FLASC

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***Abstract*  — The FLASC (Fast Liquid Analysis and Sanitization Container) is a single-device combination sanitizer and water clarity analyzer with the goal of eliminating microorganisms and providing an indicator of water quality from the convenience of a standard double-insulated stainless steel bottle. Sanitization is accomplished in three minutes using LEDs which emit UVC light (the most energetic form of ultraviolet light) to destroy pathogens on a molecular level while analysis is performed using a semiconductor laser to test for water clarity, an indicator of water quality according to the EPA [1]. The design utilizes wireless charging and communication to have a theoretically water-proof system.**

***Keywords — UVC, analysis, Bluetooth, sanitization, wireless charging, 3D printing.***

# I. INTRODUCTION

The project's final device contains several systems from a technology standpoint. It has wireless charging built into the cap to allow for convenient recharges of the device as well as improved water resistance. The optics system consists of UVC diodes for sanitizing biological contaminants and a feedback system to verify that sanitization is occurring. The bottle also has a laser and phototransistor for determining the content’s clarity as an indicator of water quality. The bottle has multiple LEDs that serve as status and result indications, a Bluetooth module for communications with a paired device, a reed switch to ensure the sanitizer and analyzer only runs in appropriate conditions, and an embedded microcontroller. All of the electronics are contained inside a bottle-top mounted device comparable in size to a soda can and which is compatible with other metal water bottles with similar cap designs. The Bluetooth functionality pairs with the CySmart app to display the battery percentage and a Boolean description of water clarity. The intent behind our design was to minimize costs and complexity for the user interface by eliminating a built-in screen and instead repurposing one the user likely already has while still maintaining functionality without said screen.

## II. SYSTEM OVERVIEW

This section will provide a macroscopic view of each sub-system and its contribution to the final project.

*A. Sanitization*

The goal of the sanitization component is to disinfect the tap water by elimination of microorganisms which are responsible for various waterborne diseases. There are different technologies being implemented around the world for sanitizing the water. We decided to go with 2 single UVC LEDs as it is a good compromise of cost, time and power efficiencies while remaining compact and easy to implement. It is important to know if the LEDs are providing enough power and sanitizing the water to be safe to drink. For this we have a feedback mechanism using a photoresistor to keep sure the LEDs are providing enough intensity.

### B. Water Clarity Analysis

The water clarity analyzer generates a Boolean metric for water clarity by shining a green (532 nm with 805 nm leakage) laser into the sample and measuring the intensity of light transmitted back into a phototransistor. An ADC reading is taken across a resistor in series with the phototransistor, resulting in lower values correlating with reduced transmission and thus poorer water clarity.

### C. Firmware

For this project it was desired that the firmware was simple, familiar, and reliable. The firmware is responsible for the proper functioning of project components, and it should also be virtually “bug-free” code. Since the code is a simple implementation, a singular blocking variable is used to prevent multiple device modes from occurring at a time. The firmware utilizes very brief interrupt service routines with the exception of the reed switch (which has highest priority), to ensure that the device is safe for the end user. A standby status loop was added to the main function which determines which device mode should run; whenever this loop finishes, the device enters low power mode to meet power consumption requirements. After sanitization is run, analysis is automatically executed, followed by wirelessly exporting the results. Additionally, logic is put in place so that if the cap is removed, or sanitization/analysis was not run, then the exporter will only report the battery percentage to the user and it will not show any results related to the quality of the water. Shown below in Fig. 1 is the flowchart for the main function:

Diagram

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Fig. 1. Firmware Block Diagram

### D. Embedded Hardware

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The embedded hardware is responsible for all system control logic, as well as a power source for other device sub-systems. The main controlling entity for the hardware is a microcontroller that can interface with other GPIOs, UART pins, as well as MOSFET gates to enable other components. To interface with other external components such as the UVC LEDs and the reed switch, two-pin connectors are included, to both make this connection reliable, and parts interchangeable. When designing this sub-system, It was important for the embedded hardware to be responsive, power efficient, and functionally sound.

The hardware also needed to be capable of relaying information to the user. Indicator LEDs are present to show various device modes throughout operation, as well as report water analysis results. There also are push buttons for the user to trigger different operating settings, and a Bluetooth module for wireless transmitting the data to an app. Fig. 2 shown below outlines the block diagram for the Embedded Hardware sub-system.

