SELF-CLEANING LOCKER

ECE 445 Design Document

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1 Introduction

1.1 Objective

Sanitation means everything, especially in a pandemic. We must make sure that ourselves and our belongings are clean in order to help mitigate the spread of COVID. Especially with more companies, buildings, restaurants, and gyms opening up, it's becoming easier for the disease to spread. Particularly with gyms, people are constantly sharing lockers with others, which can easily spread germs due to the storage of their sweaty belongings and clothes.

To combat the spread of COVID, and germs in general, we are proposing a self-cleaning locker. When the locker detects that nothing is inside, it will automatically disinfect the inside of the locker using disinfectant sprays. An LED display on the outside of the locker door will display the status of whether or not it is cleaned, and if there is still disinfectant in the locker.

In addition, we will be building an app that will monitor the status of the locker. For gym owners, the app will allow them to keep track of all their self-cleaning lockers in their locker rooms and make sure that every locker is properly maintained for the safety of their employees and individuals using the gym's lockers.

1.2 Background

We are trying to solve the issue of germs spreading between uses at gym lockers. The gym locker is the main area to hold someone's belongings while using the gym, and everyone throws their belongings in there. However, no one knows who has used that particular locker before them, and if that person has been in contact with other people who have had COVID. Since the locker room is a shared space, an individual really has no choice where else to put their belongings, and whether or not the locker they choose is COVID, or germ free in general.

The gym is one of the easiest places where bacteria can spread. Many different parts of the building and locker room have a multitude of germs. For example, the gym faucet handle has 545,312 CFU (colony forming units), which has eight times as many bacteria than a school cafeteria water fountain spigot. Gym benches have 8,241 CFU, which has six times more bacteria than an animal cage [1]. Contact with these objects can easily lead to the spread of germs. In addition, research shows COVID can last up to two days on fabric, and even up to nine days on certain surfaces [2], [3].

This is where our project comes in. The main problem we are trying to solve is allowing users to have that ease of mind by not worrying about who has used the locker before them, and whether or not it's clean to put their belongings in by eliminating bacteria that could be spread from surface to clothing, and ultimately an individual.

