UNIVERSITY OF
CENTRAL FLORIDA

Senior Design: Divide and Conquer 2.0

Smart Water Bottle

Prepared by:

Group #5
Self-Sponsored

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Project Description

Project Narrative and Motivation

According to the CDC, between 30 and 70 percent of global explorers suffer from traveler's sickness. Of those individuals, more than 80 percent fall ill due to bacterial pathogens [1]. One of the most common ways that travelers get exposed to bacteria is through the consumption of biological contaminants in water from underdeveloped sanitation systems. A single sip of improperly treated hydration can expose people to various gruesome diseases including typhoid, cholera, salmonellosis, and a myriad of unpleasant maladies [2]. With sterility in the vogue, virus and disease prevention has prime real estate in the minds of much of the population. And, due to a continuous need for water, pure drinking water is integral to personal wellbeing. This holds not only to people travelling through foreign nations but also applies to those merely going about their daily routine. Thus, this project seeks to design a long-term, portable, affordable solution for consumers seeking more assurance both abroad and throughout their workweek.

The proposed product is a smart water bottle that can sanitize its contents using UV irradiation and generating a potability report of said contents based on spectral analysis. After sanitization is complete the user will have the option to remove any remaining non-biological contaminants with a standard filter. The sanitization process will start whenever the user initiates the procedure via a button on the bottle. One intent behind this product is to ensure peace-of-mind for international travelers concerned by water-borne pathogens and parasites. However, this product is for more than just jetsetters (who are an endangered species among the laymen). Our product is also appealing to the tech savvy consumer that likes to have "smart" devices with added functionality for ease in daily life. Therefore, an app will be created so the user can receive more detailed information about the quality of their water (information which cannot be displayed on the device).

From a technology standpoint, several systems will be considered for implementation into the smart water bottle. It will have wireless charging built into the cap to allow for convenient recharges of the device as well as improved water resistance. The optics system will consist of a UV diode for sanitizing the biological contaminants and a Raman spectroscope for determining the content's potability post-sanitization. The bottle will also have LEDs for status and result indications, a Bluetooth module for communications with a paired device, a reed switch to ensure the sanitizer only runs in appropriate conditions, and an embedded microcontroller. All of the electronics will be contained inside of the cap so that users may choose any compatible metal water bottle. The Bluetooth functionality will potentially pair with an app that displays a cumulative water score based on the EPA's regulatory maximums [3]. The intent is to keep the product as simple and coherent as possible for any traveler to use while still allowing the owner to access more detailed data via the app.

Most smart bottles in the market today implement less useful features such as glowing to remind you when to drink, a built-in Bluetooth speaker, and water intake tracking. Some bottles are also UV sanitizing but tend to run on a schedule and do not allow the user to simply press a button to initiate sanitization. Other senior design smart water bottle projects also had water sanitization and smart features such as water intake and a Bluetooth app- however, these projects did not incorporate wireless charging or introduce a CREOL focus on fine-tuning optics technology for the purposes of water quality assurance and monitoring. Previous projects also lack modularity, a feature of significant importance as the proposed device can be used with a variety of vessels.

Project Components

Water Quality Sensor

This component will perform spectral analysis of the contained fluids. The sensor will consist of a spectrometer that projects the spectrum of the radiation pumped into the sample by the sanitization component onto a CCD or CMOS sensor. The stainless-steel bottle's reflective surface will serve as a feedback system, amplifying the admittedly insignificant influence of Raman scattering to the point of measurability. The spectrum will then be normalized to account for variations in transmissibility and compared to a spectrum produced by potable water. Significant deviation will trigger a warning LED via the embedded hardware. A copy of the spectrum will then be transmitted to a paired device for more detailed analysis.

Sanitization

This component is going to help with the sanitization of the water in the bottle. The components for this are going to be placed in the bottle cap. We are going to build a UVC LED which will emit 264 nm wavelength but modify it in a way that the nearby wavelengths also get enough intensity to act so making it a broad-spectrum LED. According to NIST the tunable laser is more efficient in killing the biological contaminants in the water [4]. This laser will help kill the biological contaminants present in the water and make it safer to drink the water. This will help prevent from water-borne diseases, like typhoid and cholera, that are caused by the biological contaminants in the water.

Device Power

The device will be powered by a rechar*geable battery. It has yet to be fully explored which chemical composition of battery would best suit the project needs, but the two options under investigation are Nickel-Metal Hydride and Lithium-Ion battery technologies. The charged battery will supply power to the rest of the components with DC-DC voltage regulators, specified by the various voltage requirements for each individual component.*

Charging the battery is to be achieved by wireless transmission of AC voltage supplied by a standard US 120 Volt wall outlet. The initial intention is to use a wireless power transmitter that will contain the inductive AC power transmission coil to be closely aligned with the top of the water bottle cap while not in use. There will be a set of permanent magnets installed to help the charging pad sit properly aligned on top of the water bottle. The wireless power transmission will be received by inductive coils within the water bottle cap and the AC voltage will be rectified and connected to a regulator in order to charge the battery.

Embedded Hardware

The device hardware will mainly involve sensors, LEDs, a microcontroller, and a Bluetooth module. There will be a water quality sensor, a sanitizing LED controlled by the microcontroller, and a reed switch for determining if the cap is on. Having a reed switch is especially important since UV-C light is harmful to human beings and therefore needs to be contained inside the bottle. All of the sensors will be controlled by the microcontroller. It is preferable to use a TI microcontroller due to the familiarity of embedded programming software. The microcontroller also must have enough I/O pins to support the sensors (reed switch included), LEDs, and the Bluetooth module. A microcontroller with a low power mode is strongly desired to improve the battery life of the product. Due to some of the peripherals, it will also have to be compatible with common communication protocols such as UART and I2C (perhaps also SPI). The microcontroller (even with high-drive current pins) most likely will not be able to drive enough current to the laser, so a MOSFET switching circuit will likely be implemented for enabling/disabling the UV-C laser diode. A red/green/yellow LED (preferably in one package) will be used to provide rudimentary water quality info. to the user after sanitization has taken place. It is proposed to include an Integrated Circuit to provide a dot/bar voltage display that shows the charge status of the battery in an array of 10 LEDs [5]. An additional button may also be necessary for the device to enter BT pairing mode. From a design standpoint: EAGLE PCB design software will be utilized due to ongoing familiarity, and the boards will most likely be ordered and assembled by PCBWay. A turn-key assembly will likely be utilized due to the current industry-wide chip shortage.

