Towel Bacteria Detector

ECE 445 Design Document
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1. Introduction

1.1 Problem and Solution Overview

Bath towels are used every day often after a shower, but people rarely think about how often they should clean their bath towels. In fact, most people neglect to wash their towels just once a week. Because bath towels are often damp, stored in a dark bathroom, and left to air dry, they provide the perfect environment for unwanted bacteria to grow. This can lead to a buildup of substances like mold, mildew, or bacteria on the towel [1]. Furthermore, this can result in an unpleasant odor that makes the towel unsuitable for drying use. Knowing when a bath towel is beginning to exhibit signs of unwanted bacteria would provide insights into when a bath towel should be cleaned.

We propose building a detective device that lets users know when to wash their bath towels. Our unit could let towel users know this by monitoring the amount of emitted CO_2 from bacteria and mold. As mold develops it emits CO_2 as a byproduct. In mold-free environments, there are typically around 400 parts per million (ppm) of CO_2. With mold, CO_2 concentrations can spike to over 1,000 ppm [2]. If the towel is deemed moldy, the user will be alerted via a speaker emitting noise. There will also be a smartphone app allowing users to assess the "health" of their towels.

1.2 Background

This project was originally done in Spring 2019 by team #25. However, their project extensively involved cleaning the towel with a moderately expensive UV LED solution. Rather than detecting the amount of bacteria, their UV cabinet was triggered on a timer and blasted the towel with disinfecting light regardless of if the towel actually needed cleaning or not. Their cleaning UV cabinet cost around $200.

Our solution proposes simply identifying when a towel should be cleaned and alerting the user of this. Because towels can be cleaned using traditional washer and dryer units, we sought to eliminate the inclusion of expensive UV LEDs and a cleaning cabinet altogether. Rather, we can capitalize on the existing infrastructure (in-unit washers and dryers) as our cleaning mechanism and provide a monitoring solution for towel-bourne bacteria. Additionally, this will be beneficial if users are away from home when a bath towel would not be regularly used since unnecessary cleaning would not occur.

Other attempts at preventing towel bacteria growth have rarely been made yet there are a few consumer products that exist. Special towel detergents are available to be used in a washer unit. These work primarily to reduce odor from bath towels but don't objectively specify when a towel should be washed [3]. Salons also have heated cabinets designed to keep towels bacteria-free, but these units require a significant amount of energy since they are continuously operating. Our solution is the first to accurately identify when a bath towel should be washed.

1.3 Visual Design

Below is a drawing of the front and side views of the monitoring unit respectively. It will be attached directly to a user's pre-existing towel rack and will reside under a hanging towel. It will be attached by a plastic connecting component that wraps around a towel rack.

