ECE 445

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Project Proposal

UV Disinfecting Robot for Tabletops

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1. Introduction

Objective

When restaurants are extremely busy, employees focus their attention on taking orders and seating customers, not disinfecting tables. Fully disinfecting tables takes a lot of time which some employees might not have. We have all seen employees quickly wipe down tables for visible crumbs and mess, however are they truly giving enough time to kill germs and bacteria? In a study that swabbed 10 restaurant tables, E-Coli was isolated from 20% of those tables [1].

This issue of not disinfecting surfaces does not only pertain to restaurants-- hospital surfaces also fall into this issue. For hospitals in the United States, it was reported that more than 50% of hospitals have shortages in Environmental Services personnel. It was also shown that among these personnel there was often confusion about who is responsible for cleaning different areas of the hospital [2]. Industries that must obey strict health guidelines are failing due to the lack of people. With the current outbreak of COVID-19, there is going to be a higher need for new technologies to disinfect areas. Without a reliable source that continuously disinfects areas, outbreaks such as covid-19 will be a continuous issue.

Our goal is to design an autonomous robot which will disinfect restaurant tables using UV light. We will be using a tri-wheel robot that a user can place on the corner of the table. This robot will move around the table, ensuring that 95% of the table is hit with UV. We will also ensure that this robot is safe to use around people. We will include sensors that detect when this robot is not on the table so the UV light is deactivated. The robot will also be designed so less than 1 uJ of energy leakage can be detected at .3 m away from the device.

Background

A company called UVD robots[3] designs robotic based UV disinfection solutions for hospitals. Although these robots are effective in killing bacteria in hospital rooms, we are aiming to market our design for smaller applications. We hope that small restaurant owners will be able to use our design to disinfect surface areas, such as tables. Our attempt of a UV solution will also be cost effective compared to similar technologies on the market. [3]

Our autonomous robot is essential to alleviate pressure from employees by fully disinfecting tables of bacteria and germs. If an employee only has time to wipe up crumbs and garbage after customers leave, the employee can set our device on the table to finish the disinfecting part of the task.

High-Level Requirements

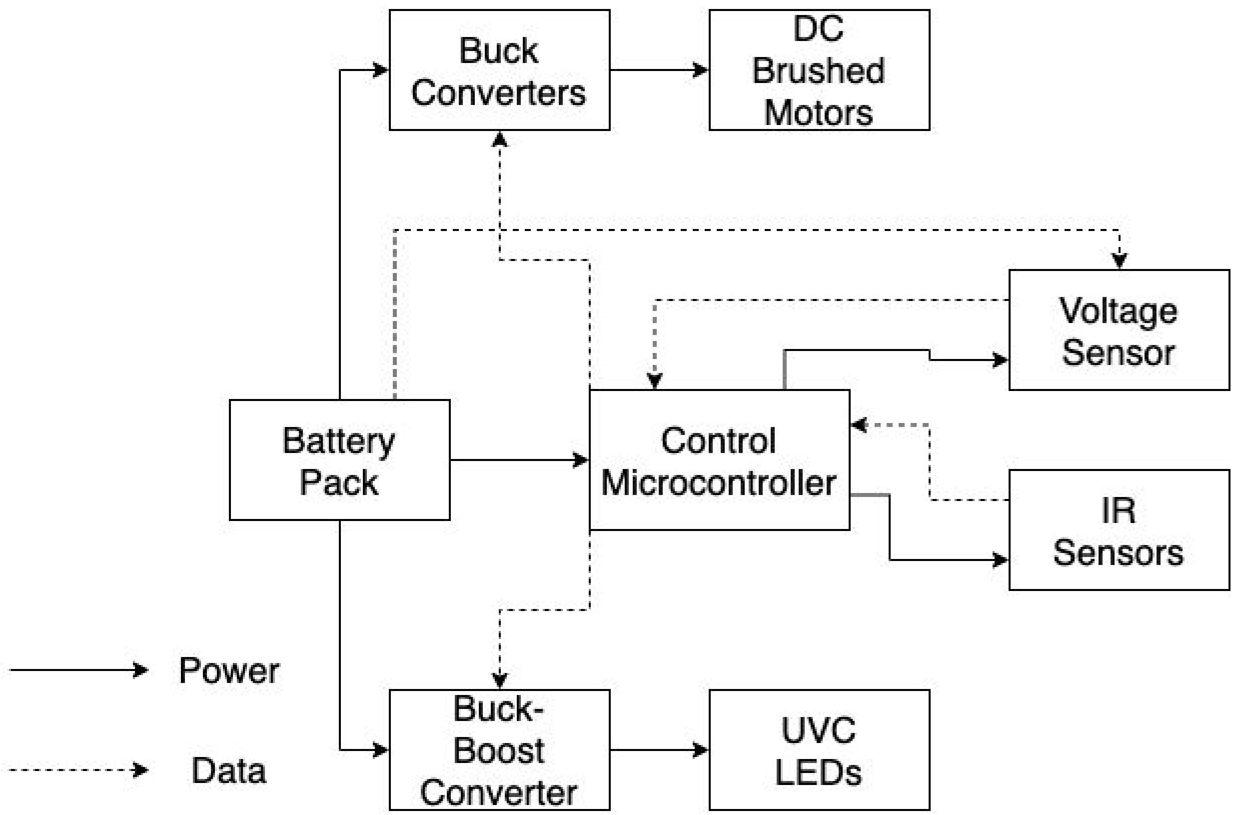
- The autonomous robot must be able to use sensors to determine when it gets within 5 cm of the edge of the table and change its trajectory to remain on the table..
- The robot must be safe to operate near customers and emit less than 10 uJ at .3 m away from the device.
- The autonomous robot must shine UV light on 95% of a rectangular table.