Software

The software will be comprised of embedded firmware for the board itself, and then rudimentary app development. Most likely Code Composer studio will be utilized for creating the firmware for the microcontroller. The firmware must be able to check that the cap is on before activating sanitization, enable/disable sanitization, check the quality of the water, display rudimentary water quality information via LEDs, and wirelessly communicate with the iOS app via Bluetooth. It will require a significant amount of time to learn about the various sensors and how to interface with them (via the microcontroller). The sensors will require implementing standard communication protocol functions such as UART Tx/Rx and I2C commands. A lot of development overhead will also go into implementing Bluetooth wireless protocols to successfully transmit water quality data to the application. It will also be necessary to include code for processing and storing the various water quality statistics. When the device is not readily being used, the microcontroller should also enter low power mode to conserve energy.

The app will receive data via Bluetooth from the device to report more in-depth water quality data to the user. This data will consist primarily of a vector of the sample's spectrum. This vector will be produced by snapping multiple photos over the sensor's activation, performing matrix addition, collapsing the rows or columns (depending on the physical orientation of the chip) by addition, and normalizing the vector. This vector will then contain values for wavelength ranges, which can be analyzed for specific excitation responses. The existence of excitation responses indicates the presence of contaminants and said responses will be compared to responses obtained from samples with known contamination levels. Exceeding the accepted maximum values will trigger an alert on the bottle while the app will show the collected spectrum information and produce estimated contaminant concentrations. The app will most likely be programmed on iOS since this platform is much easier and cheaper to implement on than programming for an android device. Apple products also tend to have capable processors which should help hasten computational analysis on the application. Device pairing will be a very important feature due to Bluetooth protocols. Simplicity will be emphasized in the app as the project members have limited experience with coding apps.

Requirements/Specifications

Performance

<table>
<tr><td>Auto-safety UV-C shutoff</td><td colspan="2">The UV-C laser should shut off in less than one second from the time in which the mechanical tab lifts up</td></tr>
<tr><td>Time for one sanitization cycle</td><td colspan="2">1 minute</td></tr>
<tr><td>Sanitization effectivity</td><td colspan="2">Kills 99.9% of contained micro-organisms</td></tr>
<tr><td rowspan="7">Sensor detects the presence of contaminants in at least these concentrations [3]</td><td>Contaminant</td><td>Concentration (ppm)</td></tr>
<tr><td>Arsenic</td><td>.010</td></tr>
<tr><td>Nitrate</td><td>10</td></tr>
<tr><td>Nitrite</td><td>1</td></tr>
<tr><td>Copper</td><td>1.3</td></tr>
<tr><td>Fluoride</td><td>4</td></tr>
<tr><td>Lead</td><td>.015</td></tr>
</table>

Table 4

Physical Characteristics/Dimensions

Water Bottle Lid	Round 3" diameter x 4" tall Plastic top to allow for inductive charging
Water Bottle Body	Round 3" diameter x 10" tall
Waterproof	All circuitries should be contained within IP44 certified. waterproof housing.

Table 5

Water Quality Sensor

Sensitivity	The spectrometer must be capable or reliably separating the spectra of sampled light and registering wavelengths which contain less than 1% of the cumulative spectra
Size	The spectrometer must utilize mirrors to function in the confines of the cap, and occupy less than ¾" in height of the base of the cap (threaded region not included)

Table 6

Sanitization

Pump Source	Multiple LED sources to get a broad spectrum.
Focusing Lenses	Researching into it more to fit it in the small space as well combine the two sources.
Output Coupler	Need a broad spectrum so just will couple the different LEDs with a lower wavelength of 230nm and a higher wavelength of 270nm.
Output lens	Will most likely be a dispersing medium like an LED or a dispersing lens as the light needs to travel in different directions.

Table 7

Device Power

Battery	Battery Life lasts the user at least for one entire day, which would include at least 10 cycles of the sanitization and sensor modules.
Inductive Charging	There is an inductive charging system oriented upward in the cap. This power supply should fully charge the battery within 8 hours.
Charging Pad	The pad will plug into a standard 120 VAC wall outlet and consist of an inductive transmitter coil, an on/off switch, protective housing, and a permanent magnet (for coil alignment).

Table 8

Embedded Hardware

Controller	Bluetooth compatibility, about 10-20 GPIO pins. Low power mode functionality with current in the tens of microamps is preferable. Lower input voltage that can be regulated down from main device power. Serial communication support for I2C and UART.
Wireless Communication	BLE: reduced power consumption. OTA data rate: 1 Mbps. 6ms
Wired Communication Protocols	UART: Full-duplex serial system. I2C: Device addressing-serial bus
CMOS/CCD Sensor	12-bit parallel output (or 3-bit for a CCD). Pixel size: 3.75-5 um. Supply voltage: 2.8V. Power consumption: 250 mW.
LEDs	Red, green, yellow: indicate water quality Blue: indicate device sanitization Green array: indicate battery charge status
Bluetooth Pairing	Device will have a button to hold down for 3 seconds and enter device pairing mode.
Charging Pad	The pad will plug into a standard 120 VAC wall outlet and consist of an inductive transmitter coil, an on/off switch, protective housing, and a permanent magnet (for coil alignment).

Table 9

Wireless Communication

Connection Distance	Device should be able to pair with a smartphone from a distance of 10 feet or less.
Pairing Time	The device should take no longer than 30 seconds to pair with a smartphone.

Table 10

Software/App

Application	iOS platform. Bluetooth pairing and compatibility. Displays the acquired spectra contrasted with a benchmark (pure) spectra, and singles out the spectra of key contaminants
Interrupt Handling	Reed switch for cap being attached to bottle, and whenever sanitization is currently taking place (based on button press)
Communication Protocols	I2C, UART, and Bluetooth (most likely 4.0/BLE)
Microcontroller low power mode	Enable low power mode to allow for a sleep current of 10 uA or less
Water Quality	Transfer CMOS outputs to microcontroller to evaluate the presence of biological contaminants

Table 11

Block Diagrams

Responsibility Legend

Dean Pickett
Ryan Koons
Matthew Woodruff
Neeil Gandhi
Unassigned

Figure 1

Water Quality Sensor

Matthew will be mostly responsible for this section, with some help from Neeil.