Diagram

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Fig. 2. Hardware Block Diagram

## III. SYSTEM COMPONENTS

This section will cover some of the integral components, and their overall contribution to the project.

### Bottle

The Triple Tree 17 oz water bottle from Amazon was chosen (ASIN B07Z4DWGF2) due to its stainless steel body and stainless steel cap (which was later discarded as machining and integrating it with components proved excessively complicated.

### Laser

The techhood 532nm 100mW laser (MPN 532nm-100mW) from eBay was chosen due to its characteristic wavelength's low absorption coefficient in water and (originally) minimal scattering from water, its low cost, and prepackaged brass housing which served as a heat sink. The laser also came with a driver to provide another layer of protection for the diode. The brass housing allowed the FLASC to avoid implementing active cooling methods or heat pipes for the laser.

### B. Phototransistor

The original implementation involved a photodiode due to its linear curve when reverse-biased, rapid response time, and extremely low dark current. During testing, however, it was determined that the photodiode's sensitivity was too low for our application, and a silicone phototransistor from uxcell (part number a19061200ux0041) on Amazon was used instead.

### C. Microcontroller

The TI MSP430FR5989 was selected as the microcontroller for this project. This was mainly because group members already had experience with this family of microcontrollers from previous courses. Team members also already had development boards that could double as debuggers for the project; thus, it was more cost effective to select a microcontroller from the MSP430 family. This particular family member for the microcontroller was selected because it offered a sufficient feature set including serial communication, low power modes, ample timing capability, and a large amount of GPIO pins. It could also run off of +3V which made it suitable for this application. Other microcontrollers in the family would have worked, but they would also have yielded an unnecessary abundance of unused pins.

### D. UVC LED

Due to our design’s portability, size, energy, and cost constraint using UVC LEDs is the best option for us. After going through various possibilities, we narrowed down to using two LEDs which match our product design and requirements. We had to look for wavelength, size, material, cost, power, and electrical requirements. Due to these constraints the 3535 LED Diode from eBay has proven to be the best match as they are cheap, easy to implement, small and does not require a lot of power to function it. The peak wavelength of the two LEDs are 265 nm and 275 nm respectively. The main reason to choose two LEDs is to have different wavelengths and high intensity. Different wavelengths have different sensitivities for DNA damage and infectivity and hence using two LEDs gives us a broader spectrum to work with. It is also a safety precaution because if one LED fails or burns out there is another to one to take care of sanitization by killing the contaminants.

### E. Photoresistor

After testing a photoresistor, phototransistor and a photodiode for the feedback loop, the best option was to go with the photoresistor as it had a broader range of difference in the value of voltage drop across it. Using the general photoresistor (2368-02-LDR2-ND from Digi-Key) applicable for 540 nm wavelength we decided to implement a fluorescent post-it note as a filter to increase the intensity of light from UVC for the photoresistor to get a larger difference in the voltages. This worked out perfectly for us having a feedback mechanism to check the UVCs with keeping the system compact and cost and energy efficient.

### F. Reed Switch

It was important to employ a safety mechanism in the device that would prevent users from accidentally engaging the UVC LEDs and green laser while the cap is removed from the bottle. We considered various options to realize this goal including a pressure-based switch and a sensor that operates from the Hall-effect. In the end, we settled for the magnetically operated type of switch because it would have fewer mechanical components that could malfunction. Between the Reed switch and the Hall-effect switch, the former was chosen due to the lower price and reduced idle current of the device.

For the implementation of a Reed switch that would draw as little power as possible over the course of a day, it was assumed that the majority of the time that the device spends turned on would be while it is properly in place on the bottle. Therefore, we decided to use a normally closed Reed switch that would pull the microcontroller GPIO pin to low in the absence of a sufficiently strong magnetic field, which would be when the device is removed from the bottle that has a magnet affixed to it. In the end we decided upon the “59025-4-T-02-A” Reed switch by Littelfuse Inc, due to its low cost, availability, and RoHS compliance.

### G. Bluetooth

The selection of Bluetooth modules was initially narrowed down to those that utilize the Bluetooth Low Energy (BLE) standard in order to maximize the battery life of our final design. Of the options that were available on the market, one company stood out for shipping modules pre-flashed with a working firmware that would handle the bonding process and receive data from the host microcontroller via UART; this company was Cypress, who had recently been acquired by Infineon. Again, we prioritized devices that were cheap, available, and RoHS compliant, which led to the selection of the “CYBLE-013025-00” unit.