Difference from Previous Design:

Our design was inspired by Team 60’s project called Self-Cleaning Table. Their design focuses on wiping down the table of small food debris and spills. Although they mention their design disinfects the table, we feel our design will improve this aspect of the overall task of cleaning a table. Team 60’s design is more mechanically intensive. They have a physical arm moving from one side of the table to another which sprays the table with disinfectant solution, squeegees the table, and then dries the table. With our design, we aim to disinfect the table without any chemical solution. We also want to improve the scalability of this robot by moving the design to an autonomous vehicle that moves around the table. Although our design would focus on rectangular tables, it will be fully scalable to tackle other shape tables unlike team 60’s design.

2. Design

Block Diagram



Battery Pack - This will be a 3 cell Lithium ion pack that will power the device. Since this is a 3 cell pack, it will have a voltage range between 9-12.6v. We are looking at powering 10 LED modules, 2 DC motors, and an Arduino for about an hour. This gives us an estimated capacity of 13 Ah for a worst case scenario. Realistically, the motors will not be running constantly at full throttle, so a more realistic range would be 10-12 Ah.

DC Brushed Motors - This is the primary method by which our robot will move. We are using DC Brushed due to their ease of control and their low cost. These will be controlled by the attached Buck Converter, which will allow for precise speed control. These motors are rated for 12 v and 1 A.

UVC LEDs - This is our primary tool for disinfecting a surface. UVC is a high energy ultraviolet radiation that is capable of destroying DNA and RNA [4]. This is what allows the LEDs to kill viruses and bacteria on a surface. The biggest concerns we have would be to make sure that we are both dousing the surface with enough radiation to disinfect and preventing a significant amount for radiation from leaking out. We would be using some control algorithm to ensure surface coverage. To prevent radiation leakage, we would use some sort of covering around[https the rim of the robot to block the UVC light and prevent it from escaping.