Water Quality Sensor Block Diagram

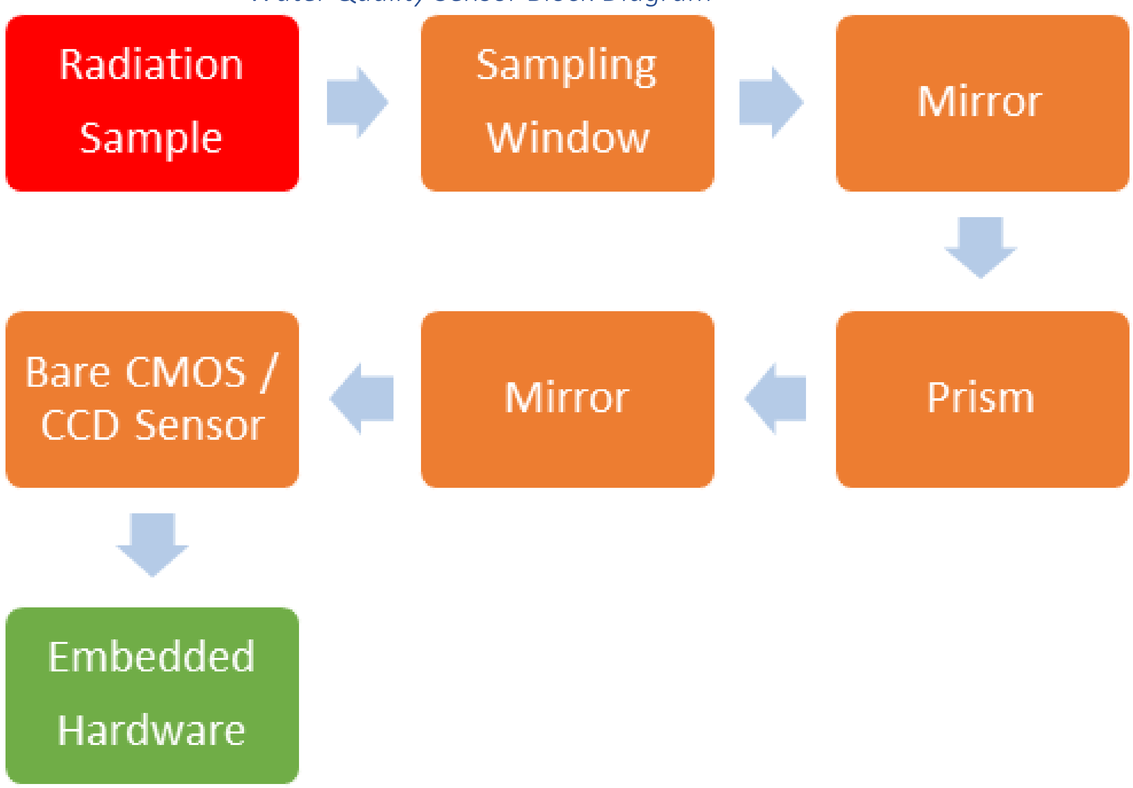


Figure 2

Proposed Water Analyzer Design

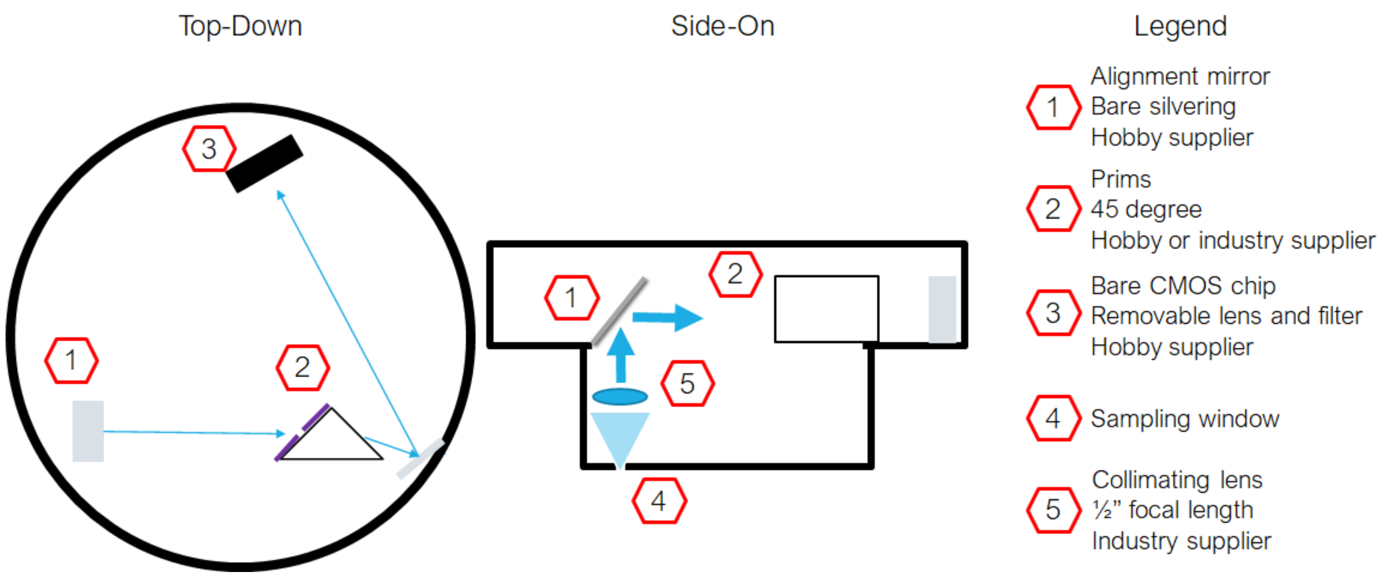


Figure 3

Sanitization

Neeil will mostly be responsible for this section, with assistance from Matthew.

