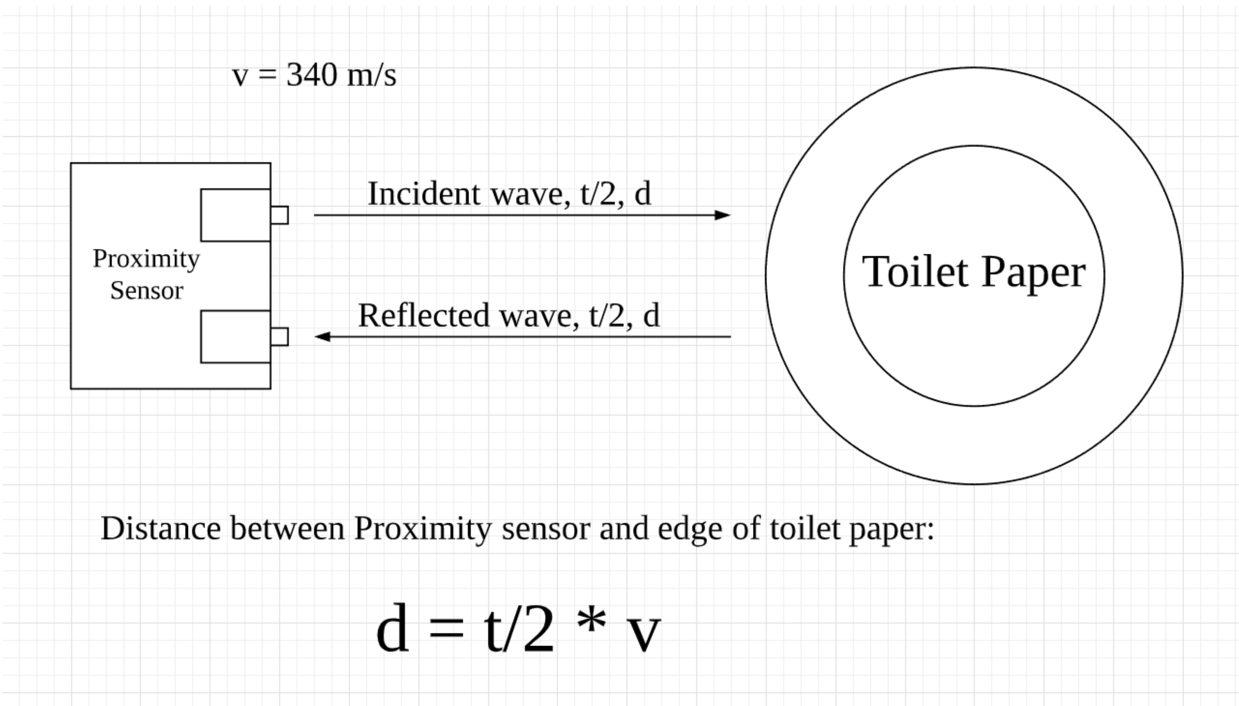


Figure 4: Distance Measured by Proximity Sensor

PWM in Proximity Sensor: PWM (pulse-width modulation) is also used in the distance sensors. PWM is a method of reducing the average power delivered by an electrical signal, by chopping the output signal into periodic discrete parts. The average voltage or current output is controlled by turning the switch between supply and load on and off, as shown in Figure 5. Duty cycle is the proportion of ON time in one period. The higher the duty cycle, the higher the average output power, as Figure 6 illustrates.

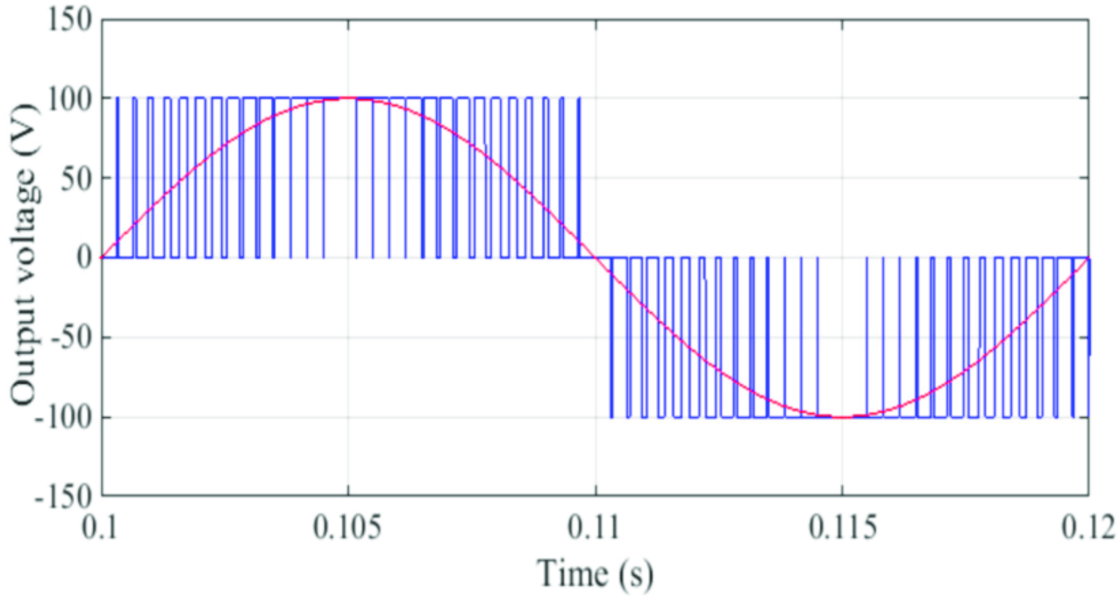


Figure 5: Explanation of PWM [4]