1.3 Physical Design

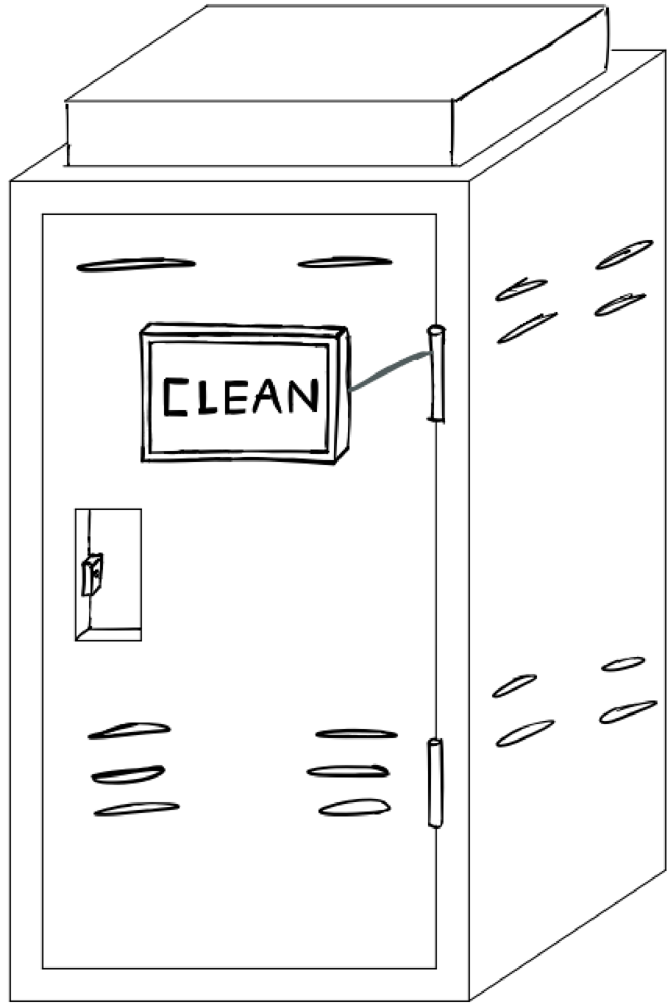

Figure 1: Sketch of locker front exterior

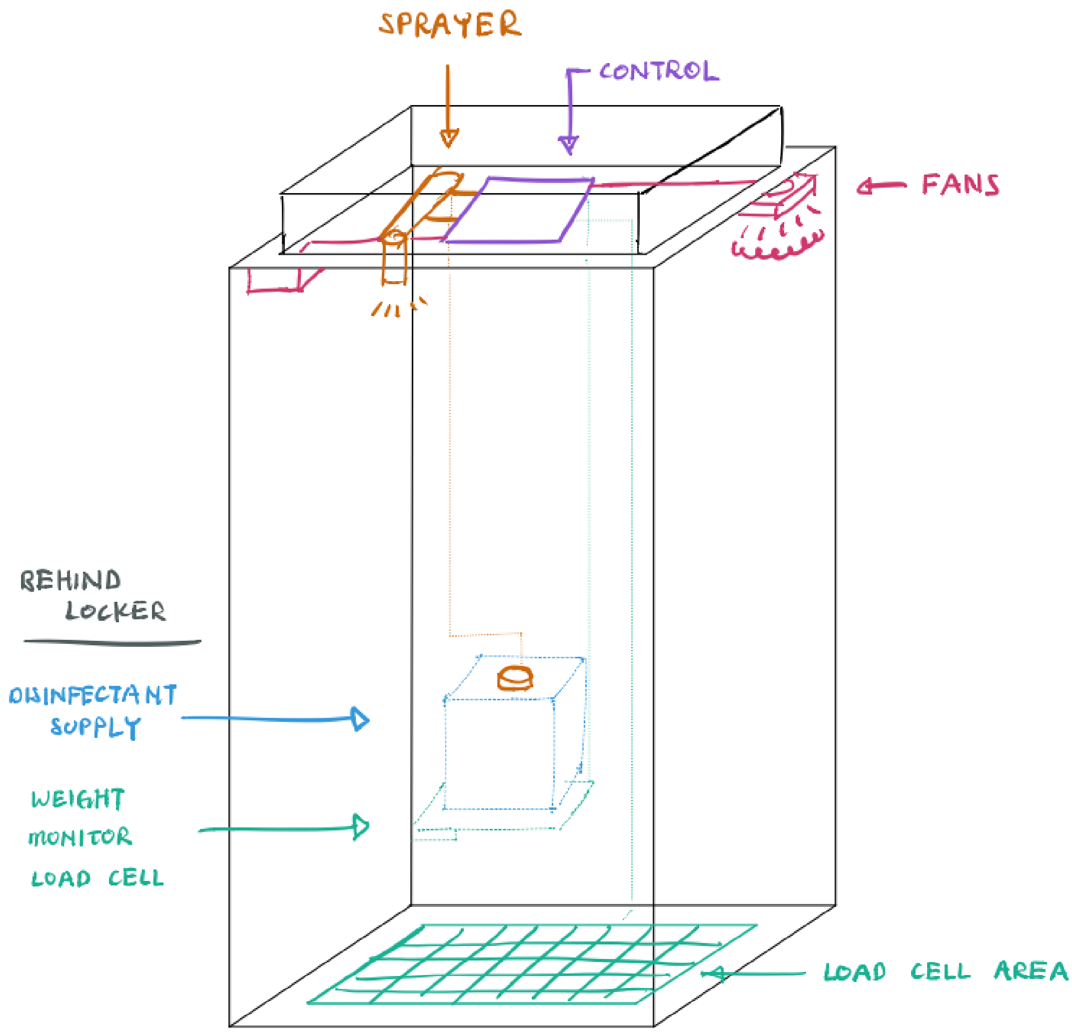

Figure 2: Sketch of locker interior with subsystems

1.4 High Level Requirements

- Weight sensors correctly detect when items weighing at least 250 grams are on top of them with an error range of roughly 5%.
- Spray correctly cleans the inside of the locker when it is empty and closed, covering at around 90% +/- 5% of the interior surface area.
- Project correctly detects different disinfectant supply levels with an error range of around 5% at each level.

2 Design

The three main subsystem modules we will be using for our project will consist of a control unit, disinfectant unit, and monitoring unit. We will go into each module into further detail.