Sanitization Block Diagram

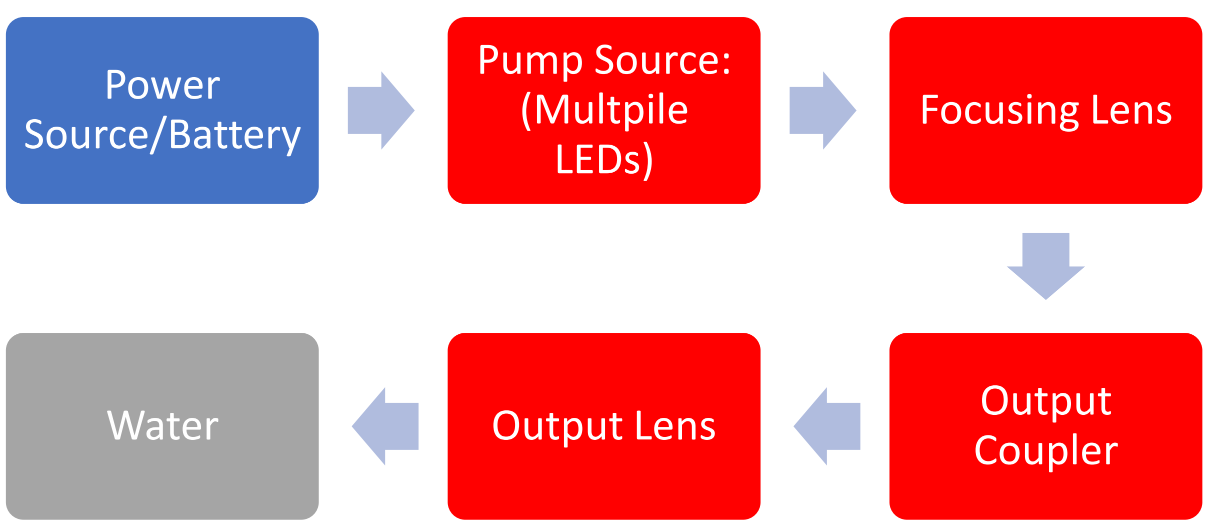


Figure 4

In-Line Optical Sanitizer

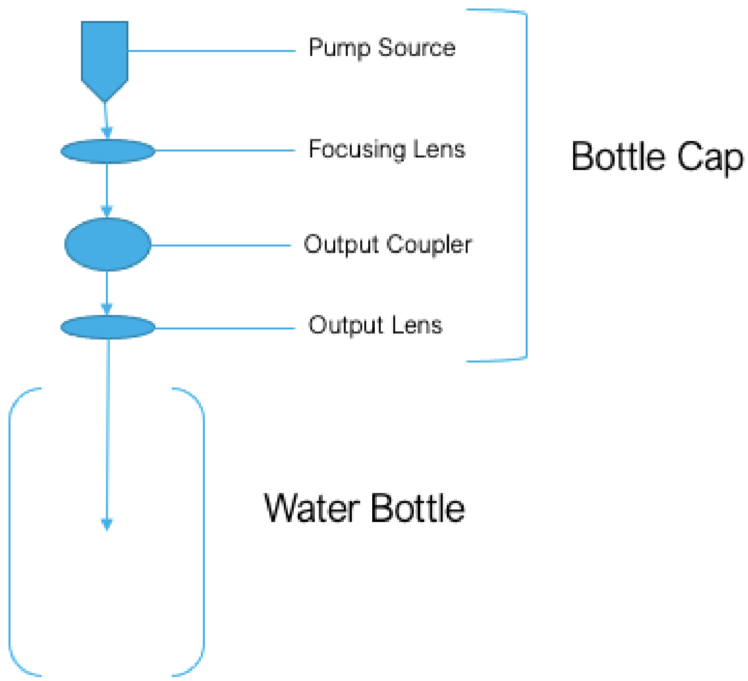


Figure 5

Device Power

Dean will be responsibility for the majority of this section, but Ryan will assist with *Voltage Regulation and DC-DC converters for the embedded hardware.*

Device Power Block Diagram

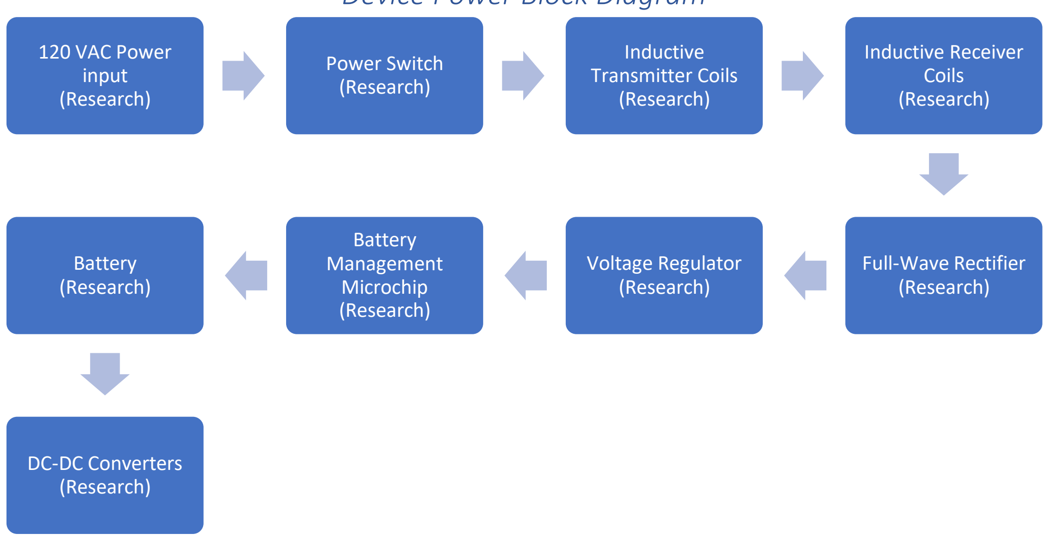


Figure 6

Embedded Hardware

Ryan will mostly be responsible for this section with some assistance from Dean.