Not only did the Cypress BLE modules come flashed with the “EZ-Serial” firmware, but there was a free application on both the Google Play and Apple App stores that was made by Cypress to connect and communicate with their products. This app is called CySmart and is able to scan for BLE devices, bond with them, discover services, display available characteristics offered by the module, subscribe to notifications/indications, and receive a payload of 20 bytes that is displayed in both ASCII and hexadecimal on the screen.

### H. Battery

The battery selection was made by first identifying the chemical composition that would best suit project needs. After initial searching, it was found that Lithium-ion and Lithium-Polymer batteries would best meet the energy density requirements for our device to last at least 10 cycles of sanitization, analysis, and data export. With the selected components for the UVC sanitizer, the green laser for analysis, the microcontroller, and the BLE module, the following values seen below in Table 1 were calculated as a power estimate for one cycle of usage.

|  |  |
| --- | --- |
| **Component (Part Number)** | **mAh consumed from 3.7V Battery** |
| Microcontroller (MSP430FR5989) | 0.16 mAh |
| BLE Module (CYBLE-013025-00) | 0.0086 mAh |
| UVC LED 1 | 9.55 mAh |
| UVC LED 2 | 9.55 mAh |
| Spectrometer Green Laser | 0.27 mAh |
| **Total** | **19.54 mAh** |

Table 1: Single Cycle Power Estimate

This estimate of power consumption was two orders of magnitude below the capacity of the 2,500 mAh battery that was selected from Adafruit. Not only was this component appropriate for the size constraints of our device but it allows a very comfortable tolerance for non-ideal leakage currents in order to meet our project requirements of lasting at least ten cycles within a day.

## IV. SYSTEM DESIGN

The project was broken up into five systems, each of which is discussed in focus in the following section.

### A. Housing Design

The housing was designed to be modular, allowing for rapid part modification with reduced waste. This proved vital at several points during the development process (most of all following the analyzer redesign). The final design consists of 6 printed pieces (which can be seen in Fig. 3) produced using PLA filament on Prusa i3 MK3S printers.

The upper 3 pieces (cap, battery level, and microcontroller level) were connected using 8 stainless-steel bolts (3-.50x12mm) from Ace Hardware creating durable, secure, removable bonds between layers. Layers were designed with matching through-holes and grip holes, and the cap had countersunk depressions for the screws.

The remaining 3 pieces (the surface-interface components and reed switch skirt) were connected by JB-Weld SuperWeld™, a light-activated superglue. While other substances (such as acetone) are more cost-effective for gluing PLA to PLA, this adhesive proved easier to handle. The surface-interface layer was printed in two pieces to simplify component mounting, and its upper portion and the reed switch skirt each had alignment plugs which inserted into corresponding holes in the microcontroller layer for rapid and accurate assembly.



Fig. 3. A full set of housing pieces. From the top left moving down columns: the surface-interface (SI), SI upper, SI lower, microcontroller section, reed switch skirt, battery holder, cap, and screws.

The housing weighs approximately 97 grams (including screws) and its assembled size is 90.5 mm in height with a diameter of 78.25 mm.

### B. Hardware Schematic Design

The first part of the hardware design involved technical investigation into every component for the project. This process involved studying datasheets and documentation to determine preferred/desired implementation into the overall schematic. From here a pin-out was constructed based on the microcontroller, as well as project requirements. Then the schematic was compartmentalized into device sub-systems. Only some of these sub-systems will be covered in this paper—for the rest of this information please consult the FLASC Final PowerPoint Presentation.

A SPDT switch was added for the user to be able to toggle device battery power. This circuit was achieved using a P-channel MOSFET (for handling battery current) that is switched on or off by a physical slider switch.

The +3V regulator was achieved by using a low drop out regulator that can supply enough current and a corresponding output voltage. The recommended implementation was also shown in the regulator’s documentation. The +6V regulator was created using TI’s power design tool “WEBENCH.”