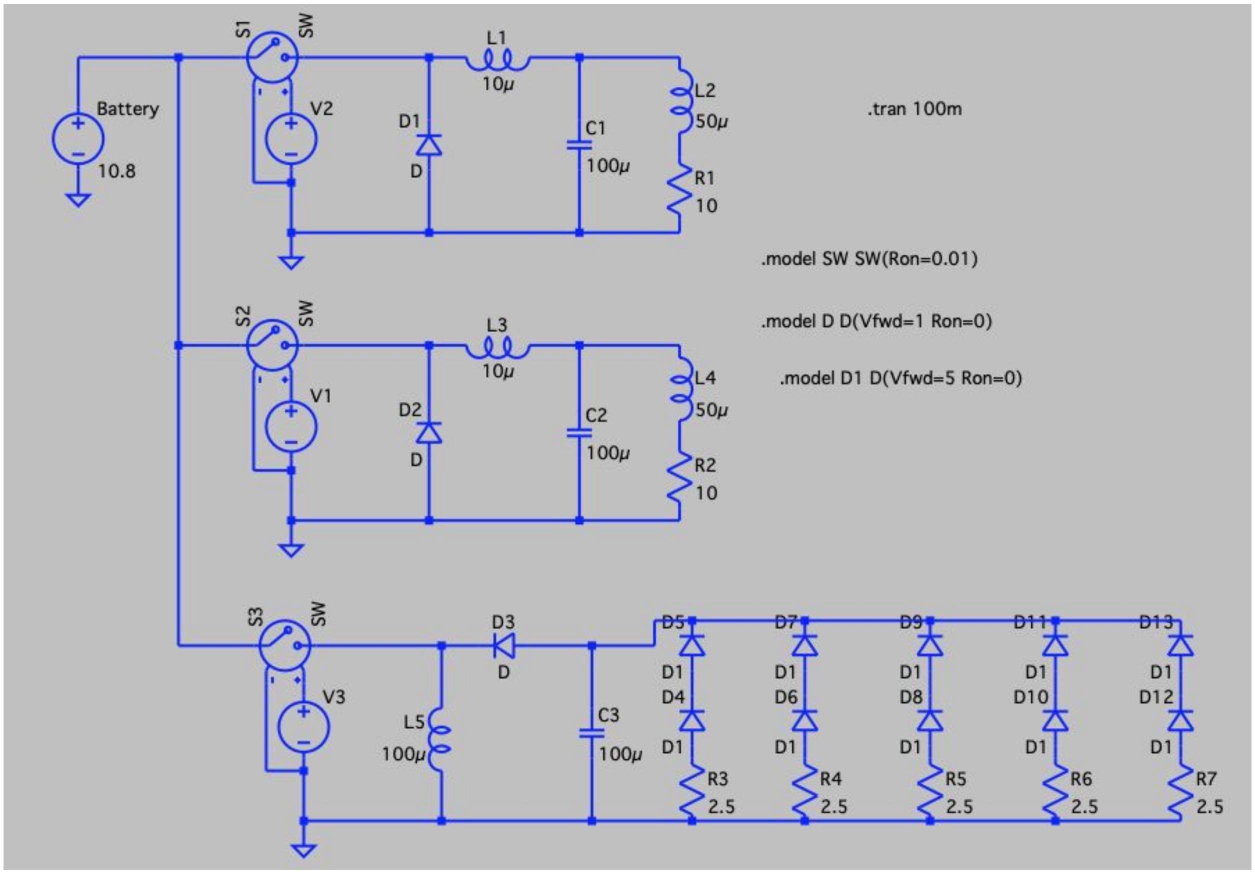
Buck Converters - This is a simple switching converter that allows a DC voltage to be efficiently stepped down to whatever voltage is needed. This is the intermediary between the controller and the DC motor. These converters will be rated to output at least 0-10 v +/- 10% along with being able to supply 1 A +/- 20%.

Buck-Boost Converter - This is used to precisely control the voltage being placed on the LEDs. Two LEDs are placed in series for each stack to improve the efficiency of the device. The problem is that the battery voltage can vary over a fairly large range. This range runs too much current through the LEDs when the battery pack is charged, but the LEDs fail to turn on when the pack is discharged. The Buck-Boost Converter allows for a precise voltage to be placed on the LEDs regardless of what voltage the battery pack is at. These converters will be rated to output at 11 v +/- 10% along with being able to supply a max of 3 A - 20%.