Embedded Hardware Block Diagram

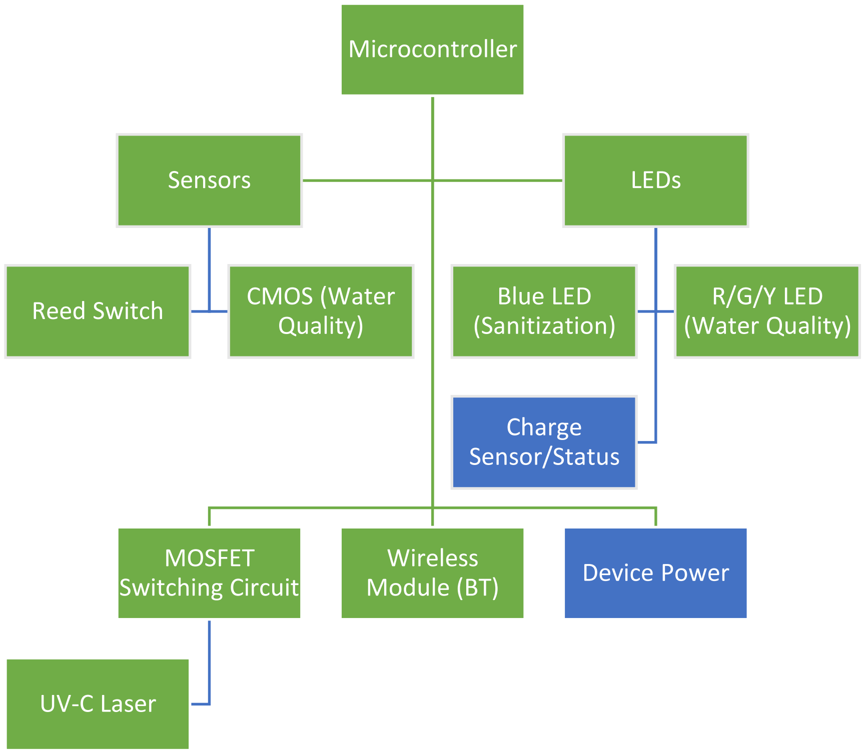


Figure 7

Software

Ryan and Dean will work on this section, with some assistance from Matthew.

Software/App Block Diagram

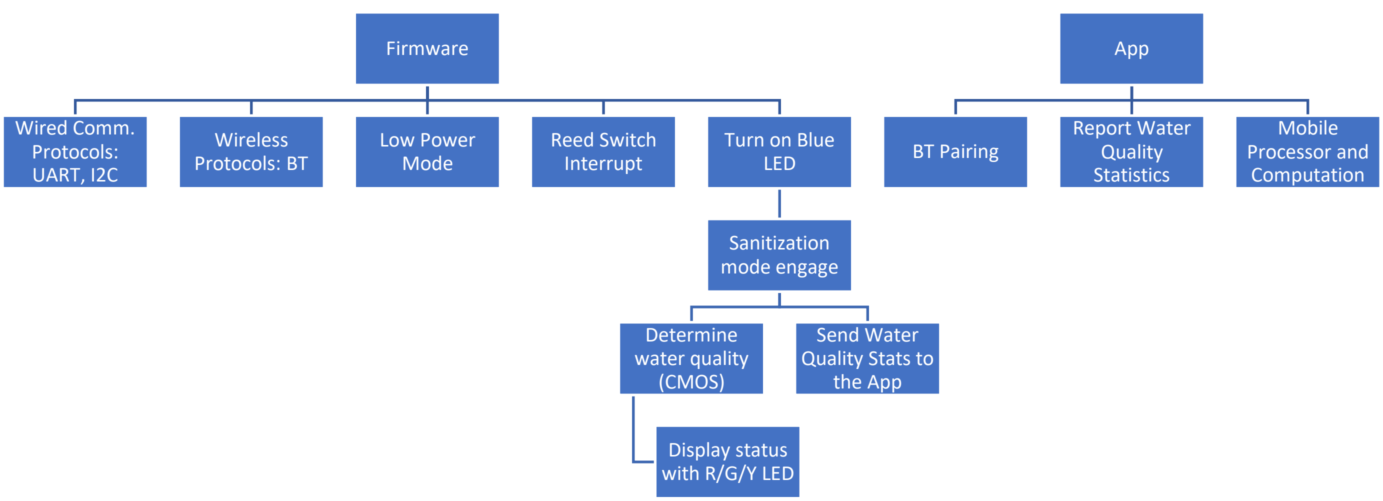


Figure 8

Estimated Budget and Financing

The table below outlines the estimated budget for both prototype/development, as well as the typical cost per unit. Production cost is an important parameter for this product's marketability, and therefore should be factored into all estimated financing.

Estimated Budget

Component	Prototype Cost	Production Cost
Stainless Steel Double Walled (Generic) Bottle and Lid	$15.00	$15.00
Quantity of Five: PCB, solder mask, and Assembly (PCBWay). Two separate board revisions ($100.00 per revision)	$200.00	$20.00
R/G/Y LED	$2.00	$2.00
Buttons (Sanitization, BT Pairing)	$2.00	$2.00
Blue LED	$0.50	$0.50
Reed Switch	$2.00	$2.00
Wireless module	$10.00	$10.00
Breadboard Prototype Kit	$20.00	$0.00
UV Sanitizing Diode (includes coupler, source, and lenses)	$20.00	$20.00
MOSFET	$1.00	$1.00
Raman Spectroscopy Sensor (Water Quality)	$36.00	$36.00
Li-ion/Li-poly charger	$6.00	$6.00
Qi Compliant Charging Transmitter	$27.00	$27.00
Qi Compliant Charging Receiver	$15.00	$15.00
Rechargeable Battery	$20.00	$20.00
Voltage Regulator Components ($0.60 x3)	$1.80	$1.80
Microcontroller (10-20 I/O)	$7.00	$7.00
SMT Passive Components	$5.00	$5.00
Approximate Total:	**$ 390.30**	**$13.80**