Most optical components require MOSFETs for switching on or off. The laser diode circuit required basic circuit analysis to select resistor values and sizes that would meet desired current and power consumption requirements. Using the simplest CSYPP implementation in the CYPRESS module documentation, the schematic for the Bluetooth module was created. When creating the schematic for the microcontroller, several bypass capacitors were added for general noise filtering.

### C. Printed Circuit Board Design (PCB)

The PCB was designed using EAGLE software. Each component required consulting the datasheet for creating a footprint and symbol in EAGLE. In order to have adequate heat sinking, a 2-layer board with a ground pour on the top and bottom was utilized. The diameter of the PCB was decided based on project constraints related to the size/dimensions of the device housing. It was also important to have planes for the regulated voltages. So, a +3V plane on the top and bottom was used for the LDO regulator, and a +6V plane was designed in accordance with manufacturer recommendations for the switching regulator. Based on the layering design of the 3D housing, it was important to keep all PCB components related to the battery/power supply on top, and the connectors for optical components on the bottom of the board. Routing was performed manually (instead of using the auto-router tool) to ensure an optimized and logical board layout. There also are keep-out regions for the Bluetooth module antenna, and the screw holes. Other general design precautions were utilized such as: widening power traces, prioritizing traces on one layer of the board, and routing traces in logical busses.

### D. Analyzer Design

The original analyzer, as was mentioned previously, originally utilized a custom Raman spectrometer to observe scattering effects caused by contaminants held in solution. This design, which held a distinct section of the housing as a platform for a prism, slit, and set-screw adjusted mirrors, was abandoned after a critical component (a stepper motor) fused during testing. This was compounded by supply-chain failures delaying the two previously ordered units to a point past the final demo, and no alternative sources were discovered for the component.

In response, the system was simplified to a clarity sensor consisting of a green laser diode and a phototransistor. The system fires the laser into the sample and takes a relative power reading from the light transmitted back to the phototransistor. An ADC reading across a resistor in series with the phototransistor serves as the water clarity metric, with higher values correlating to greater water clarity.

### E. Sanitizer Design

After testing the components, the design for LEDs we went with is having two holes at the bottom of the bottle cap in our bottle cap design and let the LEDs shine through them without any interference. When we tried to combine the two beams to have only one light shining through the bottle cap which was our original design we ran into issues as it is difficult to combine beams using a beam splitter, diffraction grating, or dichroic mirror for LEDs with such a small bandwidth difference. LEDs have a broad spectrum and hence the intensity is not very bright. When we tested the power of UVC light after passing through a UV infused silica lens the power of the LEDs was reduced by approximately five times and this would not be applicable for our system. Hence creating an optical design for sanitization did not work well for us.

# V. DEVICE OPERATION

While our device was designed to operate in a fairly straightforward manner, some rules of operation will be established in the following sections to ensure that the device performs as intended.

## A. Sample Preparation

The user should select a source which is not, from a rudimentary firsthand analysis, dirty. Muddy, algae-infested, and obviously discolored samples should be avoided. The user should fill the bottle with less than 17 ounces of liquid- while the lower limit is less exact, the bottle should be filled at least halfway (8.5 oz) to ensure that the analyzer has enough sample to verify water clarity.

## B. General Device Operation

Once the sample is prepared, the user is now ready to utilize the FLASC for sanitization and analysis. Begin by turning on the device using the left-most slider switch. A red blinking light (reed switch polling mode) will be visible until the user places FLASC on top of the bottle and lines up the reed switch to the magnet on the bottle. Ensure that the red blinking light goes away before activating any standard device mode. A standard use case begins by pressing the sanitization button; however, the user could also press the analyze button to begin analysis or hold down the analyze button to export the data. It is also worth mentioning that if the battery is below 20% capacity, then the user will see five red blinks when attempting to start a device mode.

This example will now outline the standard use case. The user should place the bottle on a flat surface and then press the sanitize button. A yellow LED will come on, and then after 10 seconds, the UVC feedback system will activate. If the UVCs are not working properly, then the device will blink the red LED five times and then terminate sanitization. If this error occurs, then the UVCs of the unit need to be replaced.

Assuming that sanitization passes its UVC check, sanitization continues for a total time of three minutes. Once it finishes, the water clarity analyzer is automatically called. At this point the yellow LED is replaced by a blue LED. Analysis takes approximately two seconds, and then the clarity result is shown. FLASC will either blink red or green ten times depending on the analysis result. For example, ten green blinks indicates that the water passed the clarity test. From here, the device will blink blue five times as it tries to export the data.