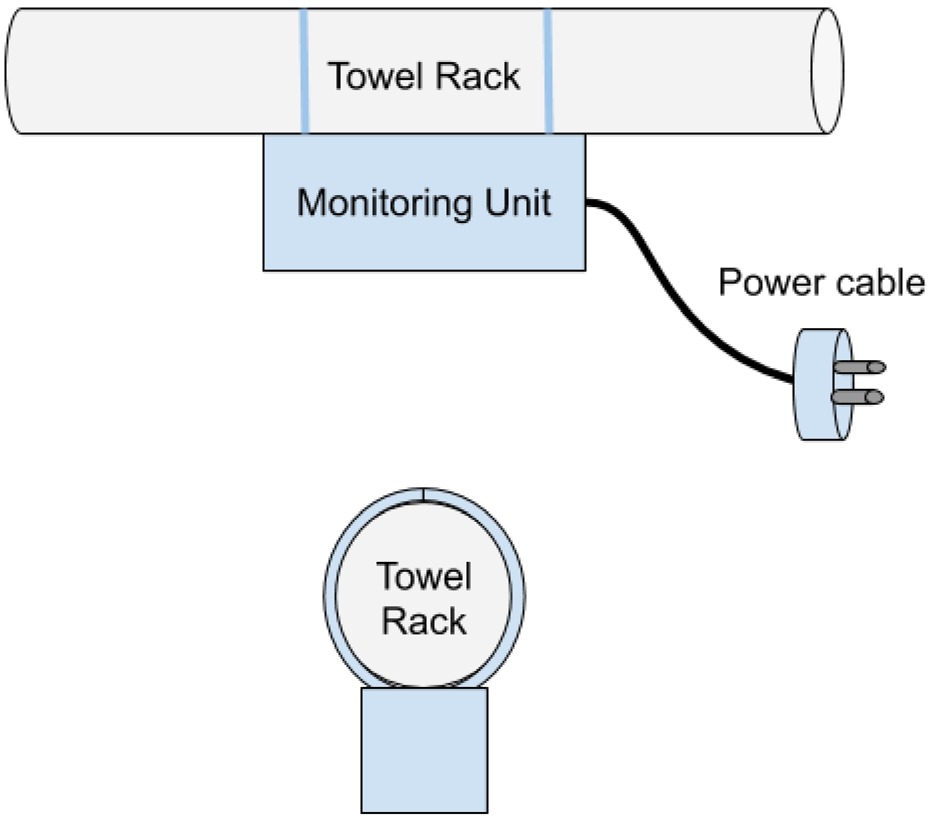

Fig. 1. Diagram of device's position during operation.

1.4 High-Level Requirements

- Detects CO2 concentration in the surrounding air in ppm with an accuracy of +/- 10%
- Audibly alerts the user if a towel is good or bad based on if CO2 concentration is at or above 1000 ppm near the towel.
- The unit can operate in a high humidity environment that is at least 70% relative humidity without resulting in faulty operation.

2. Design

2.1 Block Diagram

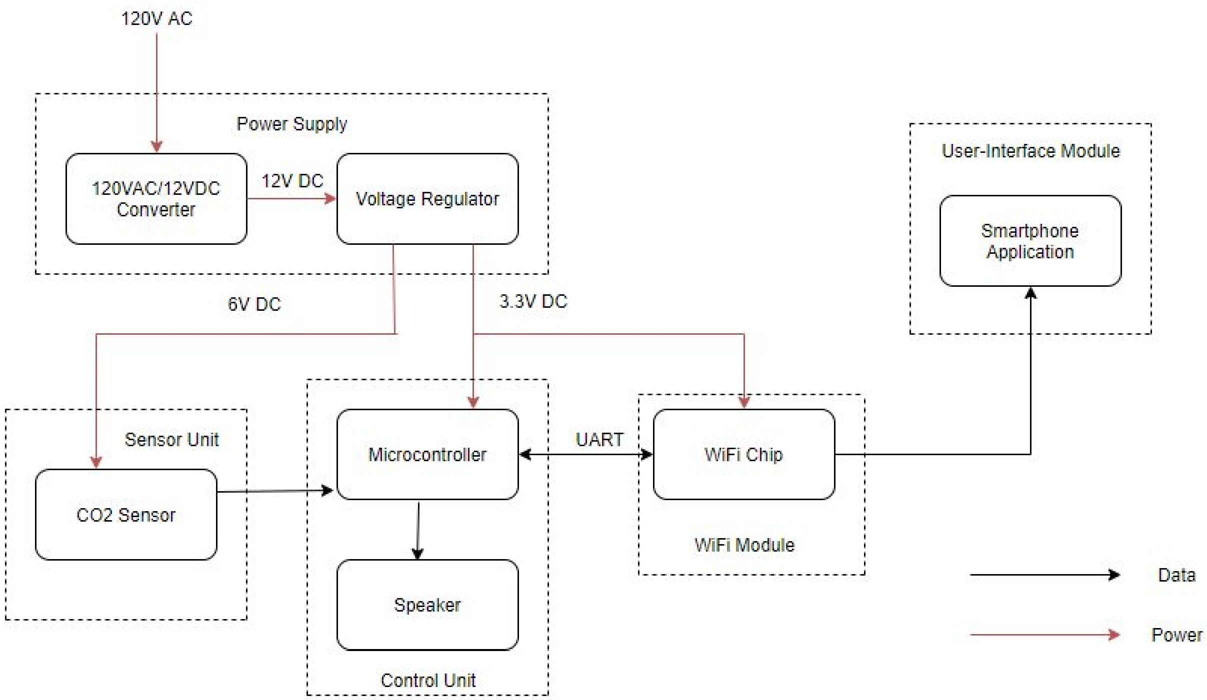

Fig. 2. Device block diagram. Black lines indicate data transfer and red lines indicate power transfer.