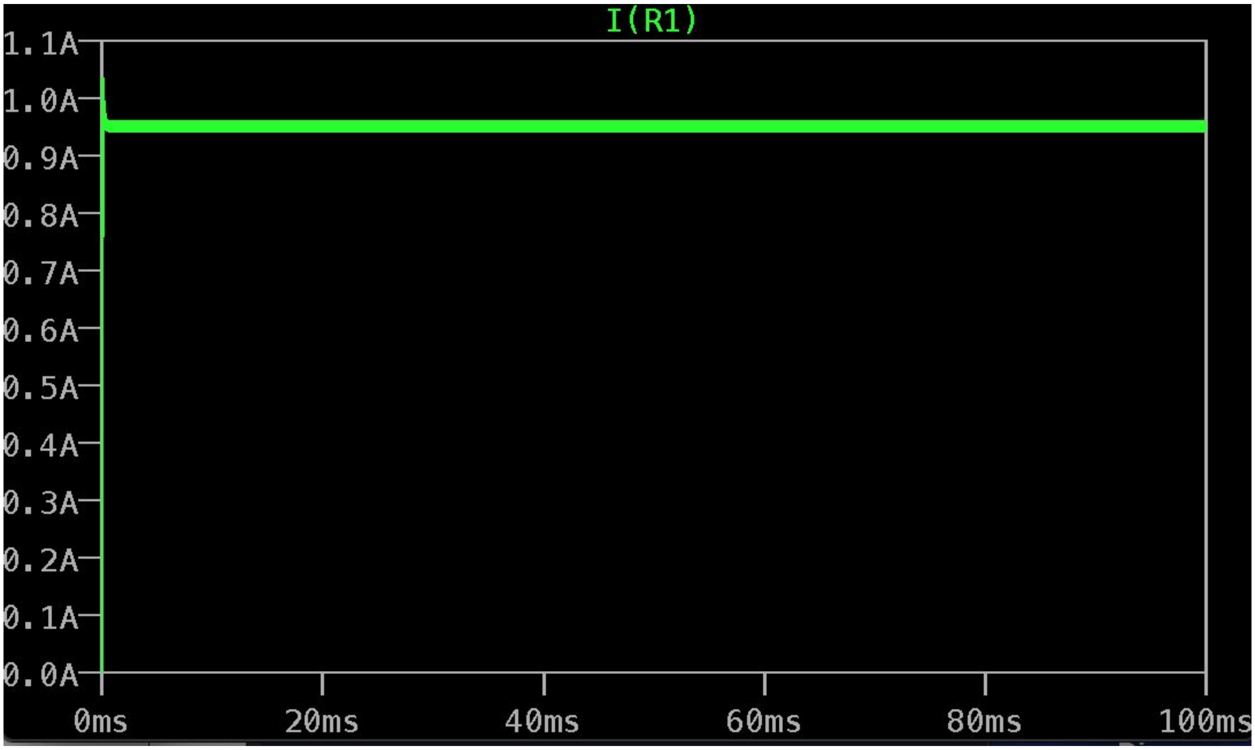
Voltage Sensor - This is used to estimate the energy left in the battery pack and also to adjust converter duty cycles as needed. Is especially important for current control in the LEDs and safely shutting off the robot at the specified voltage minimum.

IR Sensors - This is used to determine the table edges and to judge if the robot is still on the table. We do not want the robot to drive itself off of a table, therefore the IR sensors will be used to detect when the robot is about to drive off the table. We can also use these sensors to determine if the robot has been picked up off of the table. This is important for safety reasons due to the UVC light. By having this information, the robot can shut off the LEDs when it determines that it was picked up off the table. This might be switched with an ultrasonic depending on usability.