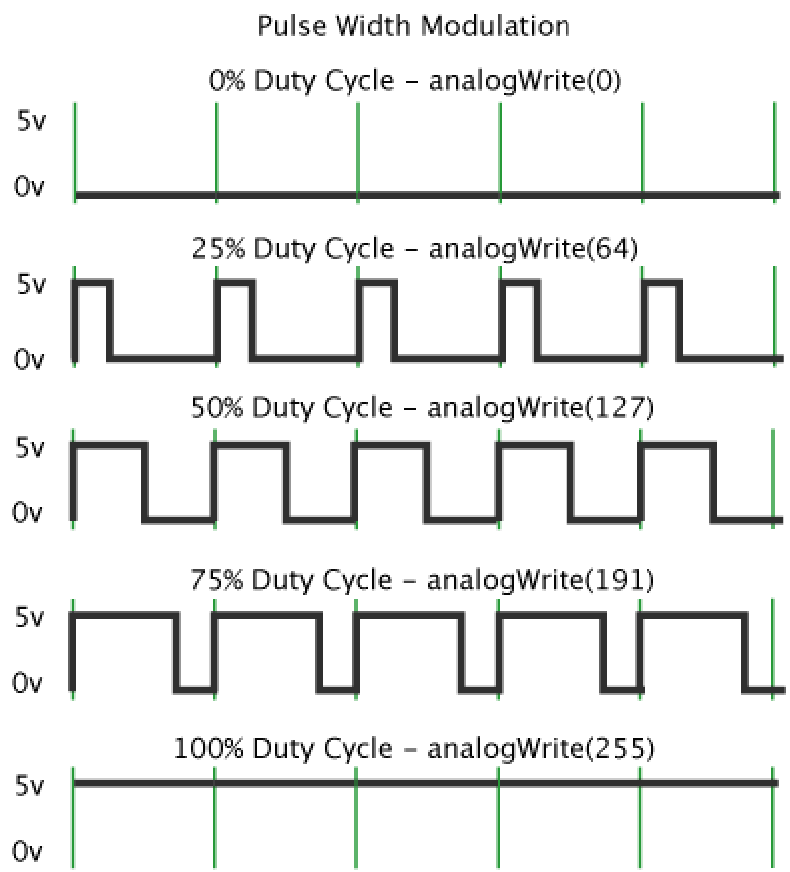


Figure 6: Explanation of Duty Cycle [5]

In an ultrasonic distance sensor, a short ultrasonic wave burst is emitted while detecting the distance to an object. The burst travels through the air, hits the object and bounces back to the sensor. The PWM then provides an output pulse to the host when the echo is detected. Therefore, the distance to the target can be measured from the width of this pulse. Figure 7 is an example showing the pulse width of an ultrasonic distance sensor.

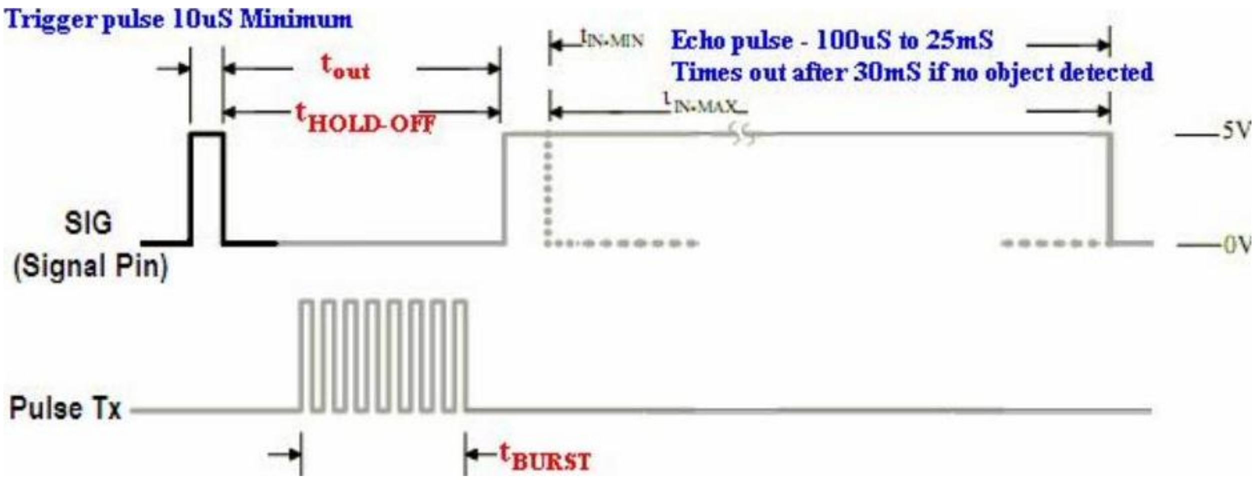


Figure 7: Example of a Pulse Width [6]

The width of the pulse t we get is the time needed for the pulse to travel to the object and back. Hence, the distance is calculated as follows:

$$d = 340 \text{ m/s} \times \frac{t}{2}$$

2.2.3 Stall Module Power Supply

The supply will include an AC-to-DC converter and a reset button. This component will supply power to the distance sensors and the microcontroller, as well as the LEDs by extension. The voltage conversion is especially critical because our microcontroller cannot handle voltages higher than 3.6 V, resulting in damage to the chip. We also want to keep voltages at a safe level in a restroom environment, where there is water involved. Table 3 further specifies the requirements for the power supply.

Table 3: Requirements and verification for the power supply.

Requirement	Points and Verification	Verified?
The power supply must convert from standard 220/110 V AC power to 3.3 ± 0.3 V DC power.	(5 points) We will use a voltmeter to measure the input voltage to the controller chip.	.
The controller must have a reset button to recover from unforeseen situations.	(5 points) We will demonstrate the controller rebooting after pressing the reset button.	.

2.2.4 Control Server

A server will be built to gather the signals from each of the WiFi modules and send them to the managers or employees for notification. Table 4 shows the requirements for this module.

Table 4: Requirements and verification for the control server.

<table>
<tr><th>Requirement</th><th>Points and Verification</th><th>Verified?</th></tr>
<tr><td>The server needs to accept at least one connection from the stall module(s). Only receiving data is required.</td><td>(5 points) We will connect a microcontroller to the server over WiFi and print a confirmation.</td><td>.</td></tr>
<tr><td>The server needs to accept at least one connection from the cell phone application(s). Sending and receiving data is required.</td><td rowspan="2">(5 points) We will connect a cell phone to the server over WiFi and print a confirmation of the toggle. If the toggle is on, we will send a reply notification.</td><td rowspan="2">.</td></tr>
<tr><td>The server needs to track which employee(s) is/are on-duty and notify them when the restroom needs to be restocked.</td></tr>
<tr><td>The server must add no more than one minute of delay, other than any programmed delay, between receiving a signal from the stall module and sending a signal to the cell phone.</td><td>(5 points) We will time the information flow with no programmed delay.</td><td>.</td></tr>
</table>

2.2.5 Cellular Phone Application

The employee's personal device will be the receiving endpoint for our notification system. The application must be capable of the requirements described in Table 5.

Table 5: Requirements and verification for the cell phone application.