2.2 Power Supply

The power supply will power the entire circuit and its components. It will convert the wall AC voltage to DC voltage levels suitable for the operation of different hardware components. It also has a switch that allows the user to turn the device on or off.

2.2.1 120V/12V AC/DC Converter

The AC/DC converter steps down the 120V AC wall voltage to a suitable 12V DC level for the input for the voltage regulator. This consists of an off-the-shelf AC adapter that is rated at 12V/1.5A.

2.2.2 Voltage Regulator

The voltage regulator takes in the 12V input from the AC/DC converter and outputs a constant 6V and 3.3V output. The 6V output voltage powers the CO_2 sensor. The 3.3V output voltage powers the microcontroller and the wifi chip. A capacitor is needed on the input and the output respectively for stability.

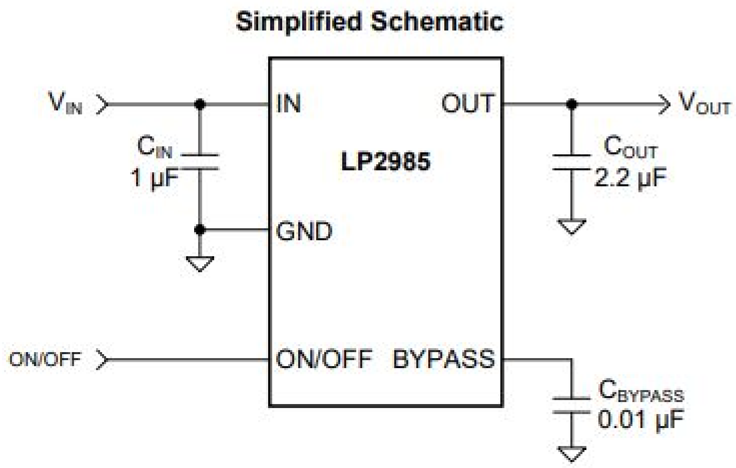

Fig. 3. Voltage regulator and input and output capacitor configuration [4].

Requirement	**Verification**
6V voltage regulator outputs a 6V +/- 0.1V output with at least 200 mA.	1. Connect a DC power supply into the input of the voltage regulator. 2. Connect a digital load to the output of the voltage regulator. 3. Connect an oscilloscope probe to the output of the voltage regulator. 4. Turn the DC power supply on to 12V. Set the digital load to 200 mA. 5. Verify that the voltage stays within an acceptable range and that the output current meets the expected value.
3.3V voltage regulator outputs a 3.3V +/- 0.3V output with at least 250 mA.	1. Connect a DC power supply into the input of the voltage regulator. 2. Connect a digital load to the output of the voltage regulator. 3. Connect an oscilloscope probe to the output of the voltage regulator.

	4. Turn the DC power supply on to 12V. Set the digital load to 250 mA. 5. Verify that the voltage stays within an acceptable range and that the output current meets the expected value.

2.3 Control Module

2.3.1 Microcontroller

The microcontroller consists of an ATmega328P-PU that converts the analog signal from the CO2 sensor to digital via an ADC. It then takes the digital data, computes the CO2 concentration, and send the data to the wifi chip via UART.

Requirement	**Verification**
Gain of ADC shows correct value and does not have bias.	1. Connect a 3.3V DC input from the DC power supply to the Vcc pin of the microcontroller. 2. Connect another DC power supply to the pins PB3 and PB4 3. Set gain as x5 and compare the voltage displayed on the ADC and the voltage meter by manually multiplying the output of the voltmeter by 5. 4. Recalibrate the gain to reduce the bias
Microcontroller calculates CO2 concentration given input CO2 sensor voltage to within +/- 10% error of expected value.	1. Connect a 3.3V DC input from the DC power supply to the Vcc pin of the microcontroller. 2. Connect another DC power supply to the pins PB3 and PB4 3. Set a known input voltage by the DC power supply 4. The microcontroller should compute the correct associated CO2 sensor

	value that is expected within 10% error. 5. Repeat this process for different input voltages within the expected range of the CO2 sensor.