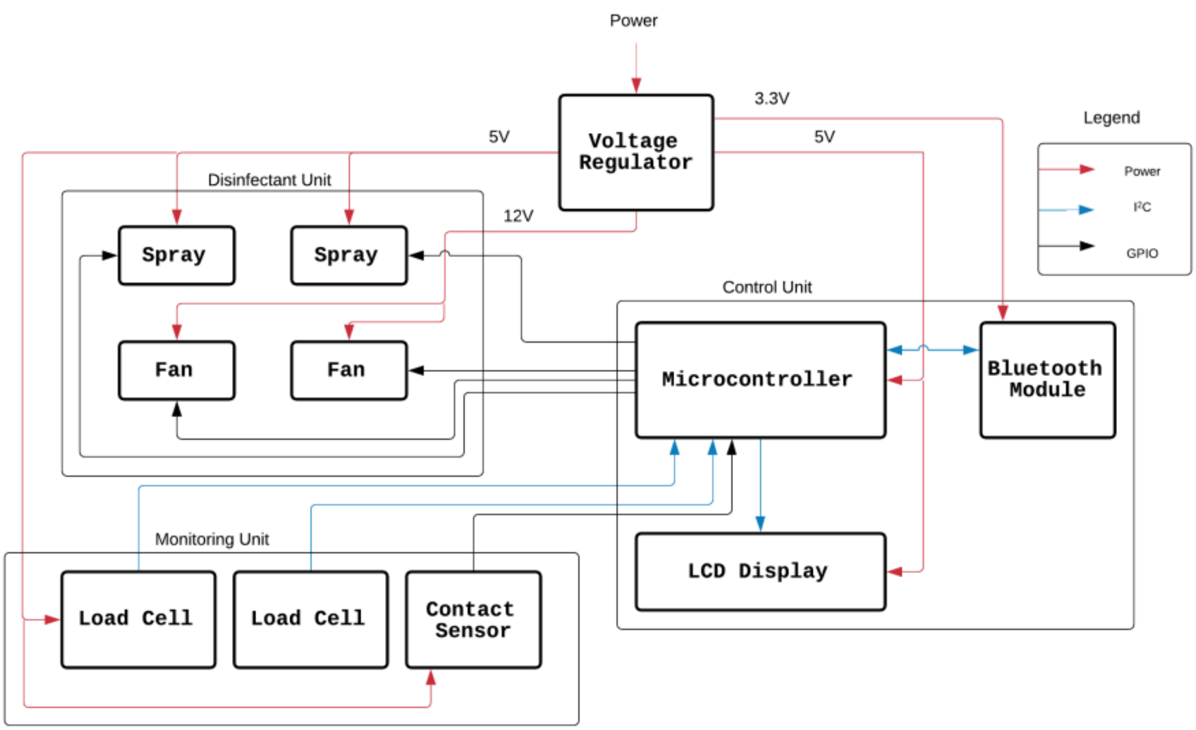

Figure 3: Block Diagram

2.1 Power Supply

Our locker will be plugged into a wall outlet but will make use of a voltage regulator to fine tune how much voltage we want to supply to certain components in our design. We will be using a power supply with two voltage rails. The first will be a 5V rail that will go to every device but the fans. We decided that we needed to have powerful fans to be able to quickly dry the locker after cleaning. Thus, we wanted to use bigger 12V fans optimized for airflow rather than tiny 5V fans that cannot really push much air.

2.1.1 Voltage Regulator

The voltage regulator will allow us to choose how much power to supply to each of our subsystems.

Requirements	Verification
1. Voltage must be regulated to +12V +/- 5% from outlet plug to power as required for specific components of the locker.	1. Connect multimeter and oscilloscope across the voltage regulator to measure if the potential difference stays within 5% of +12V.

2.2 Control Unit

Our control unit allows for all our subsystems to communicate with one another on which actions to perform depending on the conditions met within our locker.

2.2.1 Microcontroller

The microcontroller we are using, the ATMEGA328P-PU, will be used to program our LED display, along with handling communication between all our subsystems. This will control when to activate our sanitizing module and fans, and then display on our LED display whether the locker is ready to use.

Requirements	Verification
1. Microcontroller should correctly communicate progress of sanitation cycle with LED display. 2. Microcontroller should program the Bluetooth module to transmit data to the Android application.	1. Connect the microcontroller to PCB after soldering has been done. Check that host program can read data properly. 2. Examine host program to see that data packets arrive accordingly to formats specified.

2.2.2 Bluetooth Transceiver

The Bluetooth module will be used to communicate the level of disinfectant supply within our locker to our Android application. This will take in the output of the weight sensor underneath our disinfectant supply tubes and forward it to our Android application.