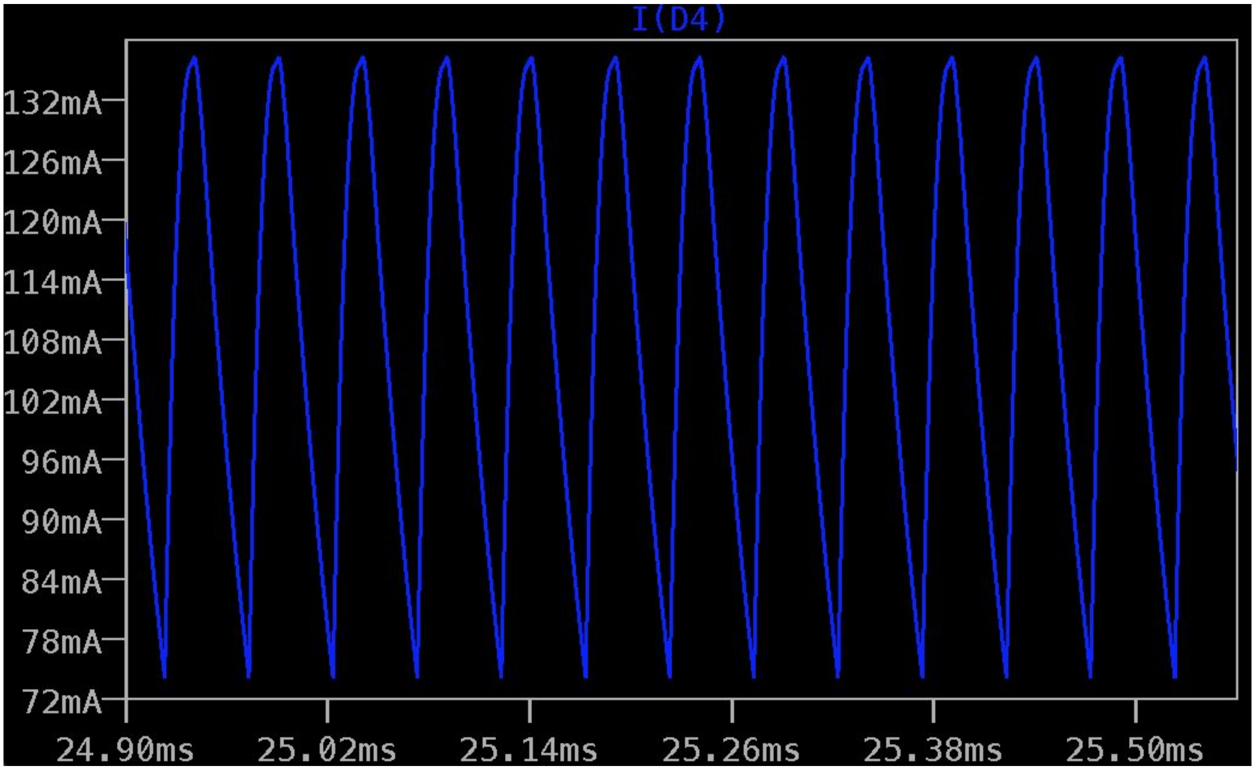
Circuit Diagram



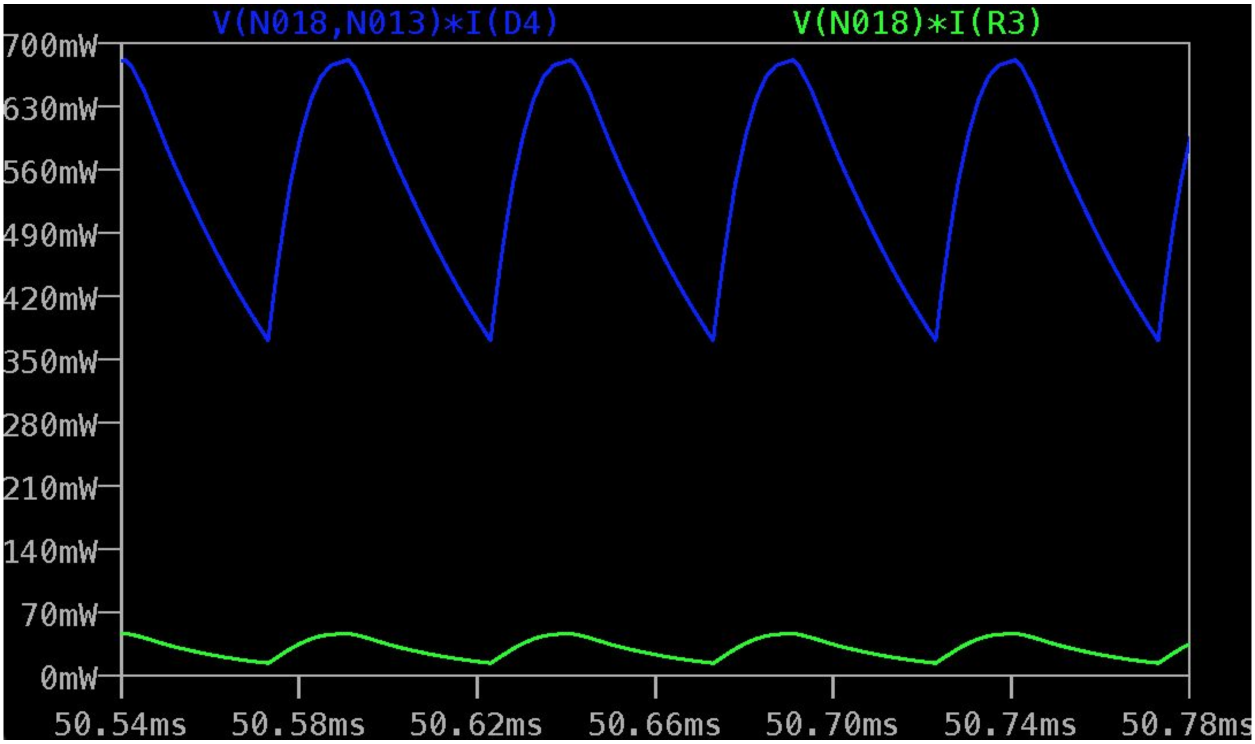
This is the electrical schematic for this design. The top two nodes are stand-ins for the DC Brushed Motors. It was difficult to find exact values for the internals to the motors so I had to make an educated guess. The IV curve and the steady state current through the motors should be comparable to that of the actual component. As shown, the buck converters are attached to each motor to allow for independent voltage control. The bottom node is the LED array. As shown, there is an attached buck-boost converter that precisely controls the voltage leading into the LEDs. Some simulations of the circuit will be shown below.