<table>
<tr><th>Requirement</th><th>Points and Verification</th><th>Verified?</th></tr>
<tr><td>The application must communicate with the control server over WiFi 2.4 GHz.</td><td rowspan="3">(5 points) We will use a similar printing demonstration program as described in Table 4.</td><td rowspan="3">.</td></tr>
<tr><td>The application must receive and display push notifications within one minute of them being received from the server.</td></tr>
<tr><td>The application must notify to the server whether the employee is on-duty or off-duty, via a toggle at the control of the user. This should also have a maximum update delay of one minute.</td></tr>
</table>

2.3 Schematics

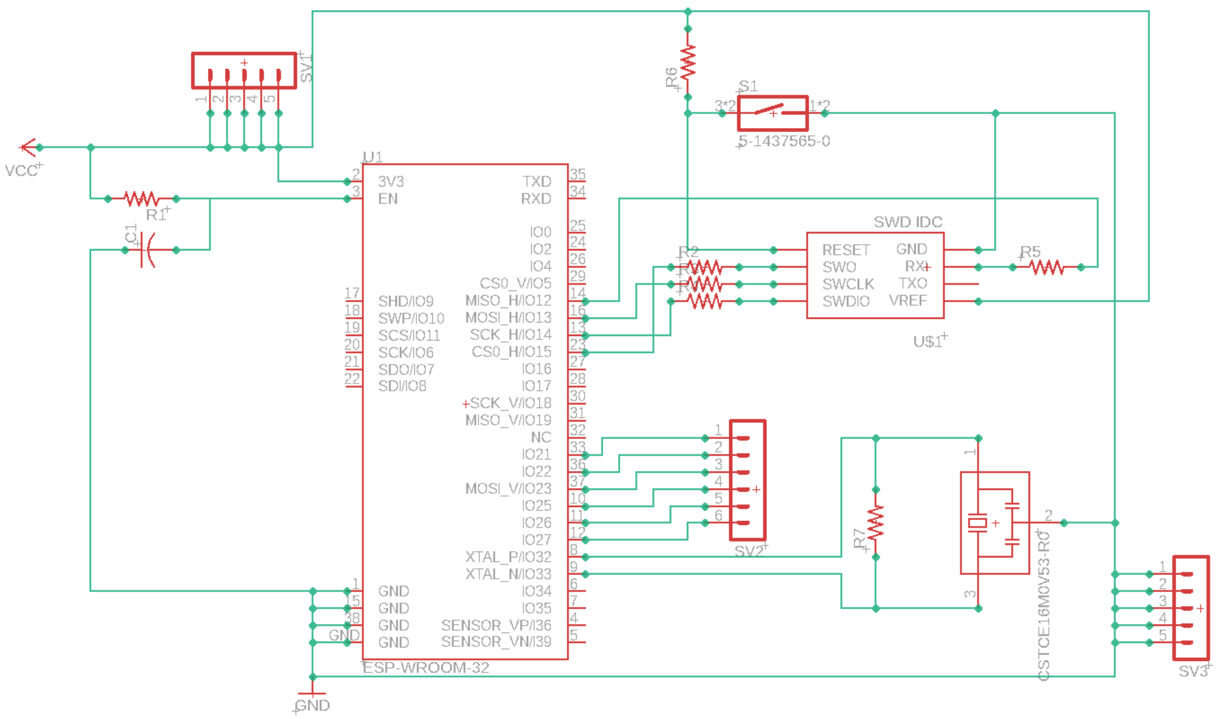


Figure 8: Body Part Schematic (ESP-WROOM-32)

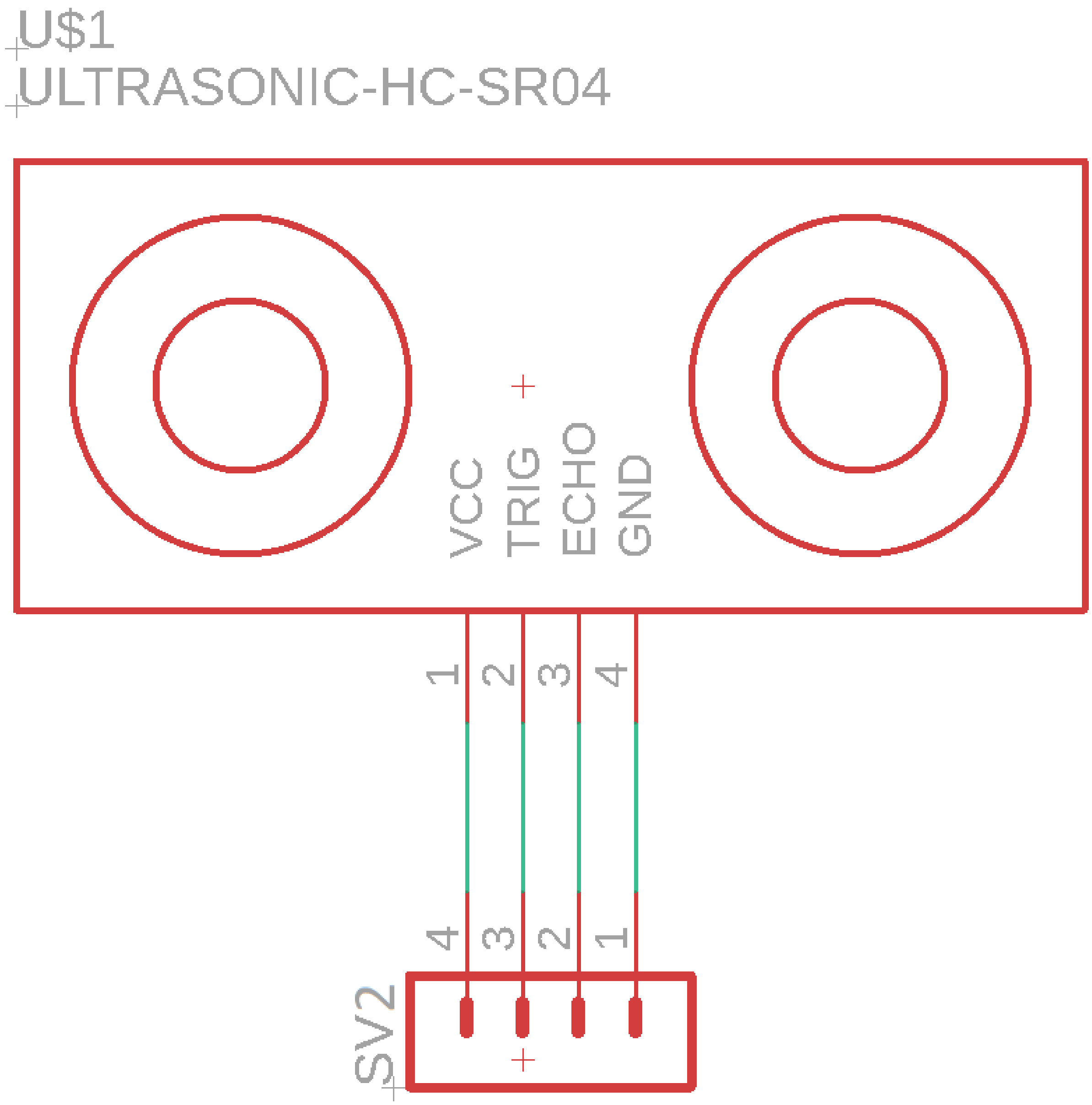


Figure 9: Sensor Part Schematic (Distance Sensor)