Table 12

Initial Project Milestones

Legend

SD1 Hard Deadlines
Tentative deadlines

Table 13

Senior Design 1 Milestones

Date	Details
5/21	Project Conceptual Brainstorming: Optics and Electrical Engineering
5/27	Project Idea Discussion
5/28	Project Selection: Decided on Smart Water Bottle
6/9	Divide & Conquer v1.0: Complete the D&C
6/11	Divide & Conquer v1.0 Due: Submit the completed D&C
6/15	D&C V1.0 Meeting with Dr. Richie: Discuss project idea, critique on initial document
6/23	Divide & Conquer v2.0 Complete: Approximately 25 pages
6/25	Divide & Conquer v2.0 Due: Submit the final D&C
6/28	SD1 Paper: 30-page draft completed
7/2	SD1 Paper: 45-page draft completed
7/5	SD1 Paper: 60-page draft completed
7/9	SD1 v1 60-page paper Due
7/16	SD1 Paper: 80-page draft completed
7/23	SD1 v2 100-page paper Due
7/30	Finishing touches
8/3	Final document due
8/6	Order prototype boards (PCBWay)

Table 14

Senior Design 2 Milestones

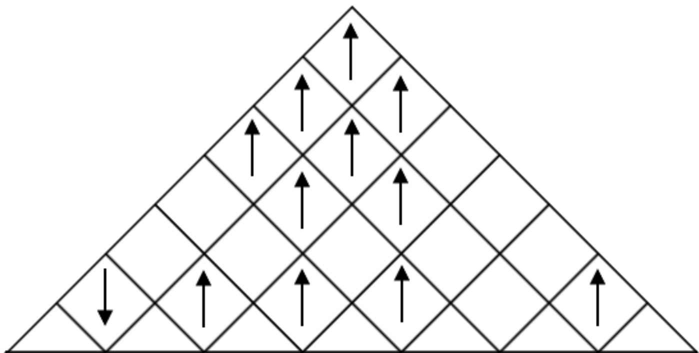
8/23	First day of Fall Semester goals
9/27	September goals -Build and test optical components
10/25	October goals- Work on software
11/24	Thanksgiving Wednesday- Have everything ready and work on testing and final paper and presentation
12/3	Last Day of Class goals – Presentation of the project
12/11	Last day of final exams – Submit the final report

Table 15

Engineering-Marketing Tradeoff

The following diagram below outlines the relationship between engineering and marketing requirements.

House of Quality



Customer Requirements \ Engineering Requirements		Cost	Dimensions	Efficiency	Charge Time	Battery Capacity	Laser Intensity	Sensor Sensitivity
		-	-	+	-	+	+	+
Affordability	-	↑↑	↓	↓	↓	↓	↓	↓
Sterility	+	↓	↓	↓			↑↑	
Accessibility	+	↓	↑		↑	↑	↑	
Safety	+	↓		↑	↓	↓↓	↓↓	↑
Sanitization Rapidity	-	↓		↓				↓
Charging Accessibility		↓	↓↓	↓↓	↓↓			
Data Availability	+	↓	↓	↓				↑↑
Target Specifications		< $1,000	Round 3" x 4"	>30%	<8 hours	4,400 mAh	>1,000 mA	*See Performance Table

Figure 9

Technology Investigation for Project Development

Charging

Inductive Charging

The simplest way to implement a wireless charging system is to use technology that relies on Faraday's Law to create a changing magnetic field in one coil, which in turn induces an AC voltage in a magnetically coupled coil nearby. Reducing the cost of the final device is one of the main engineering and marketing goals of this project, so it is strongly recommended to implement a wireless charging system that does not require a harmonic oscillator in the power transmitter. The electric power that is available through a standard household, single-phase socket already provides an alternating current at 60 Hertz that can be used for simple inductive charging.

There are three physical constraints that need to be addressed in order to implement inductive charging well. All of them involve the coupling of the transmitter and receiver coils [6]. The first constraint for this type of charging is the distance between the two coils being used. In order to maximize the magnetic coupling between the transmitter and the receiver, it is necessary to minimize the distance between concentrically aligned coils. Part of this issue can be taken care of by adding permanent magnets to the casing of the transmitter and receiver so that they are as close as physically possible during the charging process, but it is also possible to implement some simple clip that would keep the power transmitter in place. The other feature within our control would be to minimize the thickness of the casing for the transmitter and receiver. Ideally, this distance between coils would be less than 10 millimeters [6]. Along these same lines, it is necessary for the transmitter and receiver to actually be aligned concentrically in order to minimize the magnetic flux leakage between coils. This problem can also be dealt with either by implementing some sort of clip-on device or by using permanent magnets fixed to the inside of the casing for the water bottle top and the power transmitter.

The third physical constraint for using inductive wireless charging is needing to minimize the surface area of conductive material between the two coils. Eddy currents are created in any conductive surface that has a magnetic flux passing through is perpendicularly. Adding permanent magnets into the centers of the transmitter and receiver coils will inevitably create eddy current losses, which will not only reduce the overall efficiency of the charging system but will also be a considerable source of heat depending on the actual magnets used. These eddy currents could also be induced in the casing of either the bottle cap top or the power transmitter if either were made of some conductive material such as metal [7]. There is no advantage to using metal casing when compared to plastic, so this choice in material would be both cheap and beneficial to increasing the efficiency of the wireless charging. On this topic of eddy current losses, it is still up for consideration as to whether or not it would be best to implement permanent magnets into the charger design. Although we should easily be able to charge a 4,400 mAh battery within eight hours despite the losses in the magnets, it is very important to minimize how much heat is being produced within the water bottle cap since the intention is for the casing to eventually be sealed so as not to allow water ingress into the electronics.

The current standard in the market for inductive charging is called Qi (pronounced "chee") and this is specified by the Wireless Power Consortium [8]. Having a device that is Qi certified is much more complicated than simply sending and receiving power through electromagnetic induction, because this standard also specifies a communication protocol for data transfer between transmitter and receiver. This communication is used to provide feedback to the power transmitter (or base-station) about information such as the state-of-charge of the battery. Providing a means for this communication is a very important concern for charging a battery, because the worst-case scenario for continuing to push charge into a fully charged battery is starting a fire. There are premade Qi compliant power transmitters and receivers, which run for over $40 for the pair. This is much more expensive than the initial estimates for wireless charging modules but having a Qi compliant transmitter and receiver would make the final product much safer as well as allow for USB compatibility for the power transmitter.