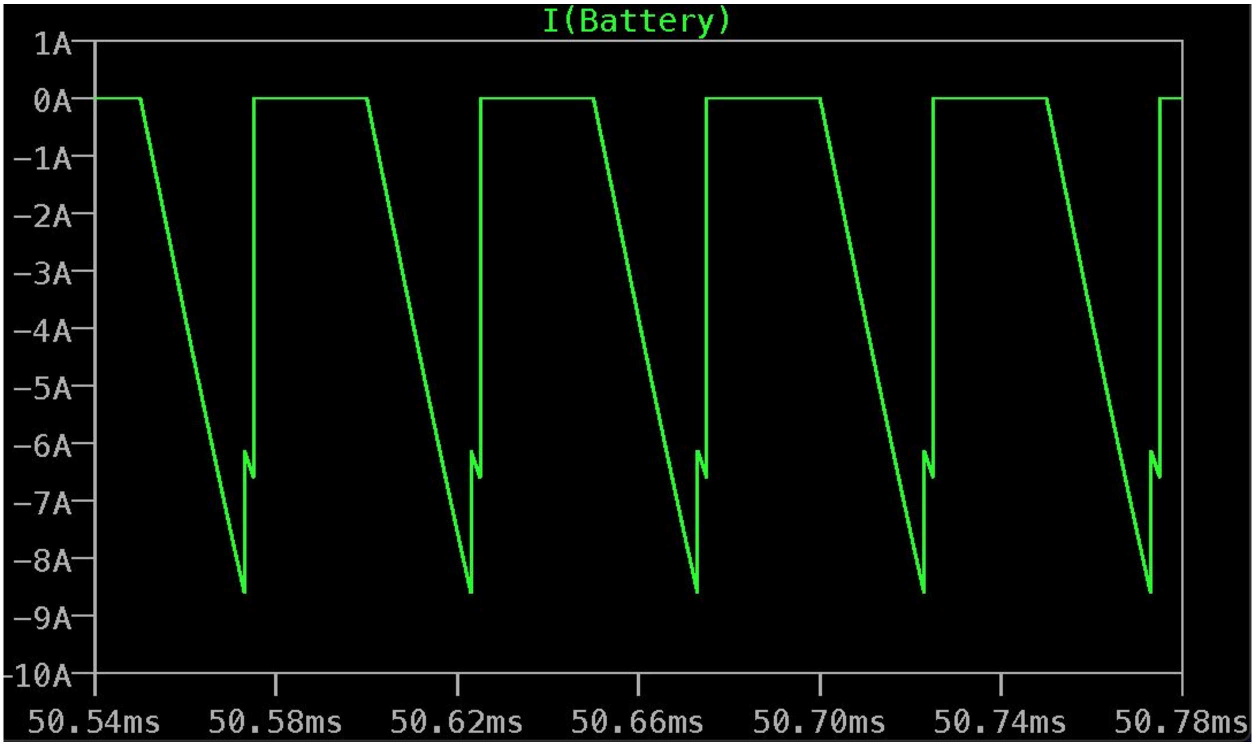
This is the simulation of the current into the motors. This falls roughly in the ballpark of what we would expect from our motors. This is less important on its own due to the estimated nature of our motor parameters, but is useful for determining load on the battery pack.