2.3.2 Speaker

The speaker is connected to the microcontroller and is an audible indication of the CO2 concentration that the device detects. If the threshold is exceeded, the speaker produces an audible warning sound that indicates that the towel is noticeably dirty and that the user should clean or change it.

Requirement	**Verification**
The speaker produces a sound when the CO2 concentration threshold of 1000 ppm is detected by the microcontroller.	1. Connect the speaker to one of the analog output ports of the microcontroller that is connected to a 3.3V DC power supply. 2. Send a dummy signal value that exceeds the set CO2 threshold to the microcontroller. 3. Note that the speaker should produce a sound that is audible from 1 meter away for one second indicating that the value is too high.

2.4 Sensor Unit

2.4.1 CO2 Sensor

The CO2 sensor detects the concentration of CO2 in the surrounding air and outputs a voltage that is inversely proportional to it. The MG811 CO2 sensor uses an electrochemical reaction to output a voltage that decreases as CO2 concentration increases.

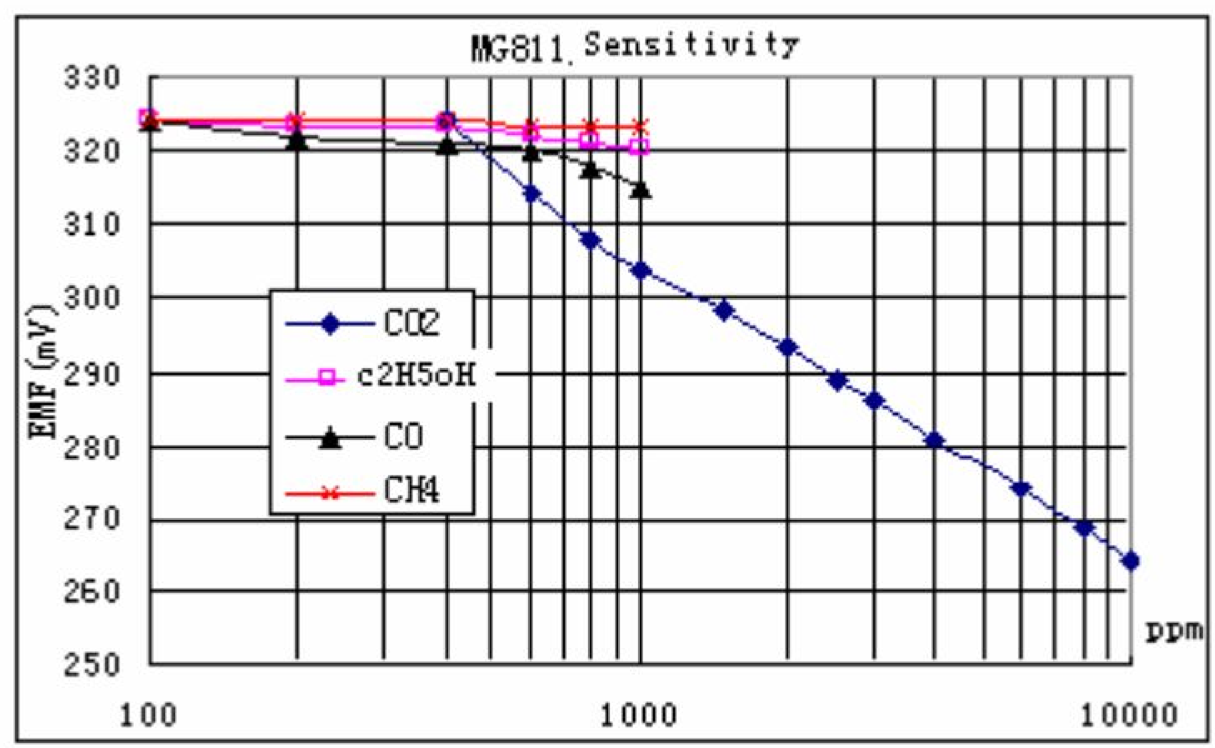

Fig. 4. Output voltage response of MG811 to various gas concentrations. [5]

Requirements	**Verification**
The CO_2 sensor should generate a voltage within a tolerance of +/- 10% of the expected output voltage at a given CO_2 concentration.	1. Connect a DC power supply of 6V to the input pin of the CO_2 sensor 2. Place an oscilloscope probe on the output pin of the CO_2 sensor. 3. Measure and note the surrounding CO_2 concentration by using another air quality detector. 4. Measure and note the output voltage of the CO_2 sensor. 5. Compare the measured output voltage to the MG811 datasheet to determine the CO_2 concentration. 6. The resulting CO_2 concentration should be within +/- 10% of the air quality detector measured CO_2 concentration.