Magnetic Resonance Charging

The newer form of wireless charging technology that is available today relies on the concept of magnetic resonance. This design of wireless power transmission is still possible due to the electromagnetic induction of an AC voltage in a coil, but the main difference is that tuning the transmitter and receiver to oscillate at the same resonant frequency strongly supports the magnetic coupling between the two coils. In other words, the transmitter and receiver do not suffer so greatly from the coils being either misaligned concentrically or separated by distances much greater than those in which simple inductive charging can operate [6]. This feature is not thought to be as useful for the purposes of this project, because the intention is to have a power transmitter that sits on top of the water bottle and easily keep coils aligned and nearby. It is also important to note that even though this technology allows for coils to be further apart and misaligned that it still does not achieve efficiency levels as high as traditional inductive charging due to the flux leakage between coils. Although it is possible to design a circuit to use the power of magnetic resonance while still keeping the coils tightly coupled in space, the added drawbacks for this sort of design are that the oscillating circuits are more complex and that these resonant frequencies are typically much higher than those used in standard inductive charging. Introducing higher frequency power signals has the possibility of creating electromagnetic interference in nearby devices. For the purposes of this project, it seems inadvisable to utilize this more advanced and newer technology.

Battery

Upon investigating various popular vendors online, it has become clear that the choice in battery chemical composition for the needs of this project is much more dependent upon availability than the specific differences in performance. The majority of battery packs that do not exceed three inches in any dimension are either lithium-ion (Li-ion) or lithium-polymer (Li-po) based. The handful of Nickel-Cadmium batteries that were found online were larger than the lithium-based counterparts of equivalent capacity as well as being more expensive in terms of charge capacity per dollar. Bearing this in mind, the two main aspects of design focus for the battery will be the rated charge capacity and safety circuitry. The options for Li-ion and Li-po battery packs that have been investigated so far typically are rated at 3.7V/4.2V, which means that the nominal rated voltage is 3.7 volts, and the maximum voltage of the battery is 4.2 volts [9]. It is typical that batteries will have a range of voltages that depends on what percentage of charge it has at the time, and this has many consequences in terms of additional circuitry that is needed to properly charge and discharge the units. One such consideration is designing voltage regulators to specifically meet the voltage and power requirements of each instrument in the project. Another factor that is more directly related to the battery itself is the need for special circuitry in ensure safely charging the battery packs. Having batteries with a denser energy content is naturally going to make them more dangerous, which is why so much care must be taken to ensure safe implementation in this project.

Monitoring the voltage and current flowing in or out of a Li-ion/Li-po battery cell is typically handled by protection circuitry that is included in the battery itself [9]. However, even with these safety features installed in the battery packs, it is still highly recommended to use a charger that is specifically designed for Li-ion/Li-po batteries of the specified voltage. This additional circuitry, which will need to be purchased separately, is designed to help control the flow of current into the battery as it is charged. There are many nuances to charging these lithium-based batteries in a way that is safe, fast, and prolongs the life of the battery by not damaging it [10]. The main takeaway from this technology research is that the additional cost of professionally designed and manufactured safety circuitry seems to be well worth the price, especially when considering the consequences of a Li-ion/Li-po battery that has been mishandled. One final consideration on the topic of battery safety is monitoring the temperature of the cells. The major causes of batteries getting too hot that can be controlled is due to improper charging and discharging [10]. However, the intention of this project is to build a unit that does not allow the flow of air and water into the casing that contains the electronic circuitry and therefore it is not unreasonable to assume that the temperature of the battery pack could reach unacceptable levels due to a lack of proper heat dissipation during operation. A significant production cost of this project is already forecasted to consist of pre-made units to ensure proper wireless charging of the internal battery, but for the sake of safety and completion, it seems worthwhile to also investigate the potential implementation of a temperature monitoring system.

Sanitization

How do you feel when you can see, taste, or smell a contaminant? It is bad, right? What do you think of the water that smells, looks, and tastes just fine? Is it good enough to drink? The answer to this is -- not necessarily. The water can be contaminated without having an odd flavor.

Microbial and organic substances cannot generally be recognized by human senses, and can lead to severe health issues down the road- for microbes in particular, the affect is generally gradual enough as to allow for significant transmission prior to diagnosis. Water may contain contaminants from pesticide or compost application. These chemicals from pesticides and manures in "water may increase cancer risk and reproductive problems, and can impair eye, liver, kidney, and other body functions" [11].

The goal of this bottle will be to sanitize the water in the bottle by killing the microbiological contaminants present in it. "The transmission of diseases such as typhoid and paratyphoid fevers, cholera, salmonellosis, and shigellosis can be controlled with treatments that substantially reduce the total number of viable microorganisms in the water" and that is what we are looking for here [2].

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 various kinds of methods for the sanitization of water, the most common and widely used are chlorination, boiling and UV-C light.

Choosing the method for the disinfection of water depends on various factors. These include:

- how effective it is in eliminating the microorganisms (bacteria, protozoa, viruses, and helminths);
- how reliable and accurate of the process and the way it can be controlled and monitored;
- whether the method leaves some residuals behind and how would that affect the disinfection process and be taken care of;
- how purified the water gets after the process is complete; and
- how accessible the technology is for the public water supplies [2].

Now we will look into different sanitization methods used in the industry and compare and chose the most feasible for our project.

Boiling System

This is one of the most common method used in a lot of areas throughout the world let it be how remote it is. In this method the source does not depend as it is ensured that even regardless of the source the water kills the pathogens on boiling. Boiling time of water depends on the altitude. Higher altitudes require longer time and lower altitudes require shorter time. “Water should be at a rolling boil for 1 minute and at altitudes greater than 6,564 feet, boil water for 3 minutes” [12]. This method has great advantages such as the source does not matter and requires a short amount of time to boil the water. But, for this project this method to kill the contaminants will not be ideal. As our product is a water bottle it would be difficult to incorporate the electronic system as it will require high voltage and hence will need a power source outside where it can be plugged to. The temperature is going to rise due to boiling and hence the material the bottle will be made of will have to be taken care of as the material should not disintegrate or mold at high temperatures. The heating will also result in the water to be too hot to drink and might also heat up the outer casing of the bottle for the user to hold it. We can add a cooling system to cool the water after the boiling process is completed but it will require more electronics. Even though these problems can be overcome it would not be the most suitable for the water bottle.