Requirements	Verification
1. Module needs to correctly communicate information about disinfectant supply level at 100%, 75%, 50%, 25%, and 0% (+/- 5% error range) with Android application. 2. Module must be able to receive and transmit information accurately from up to 20-30 feet away.	1. Using Bluetooth terminal application on Android phone along with code on Arduino, check that output on Bluetooth terminal shows values equal to output of weight sensor for disinfectant supply in the correct format. 2. Test that connection holds on physical Android phone 20-30 feet away from locker.

2.2.3 LCD Display

The LCD should communicate with our microcontroller on what the display should show on the outside of the locker.

Requirements	Verification
1. LCD should be visible from one meter away 2. LCD should display “CLEANING” when locker is sanitizing 3. LCD should display “CLEAN” when locker sanitation has finished 4. LCD should display “LOW SUPPLY” when disinfectant supply hits 25% (+/- 5% error range)	1. Check that LCD display is visible within one meter of standing. 2. Check that LCD correctly displays message sent by microcontroller depending on stage in sanitation process. 3. Calibrate microcontroller and load cell amplifier with default weight (let’s say 1000 grams), and place weight that is 1/4 of that weight, and see if LCD correctly displays “LOW SUPPLY”.

2.3 Disinfectant Unit

The disinfectant unit will be used to sanitize the interior of our locker when no items are inside the locker. Fans will be used to help dry the interior after we spray disinfectant on the surfaces of the inside.

2.3.1 Sprayer

We will use an automatic sprayer to spray our disinfectant to sanitize the interior of our locker.

Requirements	Verification
1. Have the spray be able to cover around 90% +/-5% of the interior surface area.	1. Using a colored liquid, initialize spraying unit, and afterwards, measure how much area spray covered of interior by hand and divide by total interior surface area.

2.3.2 Fans

The fans will be used to air out the inside of the locker after the spray sanitizes the inside of the locker. The locker door should be closed when the fans operate as well.

Requirements	Verification
1. Fans should be powered with 12V +/- 5% coming from the outlet plug. 2. Fans should circulate air throughout the inside of the locker to ensure that the interior is dry.	1. Connect multimeter and oscilloscope across the voltage regulator to measure if the potential difference across fan stays within 5% of +12V. 2. Check that interior is drier after fans have finished circulating air as part of sanitation process.

2.4 Monitoring Unit

The monitoring unit will be used to monitor whether there are items inside the locker and will communicate with our disinfecting unit on whether to initialize or not. This unit will also monitor the amount of disinfectant supply within the locker and will communicate with our LCD display and an Android app about certain locker information, such as supply level, and whether it is in use.

2.4.1 HX711 Load Cell Amplifier

The load cell amplifier will be used to be able to read the change in resistance in our load cells to communicate with our MCU. This will be used to find a more specific value for our disinfectant supply level.

Requirements	Verification
1. Be able to detect if there is strain on the load cell connected.	1. Attach load cell to load cell amplifier, and check if there is a Voltage output using DMM.

2.4.2 Load Cell (Locker bottom)

This load cell will be located at the bottom of the inside of the locker to detect if there are any objects on top of it to communicate to the MCU whether to start the sanitation process.

Requirements	Verification
1. Check if load cell can detect at least 250 grams on top of it.	1. Connect load cell to load cell amplifier and check if roughly 250-gram object gives an output voltage using DMM.

2.4.3 Load Cell (Disinfectant Level Monitoring)

This second load cell will be used to measure how much disinfectant there is left in our locker in order to clean it.

Requirements	Verification
1. Load cell should output different voltage values based on different weight values (increasing weight should correspond to increasing voltage out)	1. Connect load cell to load cell amplifier. 2. Place 250-gram object on load cell and use DMM to check for output voltage. 3. Place 500-gram object on load cell and use DMM to check for a larger output voltage than previous. 4. Place 750-gram object on load cell and use DMM to check for output voltage.

2.4.4 Contact Sensor

The contact sensor will be attached to the inside of the locker door to check whether the door is closed or not.

Requirements	Verification
1. Have the sensor correctly output 0/1 based on whether the door is open / closed. (0 for open, 1 for closed)	1. Connect output of sensor to breadboard and use a simple LED to check if sensor correctly outputs 0 if open and 1 if closed.

2.4.5 Application

The Android application will act as a central monitoring system for all connected lockers. Each locker will have its status listed for an employee to check on the locker room. This will be created using Android Studio.