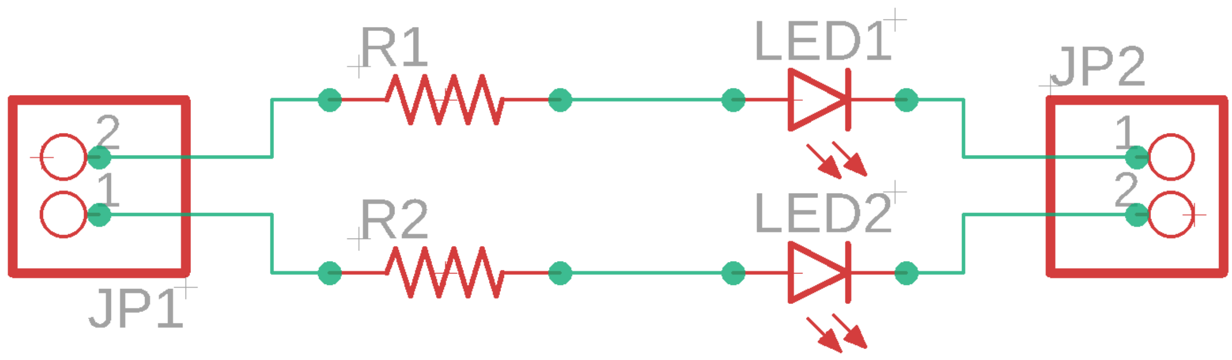


Figure 10: LED Part Schematic

2.4 Circuit Board Layouts

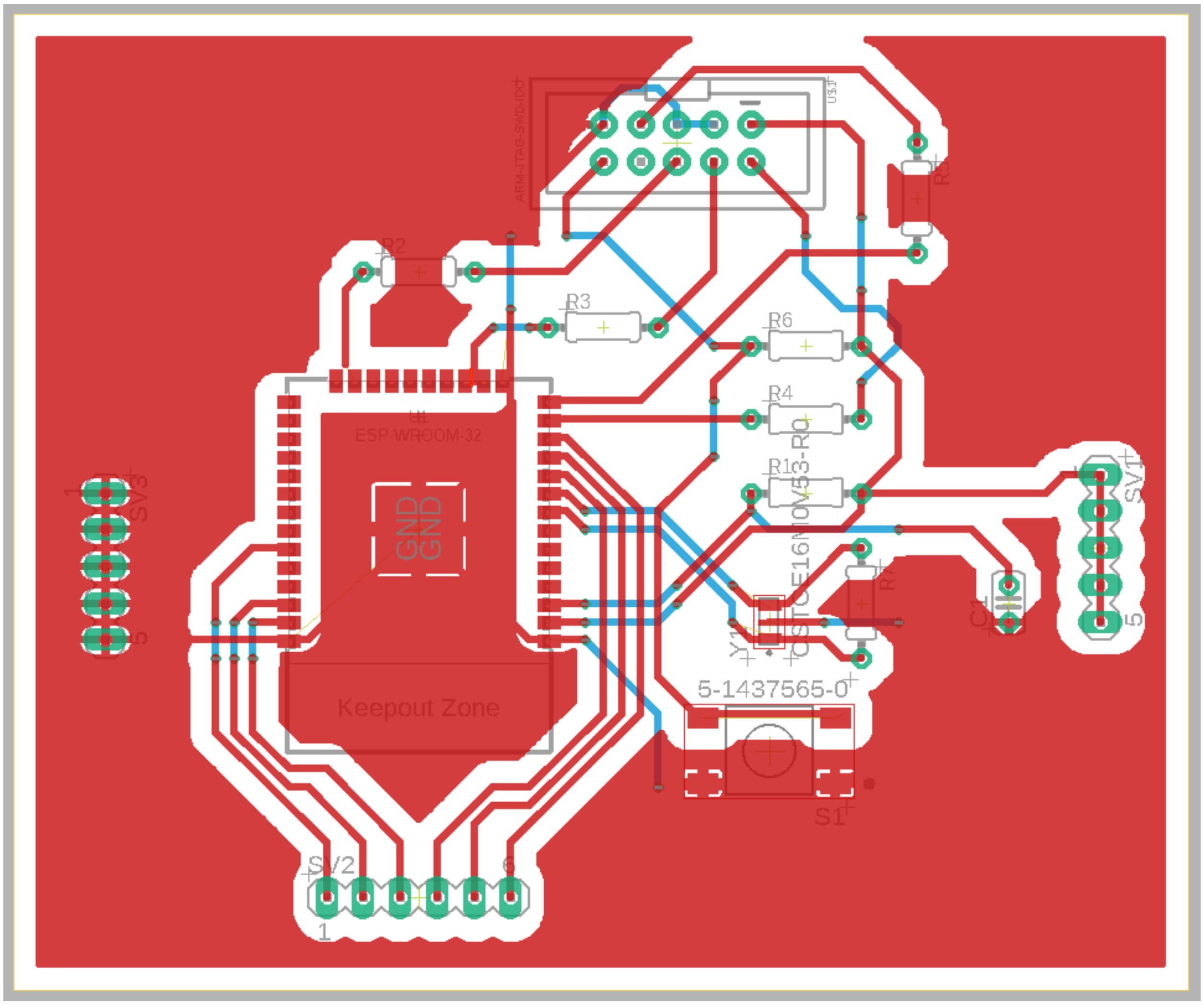


Figure 11: Body Part PCB Design (ESP-WROOM-32)