2.5 WiFi Module

2.5.1 WiFi Chip

The wifi chip communicates with the microcontroller via UART and connects to the user's home wifi. It is then able to send CO2 concentration values to connected devices via this manner.

Requirement	**Verification**
The WiFi module should successfully connect to the user's home WiFi.	1. Connect a 3.3V DC power supply to the Vcc input of the WiFi chip. 2. Attempt to connect the WiFi module to the home network using the microcontroller. 3. Pinging a known device on the network should result in a response, indicating a successful connection.
The WiFi module should successfully send data through the user's home WiFi.	1. Connect a 3.3V DC power supply to the Vcc input of the WiFi chip. 2. Send dummy data from microcontroller to WiFi module via UART. 3. WiFi-connected smartphone device should be able to receive sent data via the smartphone application.

2.6 User-Interface Module

2.6.1 Smartphone Application

The smartphone application allows the user to connect to the device via wifi and read the current CO2 concentration that it is detecting. A warning is displayed if the concentration is above the threshold value. The application can also affect the control unit by resetting the microcontroller in case of faulty operation or disabling the use of the speaker.

Requirement	Verification
Application generates a color code indicating the level of CO2 concentration that is detected.	1. At the debugging phase of the application, write test cases assigning dummy CO2 concentrations ranging from 0 to 1500. 2. A value between 0 and 400 should result in a white color code, indicating that the data is incorrect or the device is operating incorrectly (household concentration shouldn't normally be below 400ppm). 3. A value between 400 and 800 should result in a green color code, indicating normal household CO2 levels. 4. A value between 800 and 1000 should result in a yellow color code, indicating slightly elevated CO2 levels. 5. A value greater than 1000 should result in a red color code, indicating CO2 levels that may indicate the presence of bacteria or mold on the towel, requiring it to be replaced or washed.

2.7 Physical Case

Our external casing will have to be robust and able to withstand the humid conditions of a bathroom. Our casing will have two main components, the main body which houses all of our electronics and the external clips which keep the unit attached to a towel rack. This case can be 3D printed for the purposes of our prototype and partially coated with a hydrophobic spray. However, for mass production, injection molding plastic would be more ideal. The external arms will allow the case to easily attach to a towel rack. These will be printed using a flexible plastic which may be pried open by the consumer's hands and placed around a towel rack.

2.8 Tolerance Analysis

The most critical part of this device is the microcontroller taking the CO2 sensor output voltage and interpreting an accurate enough CO2 concentration from the data it is given. ADC resolution is not of concern since the relative voltage drop of roughly 25mV is relatively large for a concentration increase from 400 to 1000 ppm and the increase in concentration should be noticeable. The main concern is in the effect of other factors in the output voltage of the CO2 sensor. Since it is dependent on an electrochemical reaction, other gases also slightly affect the result including carbon monoxide (CO) and ethanol (C2H5OH). In high enough concentrations which are quite unlikely for household use, this could result in a drop of up to 6mV.