Requirements	Verification
1. Android application should be able to monitor locker disinfectant supply levels for 100%, 75%, 50%, 25%, and 0% levels (with around 5% error range). 2. Android application should report information regarding status of locker to user. 3. Android application should connect to Bluetooth transceiver within 20-30 feet of locker.	1. Using Bluetooth terminal application on Android phone along with code on Arduino, check if output on Bluetooth terminal shows values equal to output of weight sensor for disinfectant supply. 2. Test on a physical Android phone walking 20 to 30 feet away from locker and checking if connection holds.

2.5 Software

The software that will be used includes programming our microcontroller, as well as Android Studio to develop our Android application to monitor our disinfectant supply for our locker.

The microcontroller will be used to program what our LCD display shows based on our lockers condition. If there is no weight in our locker and the door is closed, the sanitation process will commence, and the LCD display will show the text “CLEANING”. Once the sanitation process is complete, the microcontroller will communicate to the LCD display to show “CLEAN”. Additionally, when the disinfectant supply level reaches 25%, that subsystem should communicate with the MCU to make the LCD display show “LOW SUPPLY”.

Android Studio will be used alongside the HC-05 Wireless Bluetooth RF Transceiver to monitor our disinfectant supply levels. We will connect our HC-05 to our microcontroller that communicates with the information from our disinfectant supply monitoring subsystem. We will have to download a Bluetooth Terminal Application on our Android phone to get information from our HC-05. Using Android Studio, we will create an application that reads the data from the HC-05 that comes from our microcontroller to display the amount of disinfectant supply at certain levels. The microcontroller will get the disinfectant supply data from our load cell amplifiers that will be connected to our strain gauge load cells for monitoring the disinfectant supply levels. The levels we want to show will be 100%, 75%, 50%, and 25% full. These will be represented by a full green battery icon for 100%, a 3/4 full green battery icon for 75%, a yellow 1/2 full battery icon for 50%, and a red 1/4 full battery icon for 25%. That way, a gym owner can see finer information about the supply levels of their lockers in a real-world application.