For Bluetooth functionality, the user can decide if they want to connect their smartphone before the exporter is automatically called, or if they want to perform at a later and more convenient time. As long as the cap is not removed or FLASC is turned off, the user can export the results of the most recent sanitization at any time. To use the CySmart app, begin by ensuring that the FLASC is turned on and selecting a BLE device named “EZ-Serial”. Next, select the Gatt Database and the service. Subscribe to the “Write and Notify” characteristic and select indicate. Now, any data that FLASC tries to export will appear in the box titled “ASCII”. When looking at exported data it is important to mention that the only time the water quality will be sent is if sanitization (which also calls the analyzer). That is, if the cap is removed or if only the analyzer is called, the water quality will not be sent to the user’s smartphone.

## B. Using the App

The CySmart app is available from the app store on both Android and iOS. Once downloaded, the app will prompt the user to turn Bluetooth connectivity on. The app then automatically starts scanning for Bluetooth Low Energy devices and shows a list of the device names along with their MAC address. The user should scroll through the list and select the device named “EZ-Serial” in order to bond with the FLASC. The CySmart app will present two different profiles that are available from the EZ-Serial firmware, the one that will allow us to establish the data pipe is named “Gatt DB”. There is only one service within the GATT database which is shown as “unknown service”; the user should select this option to proceed.

Finally, the user will see the three characteristics available for data transmission with the device. For easiest use, one may simply select either of the first two characteristics that are labeled as having a “write” capability. Specifically, the two options for data transfer are the acknowledged data characteristic (UUID: 65333333-A115-11E2-9E9A-0800200CA101) and the unacknowledged data characteristic (UUID: 65333333-A115-11E2-9E9A-0800200CA102). Selecting either of these two and then pressing the “Indicate” (for the acknowledged) or “Notify” (for the unacknowledged) will complete the process for establishing the data pipe between the smartphone and FLASC. Whenever a transmission is sent from the FLASC, the 20-byte payload will be shown on the app interface in both ASCII and hexadecimal form. The ASCII interpretation will show the current battery percentage of the FLASC as well as the status of the water if it has been sanitized since the last time the cap was put into place.

## C. Charging

The Qi standard for wireless charging is completely automated and does not require any special setup. Once any Qi compliant charging pad has been plugged in to a power source, the user may simply remove the FLASC bottle cap and place it upside down on the charging pad. A red LED will begin blinking within the FLASC to indicate that charging has begun. In order to easily differentiate the red charging LED from the red LED blinking to indicate that the cap has been removed, the user may turn the device off from the power switch. This will also eliminate any unnecessary power expenditure while the device is charging.

Once the battery has reached a full charge, the FLASC will stop the blinking red light and show a continuous green light. It is also worth mentioning that some Qi standard charging pads on the market have their own LED indicator to help the user ensure that the best alignment has been made between the transmitter and receiver. If this is the case, the user should slightly move the position of the FLASC until the Qi charging pad shows a green light. In general, the user may use the inscribed device name “FLASC” as a guiding mark to try to center the unit on the pad for the best possible charging efficiency.

## D. Recommendations for Prolonged Lifetime

In order to conserve the battery life of FLASC, it is highly recommended that the user turns the device off when it is removed from the bottle from an extended period of time. Reed switch polling mode will create a minute but continuous current draw that can unnecessarily use up battery capacity.

Extra care should be taken when handling the FLASC. Since the optical components inside are fragile, try not to drop the device at any time. And, whenever either sanitization or analysis is running, the bottle (and FLASC) should remain stationary on a flat surface.

# VI. TESTING

The proceeding sections detail the tests performed for each respective system and its components.

## Analyzer Testing

The phototransistor generated ADC readings reliably exceeding 300 for clean water samples, which was subsequently chosen as the baseline required for water clarity.

The prototype's laser's characteristic wavelength was tested using a SpectraWiz® GREEN-Wave VIS spectrometer and found to be evenly split between 532 nm (green) and 805 nm (infrared). This is likely due to a low-quality high-reflective coating on the frequency doubling chip but did not severely impact the functionality of the prototype.