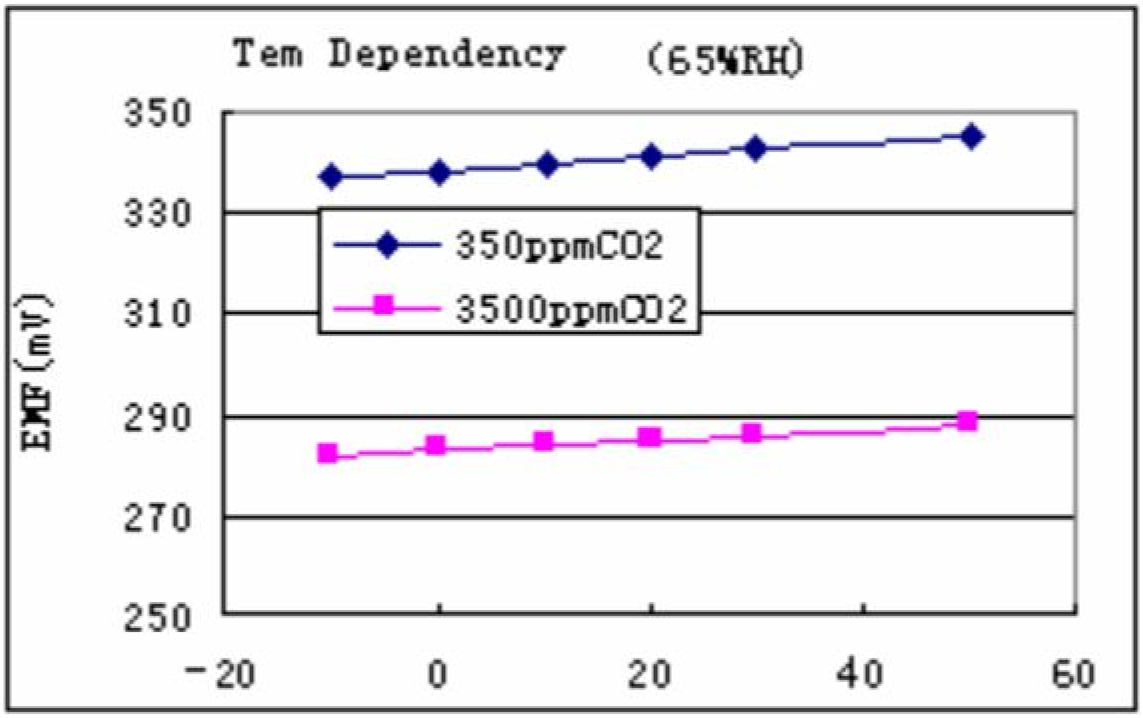

Fig. 5. Output voltage response of MG811 to ambient temperature. [5]

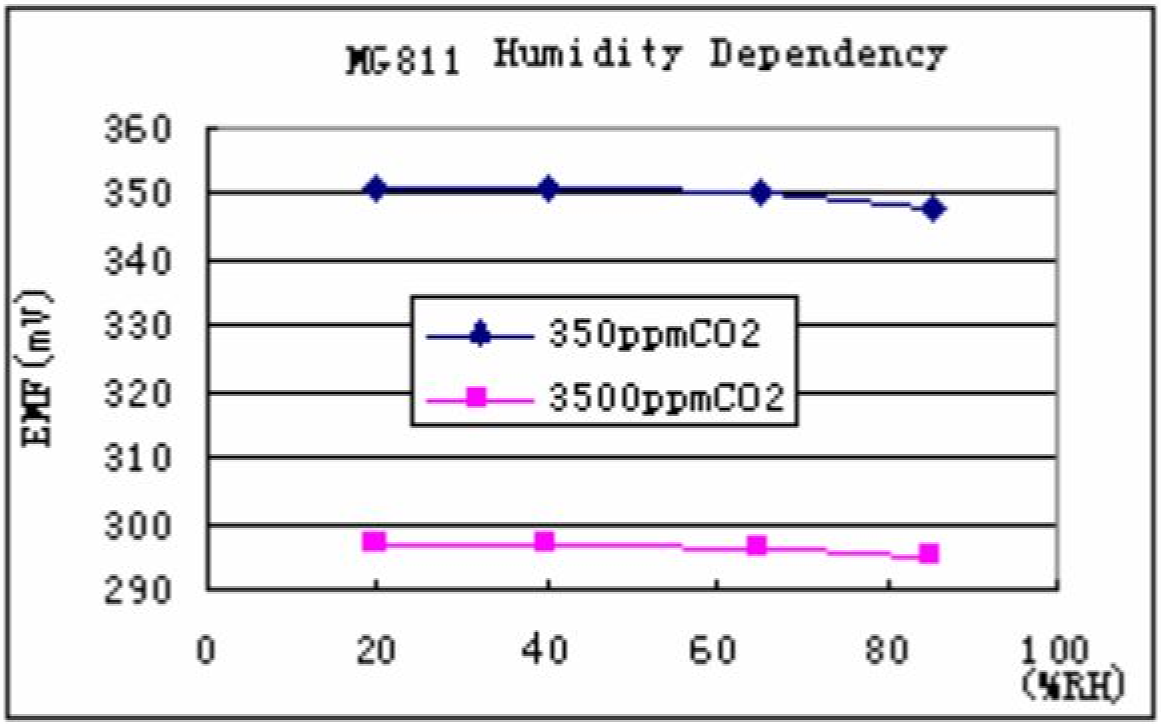

Fig. 6. Output voltage response of MG811 to ambient relative humidity. [5]