2.6 Schematics

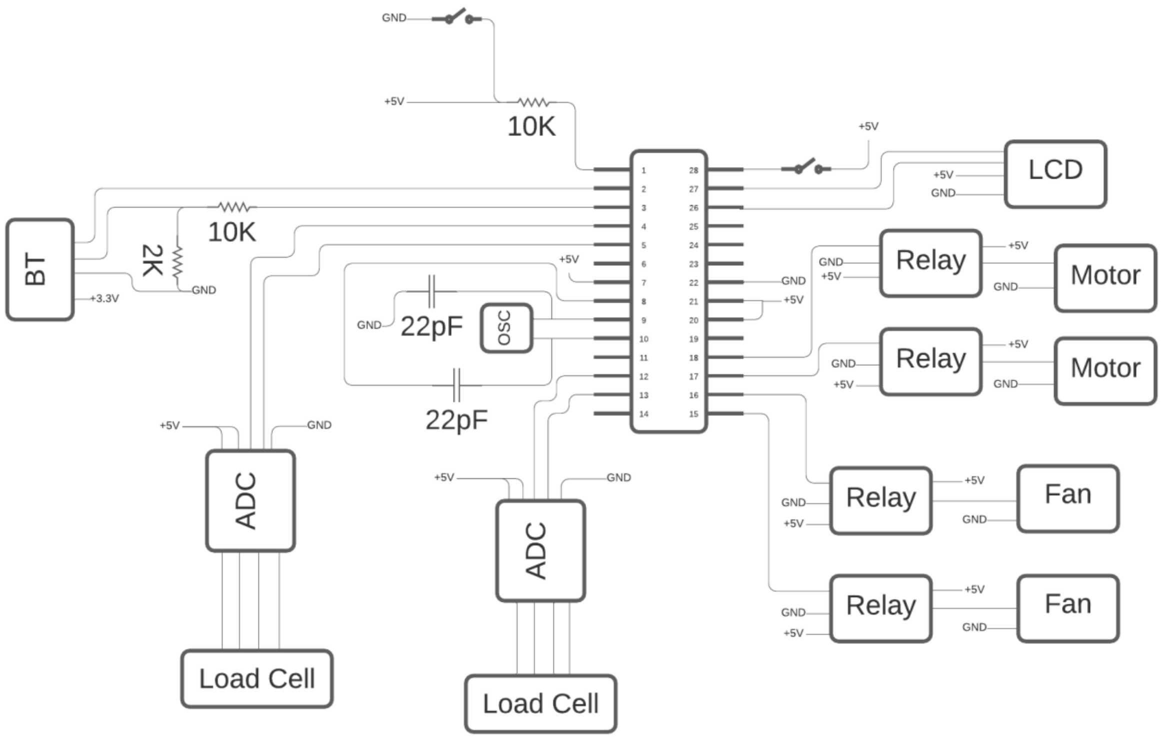

Figure 4: Circuit Schematic

2.7 Board Layout

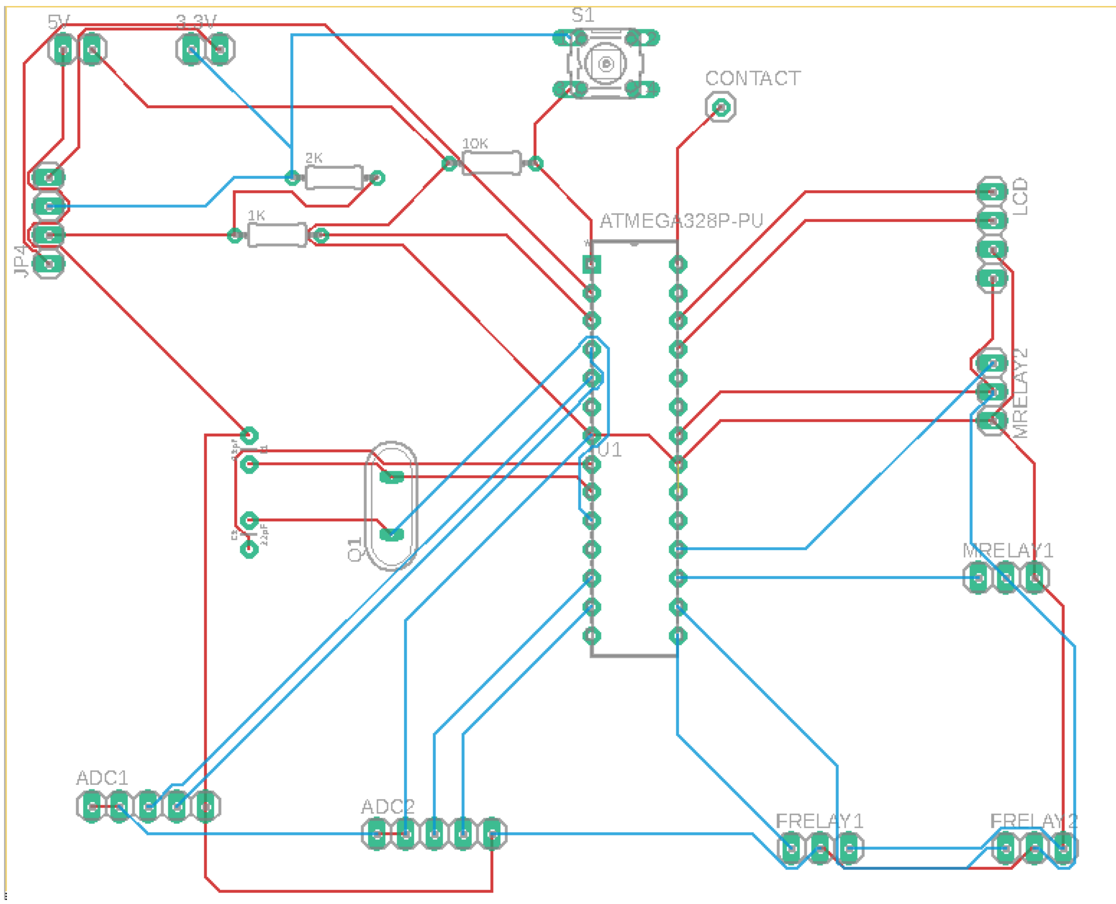

Figure 5: Board Layout

2.8 Tolerance Analysis

One important tolerance we want to maintain is being able to detect objects of at least 250 grams. Our strain gauge load cell will be used to detect if there are objects inside the locker to know whether to initiate cleaning. However, readings from the load cell are very small. Our load cell has a Wheatstone Bridge circuit built into it, with gauge sensors replacing the resistors shown in the figure below:

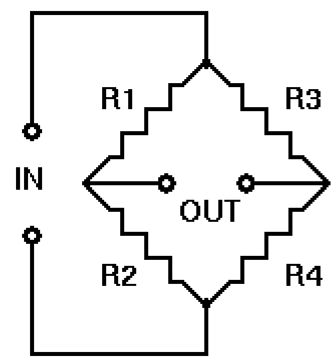

Figure 6: Wheatstone Bridge Circuit

These strain gauges commonly have a base resistance of either 120Ω, 350Ω, or 1000Ω (we will use 120Ω as a placeholder value, as the strain gauge load cells we ordered do not tell us) [7]. If R1 / R2 = R3 / R4, then our voltage output will be 0. However, when there is strain on one of these gauges, it will increase its resistance value based on the amount of strain. This percent change in resistance is given by:

$$\%\ Change\ in\ Resistance\ =\ [(Gauge\ Factor)\ \cdot\ Strain]\ \cdot\ 100 \qquad \text{(Eq. 1)}$$

Based on the Wheatstone Bridge, the output Voltage will be calculated using:

$$V_{out}\ =\ \left[\left(\frac{R3}{R3+R4}\right)-\left(\frac{R2}{R1+R2}\right)\right]\cdot V_{in} \qquad \text{(Eq. 2)}$$

We want to be able to detect at minimum 250 grams. We calculate the amount of strain by first finding the amount of stress that at 250-gram object would create. We use the following stress equation along with our locker dimensions to find this value:

$$Stress\ =\frac{Force}{Area} \qquad \text{(Eq. 3)}$$

$$Stress\ =\frac{\left(0.250kg\ \cdot\ 9.81\ {}^{m}/_{s^2}\right)}{(0.35m\ \cdot\ 0.31m)}\ =\ 22.6\ Pa$$

To find strain, we can use the following equation to find the relationship between stress and strain:

$$Strain = (Elastic\ Modulus) \cdot Strain \quad \text{(Eq. 4)}$$

The elastic modulus is the proportionality constant based on the material of the strained object. Our load cell is aluminum, so the modulus will have a value of 7.0 * 10^10 Pa [8]. Plugging these numbers into our equation 3, we get a strain value of 3.23 * 10^-10 **ε**. Plugging this strain value into equation 1, with a Gauge Factor of 2 (a common gauge factor for metallic strain gauges), we end up with a 6.46 * (10^-8) % change in resistance.

This change in resistance is very small, and plugging that into equation 2 for R1, with a voltage input of 5.5V, we would only get a voltage output of 0.0888 μV. While this value is what is expected out of a load cell, it is still a very small value to read.

To get more accurate measurements, especially with our load cells that will be reading change of weight on top of it (for our disinfectant supply monitoring system), we are using the HX711 Load Cell Amplifier. What this load cell amplifier does is allows our load cell output to be amplified with a gain of either 128 or 64, with a full-scale differential input voltage of +/-20mV or +/-40mV, based on what gain we choose [9]. Using this load cell amplifier, this will enable us to detect our base weight of 250 grams, along with being able to accurately tell between different weight values on our load cell to correctly implement our disinfectant supply monitoring system.

2.9 Risk Analysis

We think that the disinfectant supply monitoring block, specifically the application we are trying to develop, would be the most significant risk towards the completion of our overall project. None of us in the group have had to work with Android Studio in developing an app, on top of having it communicate information from our PCB through the Bluetooth module.

We would have to make sure that our Bluetooth module relays precise enough information so that our app can display different levels of disinfectant supply, similar to how modern-day devices show the battery icon dwindles down as it loses charge. We would have to then figure out how to use that data within Android Studio in regards to programming our app.

In case we run into serious issues with Android Studio or time constraints on the project, our contingency plan is to create a simple website to interface with the Bluetooth module.

For our contingency plan if the whole class were to go remote, we would continue to get tested through the school, and hopefully be able to meet up to complete our project. If one member of the group were to test positive for COVID, we would redistribute the work to the two other members if the third member were not able to work due to feeling ill.

3 Costs

Our fixed development costs are estimated to be $40/hour, for 12 hours a week for three people. We are using the length of a semester to determine the number of weeks to work on this (16).

$$3 \cdot \frac{\$40}{hour} \cdot \frac{12\ hours}{week} \cdot 16\ weeks \cdot 2.5 \ = \ \$57{,}600 \qquad \text{(Eq. 5)}$$