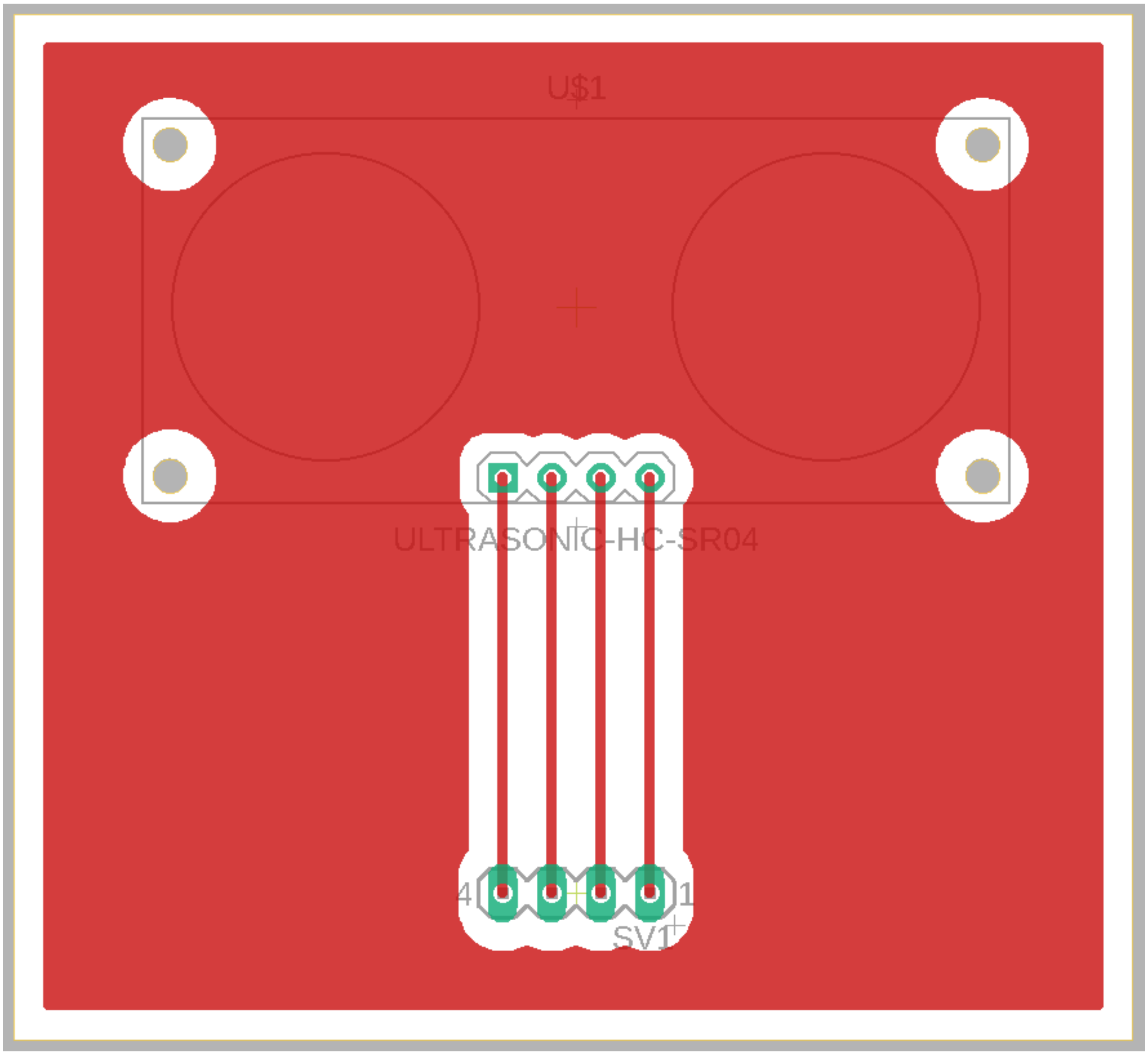


Figure 12: Sensor Part PCB Design (Distance Sensor)

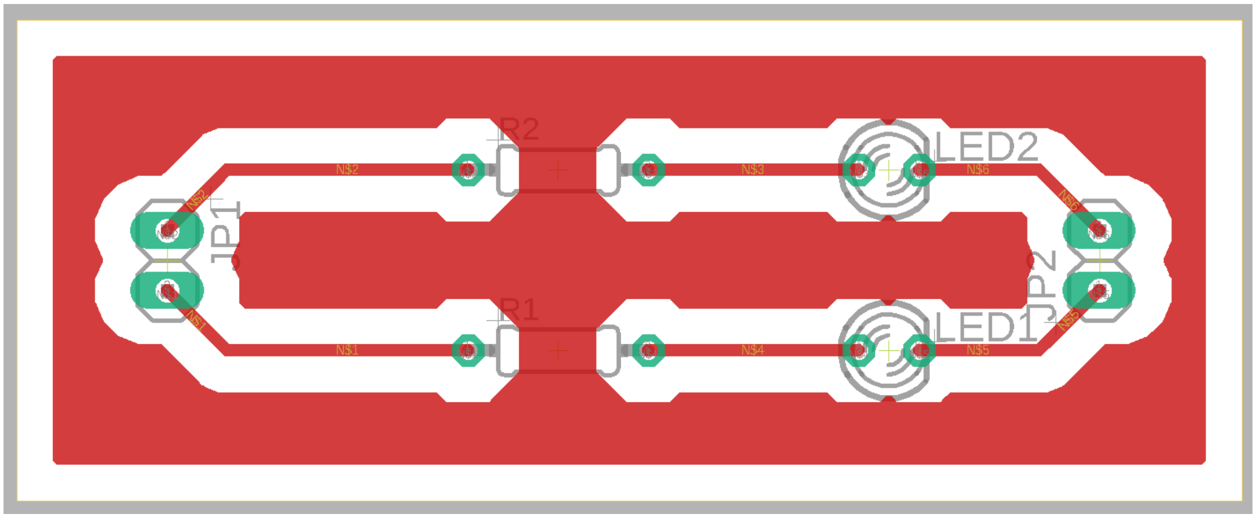


Figure 13: LED Part PCB Design

2.5 Algorithms Overview

Our second project will be slightly more computation-heavy than our earlier project, and each major segment of our design will require its own algorithm in order to function. In all algorithm descriptions, the possibility is left open to send acknowledgement messages back to message sources. For example, an acknowledgement from the server to the microcontroller as part of a handshake, although not shown in Figure 14 will increase the robustness of the communication protocols. See Section 2.6 for more analysis.

2.5.1 Stall Module Algorithm

The microcontroller will need to perform basic calculations to interpret the readings of the distance sensor. Figure 14 shows the functionalities of the stall module.

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.

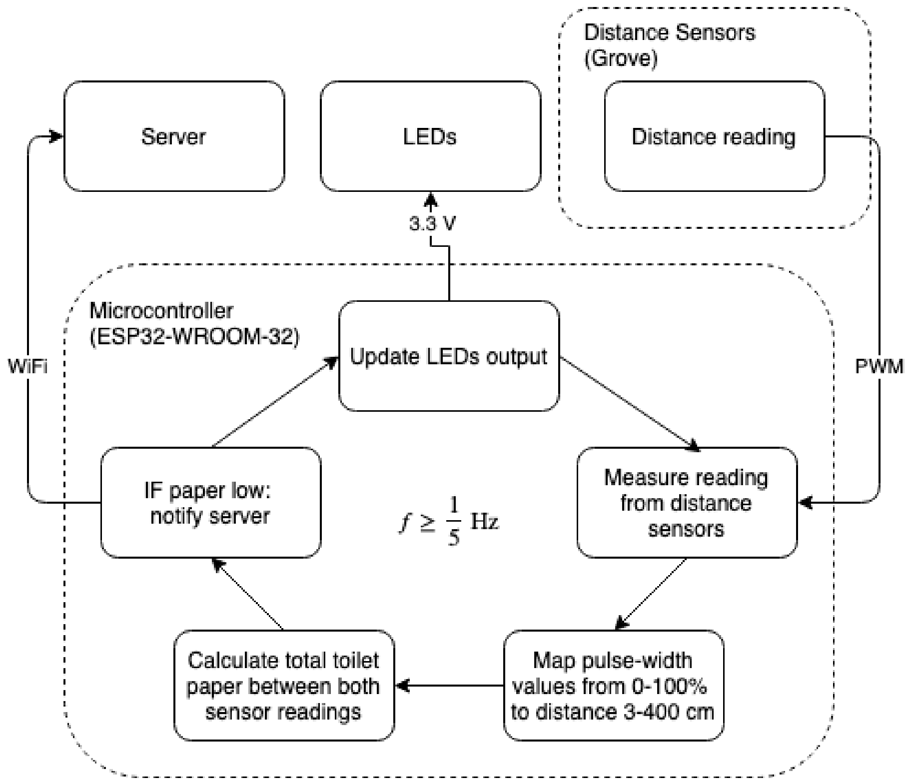


Figure 14: Basic algorithm for the stall module controller.