Besides gas concentration, humidity and temperature can also affect the resulting output voltage. A slightly higher temperature than room temperature results in about a 4mV increase while a relatively large relative humidity of 85% results in about a 3mV decrease. These conditions are expected in a shower-like bathroom environment where the unit could be used. Overall, this results in a maximum expected change of a 5mV decrease. Around 1000 ppm where the output voltage should be 305 mV, it is instead 300 mV, resulting in a 1.6% error, well below the stated threshold of 10%. The CO2 sensor then contributes, at worst, 10% of the maximum allowable error, an allowable threshold.

3. Project Differences

3.1 Overview

The original towel bacteria project (SP 2019, Team #25) focused on eliminating bacteria through the use of an enclosed cabinet and ultraviolet LEDs. Rather than identifying bacteria, this project assumed the bacteria were already present and sought to eliminate it. The use case for the consumer was to use the bacteria-eliminating cabinet after each towel use.

Our project focuses on creating a detective solution. Instead of eliminating the bacteria itself, our product detects when bacteria have reached potentially dangerous levels. While this may seem like an inferior solution since it detects but doesn't clean, it has certain trade-offs that make it advantageous over the original solution. The UV LEDs can be rather expensive for a consumer product. As a result, we sought to eliminate these in order to reduce costs. Additionally, having a completely enclosed cabinet system results in a bulky and large box that one must place in a tiny bathroom. This poses a challenge for most homeowners. So our solution fits in with existing infrastructure, the towel rack, and it relies on currently available appliances, like washing and drying machines, to disinfect the towel. By eliminating some of the original features, our product provides a minimalist solution to disinfecting towel bacteria in a safe way.

3.2 Analysis

The main advantage that this design has over the original team's design is cost. Much of the original design's cost is the polypropylene and UVC LEDs, resulting in an overall prototype cost of $326.97. Comparatively, the new design has a prototype cost of $102.66, roughly 31.4% of the original cost, resulting in a more competitive starting price point for the consumer market. It is also comparatively smaller since its volume is mainly occupied by the hardware parts while the original consisted of a large housing that could fit an entire hanging towel in it and the UVC LED array. This could be advantageous since bathroom space is often small and bulky objects could prove detracting to the relative performance of the device. The original device has a comparatively larger power consumption at 25W while the new device has a maximum power consumption of 6W, resulting in much lower operating power.

4. Cost and Schedule

4.1 Cost Analysis

Our development costs assume a developer salary close to $95,000 which is the ECE Illinois average for computer engineers right after graduation. This roughly translates to $50/hour. Our prototype will take roughly 10 weeks to complete with three people working for 10 hours each week. The total labor cost to develop this prototype comes out to:

$$\$50/hr \ * \ 2.5 * 10 \ hr/week \ * \ 3 \ people \ * \ 10 \ weeks \ = \$37,500$$

The component costs for the prototype are depicted below:

Component	**Cost (Prototype)**	**Cost (bulk manufacturing)**
VEL18US120-US-JA (AC adapter)	$12.75	$10.71
L7806CD2T-TR (6V voltage regulator)	$0.77	$0.30
LP2985IM5X-3.3/NOPB (3.3V voltage regulator)	$0.79	$0.28
C315C104M5U5TA7303 (0.1μF capacitor) x5	$1.20	$0.25

MFS201N-9-Z (switch) x2	$2.30	$1.18
ATMEGA328P-PU (microcontroller)	$2.08	$1.73
MG811 (CO2 sensor)	$49.75	$39.75
SP-1504 (speaker)	$1.92	$1.07
PCB (PCBWay)*	$23.00	$1.50
AMW007 (WiFi Chip)	$6.10	$5.78
Casing	$2.00	$0.50
Total	$102.66	$63.05