The laser's IV characteristics were not listed on the

seller's webpage and were experimentally verified using a simple DC-DC buck converter setup as a variable voltage source and multimeter.

The analyzer was tested using generic distilled water, straight coffee, and a solution containing 4 ppm fluoride contamination in water. The analyzer passed the distilled water and flagged both the coffee and fluoride solution. The fluoride solution was derived from 3M ESPE OMNI Gel™ and diluted to 4 ppm in distilled water.

## B. Sanitization Testing

The UVC LED's spectrums were verified using a UV spectrometer. The diodes were found to have central wavelengths of 274 nm and 283 nm for the 265 nm and 275 nm diodes. The linewidths of the two LEDs were also obtained and found to be 10 nm each.

The LEDs were tested using a power meter both as bare diodes and through a UV fused silica lens, resulting in ~0.5 mW for each diode when with a lens and ~2.5 mW bare.

The photoresistor feedback system was stepped through while in debugging mode and the ADC readings corresponding to successful and unsuccessful LED operation were obtained. An ADC reading of 0-1 corresponded with (simulated) LED failure while a reading of ~30 was indicative of successful operation. The threshold for a successful sanitization was set to 5.

The system's sanitization capabilities were tested using Watersafe bacteria strip tests and a sample of water from the UCF Reflection Pond. Following a three-minute sanitization the water, which had previously tested positive, tested negative, as is visible in Fig. 4.

A picture containing graphical user interface

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Fig. 4. Sanitization test results before and after sanitizing the pond water.

## C. Reed Switch Testing

The Reed switches were tested to ensure proper functionality by connecting them to a multimeter and taking resistance measurements with and without the presence of a magnet. The results were as follows:

* + Without magnet (Cap off bottle):  
    0.3 Ω
  + With magnet (Cap secured on bottle):  
    open circuit

## D. Bluetooth Testing

The Bluetooth Low Energy module was tested at a distance of 20 feet from the smartphone that it was connecting to. At this range, the Received Signal Strength Indicator (RSSI) was shown to be -79 dBm by the CySmart app and the data transmission was successful in less than a second after the button was held to export.

## E. Regulated Voltage Testing

Each regulated voltage was measured and its deviation from the ideal value was computed. This test confirmed that each regulator was working as desired and produced acceptable voltages for project functionality. The results of this test are shown in Figure x below:

|  |  |  |
| --- | --- | --- |
| Desired (V) | Actual | Error (%) |
| 3.000 | 3.018 | 0.6% |
| 6.000 | 5.981 | -0.3% |

Table 2. Regulated Voltage Testing Results

## VII. CONCLUSION

While our team faced an array of hurdles ranging from part failure and supply-chain issues to motivation shortages, the group's adaptability and ingenuity led our project to a successful prototype.

## ACKNOWLEDGEMENTS

The group would like to thank Dr. Divliansky for letting us use his lab and equipment such as spectrometer, power supply and soldering machine to test and design our system.

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We would like to thank Blaine Andersen from I-CON Systems for all of his advice and assistance regarding embedded hardware and software design. Ryan personally feels that Blaine’s mentorship and experience in the field was integral in the success of this project.

## REFERENCE

1. https://www.epa.gov/national-aquatic-resource-surveys/indicators-water-clarity

BIOGRAPHIES

Ryan Koons is graduating and receiving his Bachelor’s of Science degree in Electrical Engineering in December of 2021. From here, he will be pursuing a career as an “Electrical Engineer I” at CAE USA Inc. in Tampa, Florida. He loves drumming, listening to music, and spending time with his friends and family.



Matthew Woodruff is on course to graduate with a Bachelor's of Science degree in Photonic Science and Engineering in December 2021 and intends to find employment locally. He enjoys cooking, horticulture, programming, and tinkering with projects.

A person with a mustache

Description automatically generated with low confidenceNeeil Gandhi is an international student from India who will be graduating in December 2021 with a Bachelor’s of Science degree in Photonic Science and Engineering. After graduating he will be going to work at General Medical Engineering Company in Erlangen, Germany. In his free time, he enjoys dancing, reading, playing sports and spending quality time with friends and family.



Dean Pickett is scheduled to graduate in December 2021 with a Bachelor of Science degree in Electrical Engineering. His degree track is Power and Renewable Energy, and he hopes to find local employment in the power industry. He enjoys traveling with friends and family.