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 15 shows the algorithmic responsibilities of the central server.

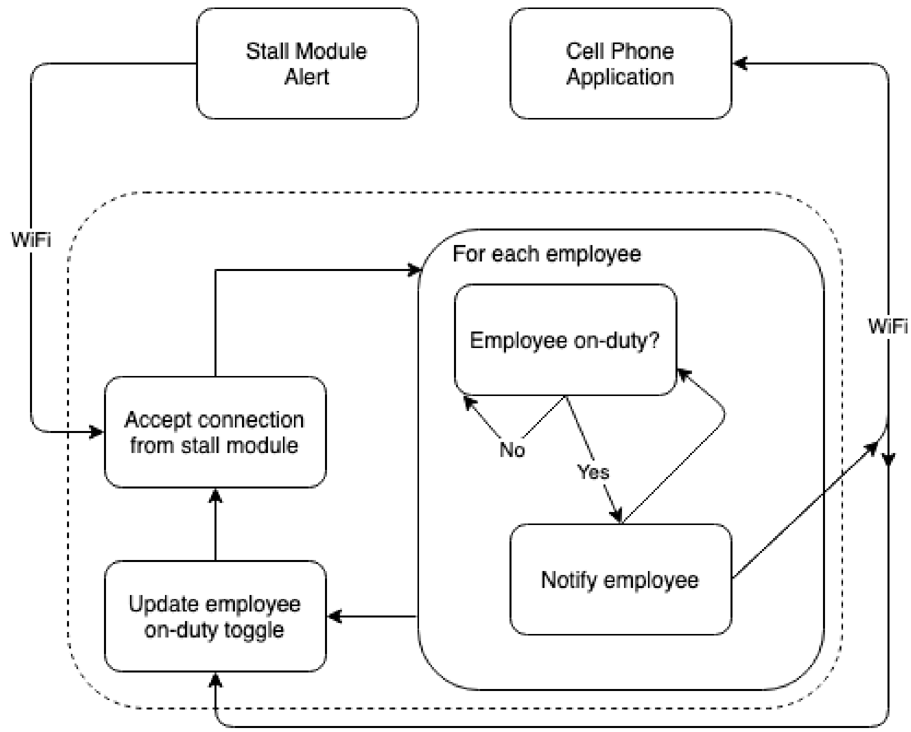


Figure 15: Basic algorithm for the stall module controller.

2.5.3 Phone Application Algorithm

The cell phone application must reliably receive notifications from the server. Figure 16 shows the algorithm of the cell phone application.

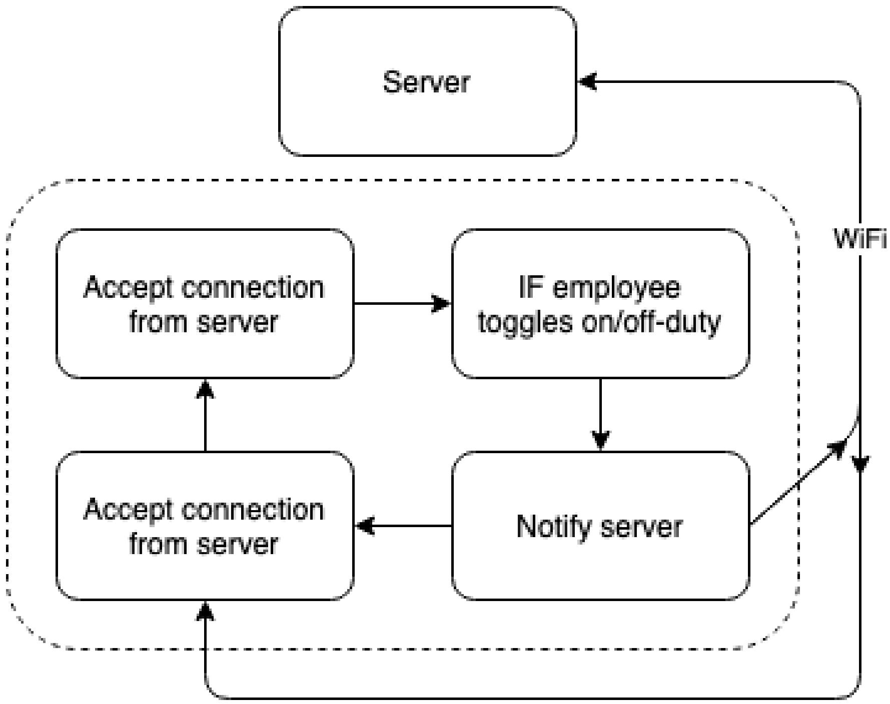


Figure 16: Basic algorithm for the stall module controller.

2.6 Tolerance Analysis

The most difficult component in our project will be the WiFi module. We need to establish wireless communications between the stall modules and the cell phones of the employees, so the most straightforward method would to connect all of those modules via WiFi. While a WiFi module can prove to be complicated and power-consuming, it has better wireless range and socket-based networking compensated for potential increases in the complexity of each stall module, which is superior to other alternatives like Bluetooth.

For the sake of convenience, we would connect all the WiFi chips from all stall modules to the same central receiver by running a server using a Wireless Local Area Network (WLAN) or other limited-access WiFi networks. The server would receive messages from the microcontrollers of the stall modules, and then send messages to the cell phones of the employees. Three problems may be encountered in this server system, and each of those problems we propose a potential solution in the following sections:

1. Ensuring the connections between stall modules and the server and between the server and the employees' cell phones, either through a WLAN or the Internet.

2. Dealing with more than one communication at the same time.

3. Traffic issues, or outages in the network.

2.6.1 Handshake

The connection between stall modules and the server can be verified when the central server sends a message to each node, and each node sends a message back. If the server receives the message back, the connection is ensured. This process is called a "handshake", as shown in Figure 17. The connection between the central server and the internet can be verified via handshaking as well. We can write a system in which the server, the phone, and the microcontroller all send and receive messages from one another.