*PCB prototype cost including shipping cost 18$, minimum order quantity of 5

4.2 Schedule

Week	**Mike**	**Josh**	**Yoon**
Week 1	Research components and order	Research components and order	Research Microcontroller and order
Week 2	Layout Design document	Design Circuit schematic and work on Design Document	Work on Design Document
Week 3	Design Document	Submit PCBOrder	Design Document
Week 4	Unit Test CO2/Humidity sensor components	Unit test power supply components	Unit Test Microcontroller/control module
Week 5	Begin integrating sensors with microcontroller	Begin integrating power supply with microcontroller and sensors	Unit test wifi module, begin app design
Week 6	Integrate power supply, hardware sensors, and microcontroller into one unit	Integrate power supply, hardware sensors, and microcontroller into one unit	Integrate power supply, hardware sensors, and microcontroller into one unit

Week 7	Integrate Wifi Module, Test our combined unit	Test our combined unit	Integrate Wifi Module, Test our combined unit
Week 8	Finish smartphone app	Test entire combined hardware unit	Finish Smartphone app
Week 9	Test the entire system (hardware & software)	Test the entire system (hardware & software)	Test the entire system (hardware & software)
Week 10	Present and Demo	Present and Demo	Present and Demo

5. Discussion of Ethics and Safety

Our product will certainly have associated safety and ethical concerns since it is operating in a humid environment with electrical components, detecting harmful CO2, and preventing the spread of disease-causing bacteria. Operating in a humid and wet environment poses significant challenges to electrical components. Failure to properly secure and enclose a device in such an environment can result not only in electrical failure but also can pose a safety risk to those using the device. The IEEE Code of Ethics states as its first principle “to hold paramount the safety, health, and welfare of the public” [4]. In order to abide by this principle, we will enclose our device in a waterproof casing, spraying our most vulnerable components like our PCB with a hydrophobic coating, and providing caution labels on our packaging to prevent improper use like submerging the device in water.

Another key concern is how well our solution can detect CO2 produced by bacteria and mold. CO2 electrical sensors do have tolerance for error. As a result, we will provide a clear and honest description of these limitations on the product’s packaging. This is in line with the third IEEE principle “to be honest and realistic in stating claims” [6]. We view this as necessary since we don’t want our sensor to be interpreted and used solely as a life-saving CO2 detector when it is not.

We also want a safe amount of voltage to be delivered to our device. This is of the utmost importance when operating in a wet and humid environment. Here, our voltage regulator will be key to mitigating any risk to users of this product. We will require a safe voltage step down from our power supply, and we have to extensively test this vital component.

Bacteria and mold can often grow on damp bath towels, and these substances can pose significant health risks to humans. Because of this, it is vital that our sensors work properly in detecting bacteria. Having disease-causing bacteria go undetected can be harmful to users especially if they have a high level of confidence in our device working. The risk of our device giving false positives can be lessened with extensive unit testing. It can also be mitigated by including a cautionary label on our product packaging.

6. Citations

[1] Abrams, A. (2017, September 21). Your Towels Are Way Dirtier Than You Think. Retrieved April 29, 2020, from http://time.com/4918624/wash-towels-bacteria/

[2] T. Hoskins, *Monitoring mold by measuring CO2*, Iowa Farmer Today, Aug. 2009. Accessed on: Apr. 3, 2020. [Online]. Available: https://www.ars.usda.gov/plains-area/mhk/cgahr/spieru/news/modeling-erosion-of-particulate-matter/monitoring-mold-by-measuring-co2/

[3] *"Smelly Washer Towel Cleaner, 24 Treatments,"* Accessed on: Apr. 3, 2020. [Online]. Available: https://www.amazon.com/Smelly-Washer-All-Natural-Laundry-Treatments/dp/B0032TW6I0

[4] Texas Instruments, "LP2985-N Micropower 150-mA Low-Noise Ultra-Low-Dropout Regulator in a SOT-23 Package Designed for Use With Very Low ESR Output Capacitors," LP2985-N datasheet, Mar. 2000 [Revised Dec. 2016].

[5] Hanwei Electronics Group, "MG811 CO2 Sensor," MG811 datasheet.

[6] "IEEE Code of Ethics." IEEE.org. https://www.ieee.org/about/corporate/governance/p7-8.html (retrieved Feb. 13, 2020).