Part	Cost (prototype)	Cost (bulk)
Battery Powered Sprayer (Amazon; Craftsman; B08KH81W9Q)	$7.56	$7.56
ATMEGA328P-PU Microcontroller (Digi-Key; Microchip Technology; ATMEGA328P-PU-ND)	$2.52	$2.09
HC-05 Wireless Bluetooth RF Transceiver (Amazon; HiLetgo; B071YJG8DR)	$7.99	$7.99
MC-38 Wired Door Sensor (Amazon; Gikfun; B0154PTDFI)	$6.98	$6.98
DC 12V Cooling Fan (Amazon; PANO-MOUNTS; B07D493BDX)	$13.99	$13.99
HX711 Load Cell Amplifier (SparkFun; SEN-13879 ROHS) x2	$19.90	$8.46
LCD Module (Amazon; KNACRO; B01ID8O574)	$6.22	$6.22
Strain Gauge Load Cell - 4 Wires - 20Kg (Adafruit; 4543) x3	$11.85	$3.16
Locker (Ikea; 204.765.20)	$40	$40
12V DC 2A Wall Power Supply Adapter (Amazon; XINKAITE; B07GRZB5Y9)	$9.99	$9.99
10pcs Mini360 3A DC Voltage Step Down Power Converter (Amazon; SongHe; B07T7L51ZW)	$6.88	$6.88
Capacitor Ceramic 22pF (SparkFun; COM-0857) x5	$1.25	$0.23
Oscillators (Digi-Key; 887-2015-ND) x3	$0.90	$0.14
Total	**$136.03**	**$113.69**

We will only be making one locker, and therefore our total prototype cost will be $136.03 for one unit, which includes the locker cost. Without the locker cost, the rest of the components have a total of $96.03.

The total development cost will be $57,736.03. The quoted machine shop labor is $56.12 an hour, with 12-16 hours spent on it approximately.

4 Schedule

Week	Chilo	Nithin	Immanuel
3/8/2021	Go to lab to start testing components and building subsystems	Go to lab to start testing components and building subsystems	Go to lab to start testing components and building subsystems
3/15/2021	Develop baseline Android application	Continue building out physical circuit schematic	Finalize PCB Design 1
3/22/2021	Test Bluetooth module with Android application	Testing load cell accuracy for overall project	Finalize PCB Design 2
3/29/2021	Connecting sanitation subsystem to monitoring unit on breadboard	Connecting sanitation subsystem to monitoring unit on breadboard	Connecting sanitation subsystem to monitoring unit on breadboard
4/5/2021	Program microcontroller	Program microcontroller	Finalize PCB Design 3
4/12/2021	Final testing	Final testing	Final testing
4/19/2021	Mock Demo & remove bugs	Mock Demo & remove bugs	Mock Demo & remove bugs
4/26/2021	Demonstration	Demonstration	Demonstration
5/3/2021	Presentation & Final Paper	Presentation & Final Paper	Presentation & Final Paper

5 Ethics and Safety

We are responsible for keeping the public’s safety, health, and welfare in mind when designing this project. This refers to the IEEE Code of Ethics, #1, stating “to hold paramount the safety, health, and welfare of the public” [10]. We must be sure that our locker does not pose any safety concerns for people when using our device. We will go into how we would implement the required safety restrictions in our project later in this section.

Another ethical concern that is out of our control would be the discrimination of use with our product. This refers to the IEEE Code of Ethics #7, stating “to treat all persons fairly and with respect, and to not engage in discrimination based on characteristics such as race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression” [10]. While we will never discriminate the use of our product based on the characteristics of a person such as race and gender, in a real-world application of our product where it is readily available in public gyms, certain establishments may discriminate against certain people on the use of the lockers. We do not have a solution for this, as it is out of our control as to how someone else may allow others to use our locker. The best thing we can do is to investigate whether a buyer has a good record of respecting an individual’s race, gender, religion, etc., if we were to sell this product.

In terms of safety for our self-cleaning locker, we must make sure that our pressure sensor is accurate in detecting whether there are items, even small ones, in our locker. We must make sure that no one's belongings get wet on accident by our sensor not detecting that they are there. Another safety issue that can come up is the issue of wiring in our project. We want to make sure that our wires do not short and cause damage to anything. We will address this by covering our wires with electrical tape whenever possible, along with having circuitry in a separate encasing on the exterior of the locker.

Another health concern will be the issue of the toxicity of disinfectant used in our locker. There has been research on the effects of disinfectant spray inhalation and the effect that it has on people. There have been studies on asthmatic patients inhaling disinfectant spray (three doses of 0.6 mg of benzalkonium chloride in water), and 20% of those patients observed signs of Bronchoconstriction [11]. The amount of spray that is released and how much the fan dries it off to prevent inhalation of sanitation solution must be monitored carefully, along with looking at more research, to ensure that our locker does not pose any health concerns to users of the locker along with people in the surrounding area.

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