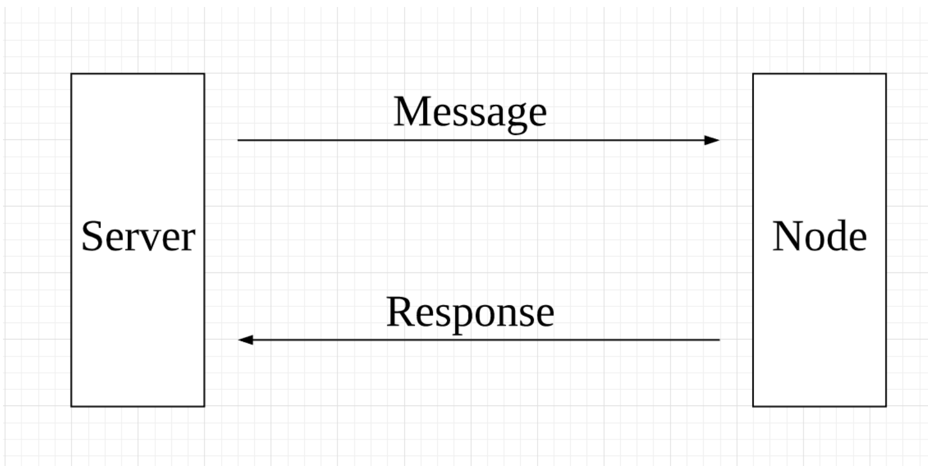


Figure 17: Simple Explanation for Handshake

2.6.2 Handling Multiple Server Connections

The traffic issues happen when, for instance, all the nodes want to send a message at the same time. This can be solved by queuing the messages on the client side, and dealing with them one at a time. Due to the relatively time-insensitive nature of necessary connections for our project, stall module controllers and cell phones will simple retry sending messages intermittently (every 10 seconds) until obtaining a successful socket connection with the server. A simpler alternative to a local a server would be using an Amazon AWS server that acts as a "middle man" between the toilet paper controller and the phone. However, this would entail an extra payment for service, and it is likely that establishments with commercial-size restrooms already have some sort of internal wireless network.

2.6.3 Dealing with Outages and Interruptions

Internet reliability: The internet cannot be guaranteed to have good connections at all time. A common network people usually use, AT&T, has an uptime of 99.95% [7]. Assuming operation of a local network without outside dependencies, it is highly likely that a WLAN would be even more reliable. When the toilet paper is low, the WiFi system should go through handshaking before the signal is sent. However, despite such a high percentage of uptime, there still may be times when messages cannot be successfully sent. Applying the average network uptime to a typical allocation of business hours over a year, we find that the average downtime of a network will be

$$(100\% - 99.95\%)\text{ down } \times 52\ \frac{\text{wks}}{\text{yr}} \times 40\ \frac{\text{hrs}}{\text{wk}} = 1.04\ \frac{\text{hrs}}{\text{yr}}\text{ down.}$$

On the side of the stall module, a simple re-sending of the message will suffice for our purposes, as described in the previous sections. In order to ensure restroom service continues in times of network interruption, the applications of on-duty workers' phones should handshake with the server every 5 minutes, and notify the employee after two failed handshakes. This ensures that non-communicative stalls receive service no more than 15 minutes after the start of an outage.

Internet Speed, Latency, and Jitter: To get an idea of average data speeds and network loads, we will again use AT&T as a common comparison. According to the AT&T internet speed test website, the average internet speed is 245.25 MBPS, average latency is 48.10ms, and the average jitter (the congestion when many millions of Internet connections are trying to compete with each other at the same time) is 203.93ms [8]. Bulk internet speed is most important when handling large documents and files, while latency and jitter are most impactful in streaming situations. Our system, which only sends small messages, and only when the toilet paper is low, shall not have high demands for the internet speed and latency. In fact, for our purposes, the latency and jitter can be ignored, since we do not require the employees to refill the toilet paper immediately. As long as the internet is not too cluttered due to heavy usage like streaming, it should suffice our project. These concerns are even less likely to have an impact in dedicated WLAN environments, but since the same router may handle public and private network traffic, it is important to consider these variables.

3 Project Differences

3.1 Overview

When addressing the issue of toilet paper shortage, the previous group placed their focus on a home environment, and who used the toilet paper within a particular household. 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.

3.2 Analysis

On the surface, a $70 toilet paper dispenser would attract little attention in private household settings. As described in Table 6, for less than $70, we can purchase ample parts to construct a prototype **and** extra critical components for development and experimentation processes, such as microcontroller chips. 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 improvement on the 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 abundance of personal data collection 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 [9]. Figure 18 shows these and further statistics presented in the article.

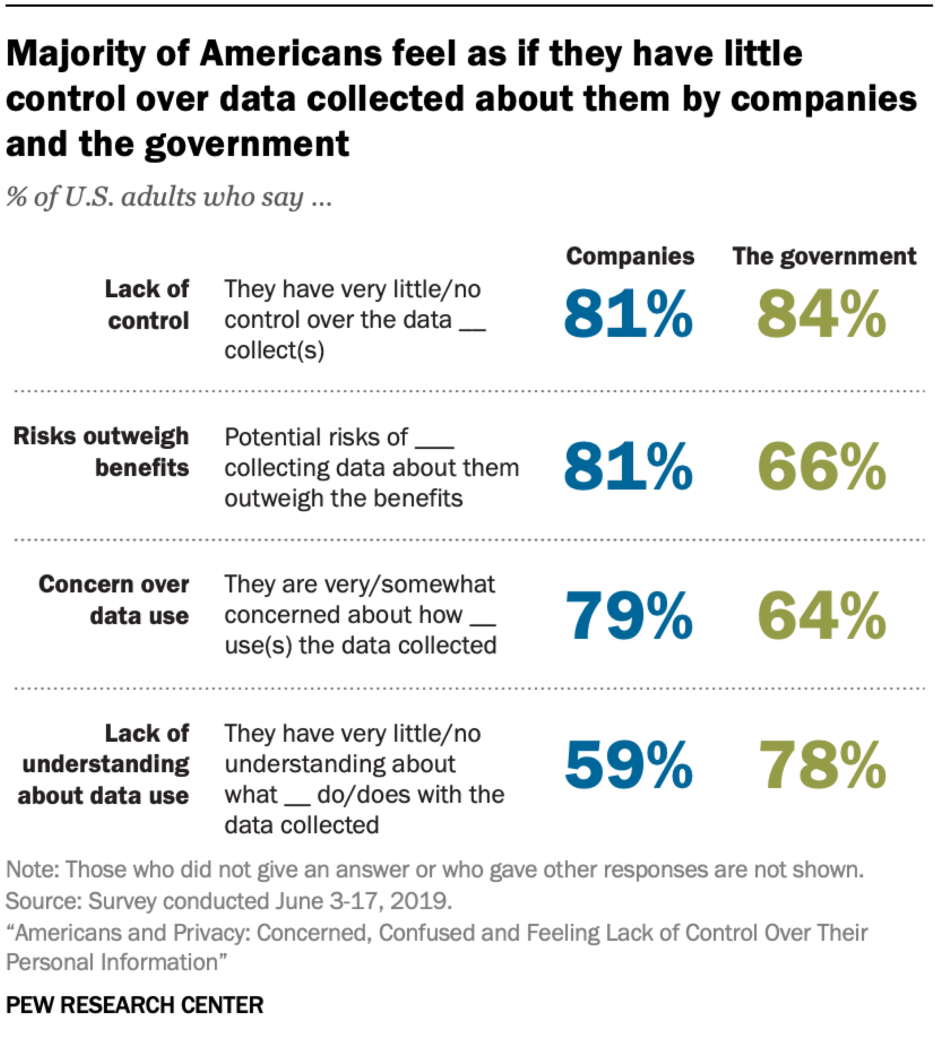


Figure 18: Privacy concerns among American adults. [9]

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 in turn 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 the product viability and expand its applications.