This is the estimated “safe” levels of current that we would be able to push into the LEDs. This current ripple stays below the absolute rating of 150 mA and gives us an average of around 100 mA. We may be able to push this higher as needed, but we currently do not think the trade off will be worth it.



This chart shows the power consumption for a single LED vs the current limiting resistor, which is what led to the double LED design. Originally, we were using a single LED vs the resistor and there were large losses through the resistor. By doubling up, we not only required less components, but our efficiency increased as the resistor was able to current limit two LEDs. The double LED design also pushed down the voltage drop on the resistor thus further dropping its power consumption.



This final simulation shows the current being drawn from the batteries. This 9 A spike is manageable from a single stack of lithium-ion batteries. Since we plan to add several stacks to improve the capacity of the device, this spike current is no problem for our pack. Also the average current should be around 2 A when this waveform is averaged along time, which makes the building for a two hour capacity easier. One thing to keep in mind is that the microcontroller was left out of this simulation. Realistically, the arduino will add anywhere between .5-1 A extra to our values. This was less interesting to model as it could operate directly from the battery pack ,so it will be added in as extra required current in the end. Therefore, the true steady state current will be somewhere around 2.5-3A.

3. Ethics and Safety

The safety aspects that are the most concerning with this project are unintentional exposure to UV radiation, exposure to ozone, and incomplete removal of viruses and bacteria.

As engineers, we must protect the public from known hazards; UV light poses many health risks. [5] There are three types of UV light: UVA, UVB, and UVC. Each operates at a different wavelength range, and UVC has the highest potential of hazard. All types can harm humans when exposure is sufficiently high. UVC light in particular can cause photokeratitis, an inflammation of the eye, and erythema, a burning of the skin. [6] Repeated exposure can lead to cancer as well. According to the World Health Organization, the best way to limit damage caused by UV light is to wear personal protective equipment (PPE), which includes UV-resistant clothing, goggles, and face sheilds, and have robust engineering controls and training. [7] Since our project will contain UVC LEDs, it is imperative that engineers working on the project are sufficiently protected with PPE. The robot itself should also have a mechanism to block the light from the nearby area or concentrate it only directly beneath the device. Additionally, it is necessary to place a warning label on the device clearly explaining that is emits UV light which poses hazards. [8]

We must hold the health of our users in high regard. [5] Ozone is highly reactive in the respiratory tract and can lead to degradation of the lungs and airways if inhaled, and overall is associated with increased mortality, according to the EPA. [9] Ozone can be generated from UV lights that emit light at a wavelength below 250 nm. [10] Therefore, it is imperative that our device does not emit light of that nature to minimize the amount of ozone the user is exposed to. It would be beneficial to advise the user to remain as distant from the robot while operating when possible to mitigate these negative effects.

According to the IEEE Code of Ethics, we must ensure that we are realistic when stating claims or estimates of the performance of our device. [5] The user must understand that no method of disinfection can remove 100% of pathogens, germas, viruses, or bacteria. Typically, ultraviolet germicidal irradiation (UVGI) measures reduction on the log-reduction scale. For example, a 3-log reduction would make the number of microbes 10^3 times smaller, or remove 99.9% of microbes. [11] Given current research on UVGI, we believe that we could reduce microbes with at least a 2-log reduction. [12] While a 99% reduction in microbes is certainly better than none, the user would need to understand the risk of possibly becoming infected with the stated targeted pathogens even after using our device.

Citations

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[4] D. Chitnis, G. Katara, N. Hemvani, S. Chitnis, and V. Chitnis, “Surface disinfection by exposure to germicidal UV light,” *Indian Journal of Medical Microbiology*, vol. 26, no. 3, p. 241, 2008.

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[12] M. Eickmann, U. Gravemann, W. Handke, F. Tolksdorf, S. Reichenberg, T. H. Müller, and A. Seltsam, “Inactivation of three emerging viruses – severe acute respiratory syndrome coronavirus, Crimean–Congo haemorrhagic fever virus and Nipah virus – in platelet concentrates by ultraviolet C light and in plasma by methylene blue plus visible light,” *Vox Sanguinis*, Dec. 2020.