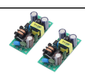
4 Cost Analysis

There are various costs associated with the development of any engineering project, including development materials, costs of labor, and design parts themselves. This section estimates and quantifies these costs for our project.

4.1 Bill of Materials

Specific parts, price, and links are listed in Table 6.

Table 6: Parts list for toilet paper tracker.

Part/Link	Mft	Desc	Price	Qty	Total
CSTCE16M0V53-R0 	Murata Electronics	10pcs CERAMIC RES 16.0000MHZ 15PF SMD	\$7.55	1	\$7.55
ESP32-WROOM-32 	Espressif Systems	Bluetooth, WiFi Transceiver Module 2.4GHz 2.5GHz Surface Mount	\$3.80	3	\$11.40
101020010 	Seeed Studio	3.3 V/5 V, Ultrasonic Distance Sensor	\$3.90	3	\$11.70
B07V811RPY 	HiLetgo	2 *85-264V AC To 3.3V DC Isolated switching Module	\$9.19	1	\$9.19
L6LAC004-DT-R 	Amazon Basics	18 AWG (American wire gauge) universal power cord	\$8.57	2	\$17.14
ARM-JTAG-SWD 	Olimex Ltd.	Sockets and Adapters ARM JTAG SWD ADAPTER ROWLEY CROSSWORKS	\$5.93	2	\$11.86
Push buttons (from ECE electronic shop)	UIUC ECE	5V, Digital	0	10	0
LED lights (from ECE electronic shop)	UIUC ECE	3.3V, Digital	0	10	0
Resistors (from ECE electronic shop)	UIUC ECE	100 - 10k Ohm	0	5-20	0
Capacitors from ECE electronic shop	UIUC ECE	10n - 100u F	0	5-20	0
Total Price					\$68.84

4.2 Cost of Labor

The estimated working time per week for our group is 6 - 9 hours, with 8 hours weekly average through the semester. Two meetings of 3 hours are made on average presently, but an increase to 3 meeting total 9 hours is expected as the actual parts come in. Each of our group member is paid with \$40 / hr, which is a typical engineer salary. Factoring in Hofstadter's Law [10], we would expect the cost of labor to be

$$2.5 * 16 * 8 \text{ hrs} * \$40/\text{hr} * 3 = \$38400.$$

4.3 Total Cost

The total cost would be \$68.84 + \$38,400 = \$38,468.84.

5 Schedule

Week	Tasks	Members
02/17	Design Document - Introduction; Design Document - Blcok Requirement;	Marshall
	Design Document - Block Diagrams; Design Document - Schematic;	Seongje
	Design Document - Tolerance Analysis; Design Document - Cost Analysis;	Yaning
02/24	Design document check; Research micro-controller to use; Design Document - Formatting;	Marshall
	Design document check; Research sensors to buy; Design Document - Block Diagram Improve;	Seongje
	Design document check; Design Document - Schedule; Research AC-to-DC converter and power cable to buy.	Yaning
03/02	Design document review; Discuss parts needed for machine shop Use EagleCAD to design toilet paper container Conversation with machine shop; Design PCB; Discuss PCB order with TA; Possibly pass PCBway's audit.	Marshall
	Design document review; Discuss parts needed for machine shop Use EagleCAD to design toilet paper container Design PCB; Discuss PCB order with TA; Possibly pass PCBway's audit.	Seongje
	Design document review; Discuss parts needed for machine shop Use EagleCAD to design toilet paper container Design PCB; Discuss PCB order with TA; Possibly pass PCBway's audit.	Yaning
03/09	Teamwork evaluation 1; Use EagleCAD to design toilet paper container Possibly pass PCBway's audit; Early bird PCBway order (5 bonus points); Soldering assignment.	Marshall

	Teamwork evaluation 1; PCB design improve; Possibly pass PCBway's audit; Early bird PCBway order (5 bonus points); Soldering assignment.	Soengje
	Teamwork evaluation 1; Use EagleCAD to design toilet paper container Order parts online; Possibly pass PCBway's audit; Early bird PCBway order (5 bonus points); Soldering assignment.	Yaning
03/16	Write code for the micro-controller;	Marshall
	Assemble parts; Test code;	Seongje
	Assemble parts; Test chips and sensors.	Yaning
03/23	MUST pass PCBway's audit; First round PCBway order; Last day for machine shop revision; Individual progress reports due 03/30; Test wifi module; Test chips and sensors.	Marshall
	MUST pass PCBway's audit; First round PCBway order; Last day for machine shop revision; Individual progress reports due 03/30; Assemble parts; Test Stall Module;	Seongje
	MUST pass PCBway's audit; First round PCBway order; Last day for machine shop revision; Individual progress reports due 03/30; Assemble parts; Test Receiver Module.	Yaning
03/30	Individual progress reports due Monday Test code in simulated environment.	Marshall
	Individual progress reports due Monday Assemble parts; Test electronic parts in simulated environment.	Seongje
	Individual progress reports due Monday Assemble parts; Test mechanical parts in simulated environment;.	Yaning

04/06	Final Round PCBway Orders; Prepare for Mock Demo	Marshall
	Prepare for Mock Demo	Seongje
	Prepare for Mock Demo	Yaning
04/13	Prepare for Mock Demo Debug	Marshall
	Prepare for Mock Demo Test electronic and mechanical parts	Seongje
	Prepare for Mock Demo Test electronic and mechanical parts	Yaning
04/20	MOCK DEMO; Prepare for presentation	Group
04/27	DEMONSTRATION; Prepare for presentation; Final report Write lab notebook	Group
05/04	PRESENTATION; Finish final paper; Lab notebook due; Lab checkout; Team evaluation 2	Group

6 Conclusion

6.1 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 hearing it. Very loosely, this corresponds to the guidelines of IEEE Policy 7.8.9 [11].

- 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)[11].

6.2 Safety Considerations

- The devices would 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 [11], 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 [11].

- 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)[11].

- 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)[11].

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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