Chemical Treatments

There are several chemicals that can be used to disinfect the water. The most commonly used chemicals are chlorine, iodine, bromine, and oxidizing agents. Chlorination is a widely used process in big factories, but in a project like this it has various drawbacks as it leaves residuals behind, which can be dangerous when consumed. Other chemical like Iodine has a better efficiency but it is tough to store Iodine as it deteriorates in sunlight. It also leaves a bad metallic taste behind. Bromine has its drawbacks in storing and transporting too as it highly reactive. Bromine’s major drawback is its reactivity with ammonia or the other amines that affect its treatment of disinfecting the water. Oxidizing agents have great efficacy but due to its high cost and desired pH concentration it is not really viable for us to use it. All these being chemicals they can react and act differently with different foreign viruses and hence will not give the accuracy we need. This method is easily accessible and does not require any electrical components, but they have various drawbacks such as pH of water, temperature of water, it leaves residuals, leaves an after taste, and takes a longer time for disinfecting the water.

Ultraviolet Light

Ultraviolet (UV) light means “beyond violet” coming from the Latin word “ultra”. Naturally, UV light comes from the sun. UV light spectrum lies between visible light and x-rays. The discovery of UV light was done in 1801 by a German physicist Johann Wilhelm Ritter. He observed in his experiment that the light rays beyond violet light darkened silver slats [13]. Ultraviolet light has an electromagnetic spectrum ranging from 10 nm to 400 nm with corresponding frequency ranging from 750 THz to 30 PHz. These wavelengths are too short for the human eyes to see.

Ultraviolet light is broken into four categories:

- Ultraviolet A (UVA) – also known as Long Wave/ Near UV as it has longer wavelength and is closer to the violet light. The wavelength ranges from 315 nm to 400 nm. This light is not blocked by the ozone layer.
- Ultraviolet B (UVB) – this is also known as the medium wave UV. It has a wavelength between 280 nm and 315 nm. This light not completely blocked by the ozone layer but most of it is absorbed by it.
- Ultraviolet C (UVC) – known as short wave UV or commonly referred to as germicidal. This light is completely absorbed by the ozone layer. UVC has wavelength between 100 nm to 280 nm.
- Vacuum Ultraviolet – this has a spectrum from 10 nm to 100 nm. They are absorbed by the nitrogen in the atmosphere and hence cannot penetrate through.

Electromagnetic Spectrum showing the wavelengths of sub parts of UV Light

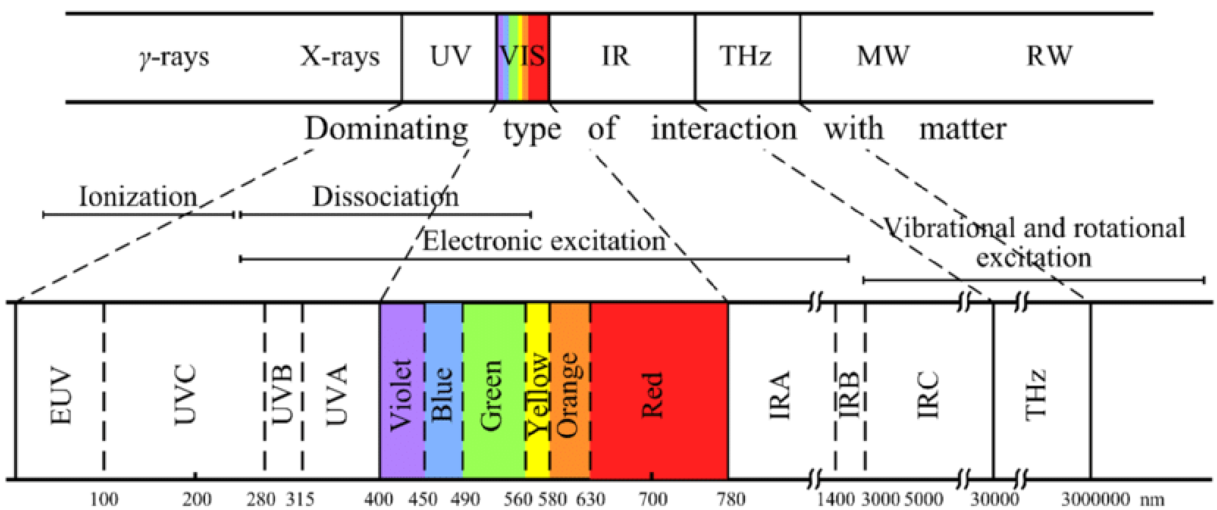


Figure 10: Figure taken from [14]

Pathogens like bacteria have genetic information coded like DNA and RNA similar to that of the cells in our body. We all know the steps for the central dogma of biology: DNA to mRNA to Proteins. If the process is interrupted at any time the cell dies. “DNA is like a blueprint; a little alteration can greatly affect the intended structure and cause a collapse in the entire cell” [15]. All viruses contain either DNA or RNA.

Sufficient intensity of any radiation has the possibility to kill. For example, when there is an atom bomb blast, the gamma radiation has the capability to vaporize an entire person within a few hundred feet but occasional photons of gamma radiation, which are experienced by all the passengers traveling by air causes no damage [16].

Now we know that occasional photons of gamma radiation can damage the DNA and RNA. When the damage done is minimal, cells have the ability to self-repair and recover. “The persistent radiation- induced changes in DNA/RNA may express themselves as cancer” [16]. When the radiation is strong then it completely damages the DNA/RNA, and the cell dies.

Similar to gamma radiation UV light with appropriate wavelength and intensity can destroy the cells and viruses. DNA and RNA are particularly more sensitive to UVC light. The efficiency of destroying the microorganisms depends mainly on the distance, wavelength, intensity, and duration of exposure. “A standard UVC 270 nm LED fixture can kill most microbes within a six-inch radius in 10 seconds” [15]. The following figure shows how the DNA and RNA breakdown occurs due to UVC light. This molecular rearrangement of the biological components in the microorganisms causes inactivation of organisms functioning and hence kills it without leaving any residuals.

DNA Breakdown Illustration via UV Radiation

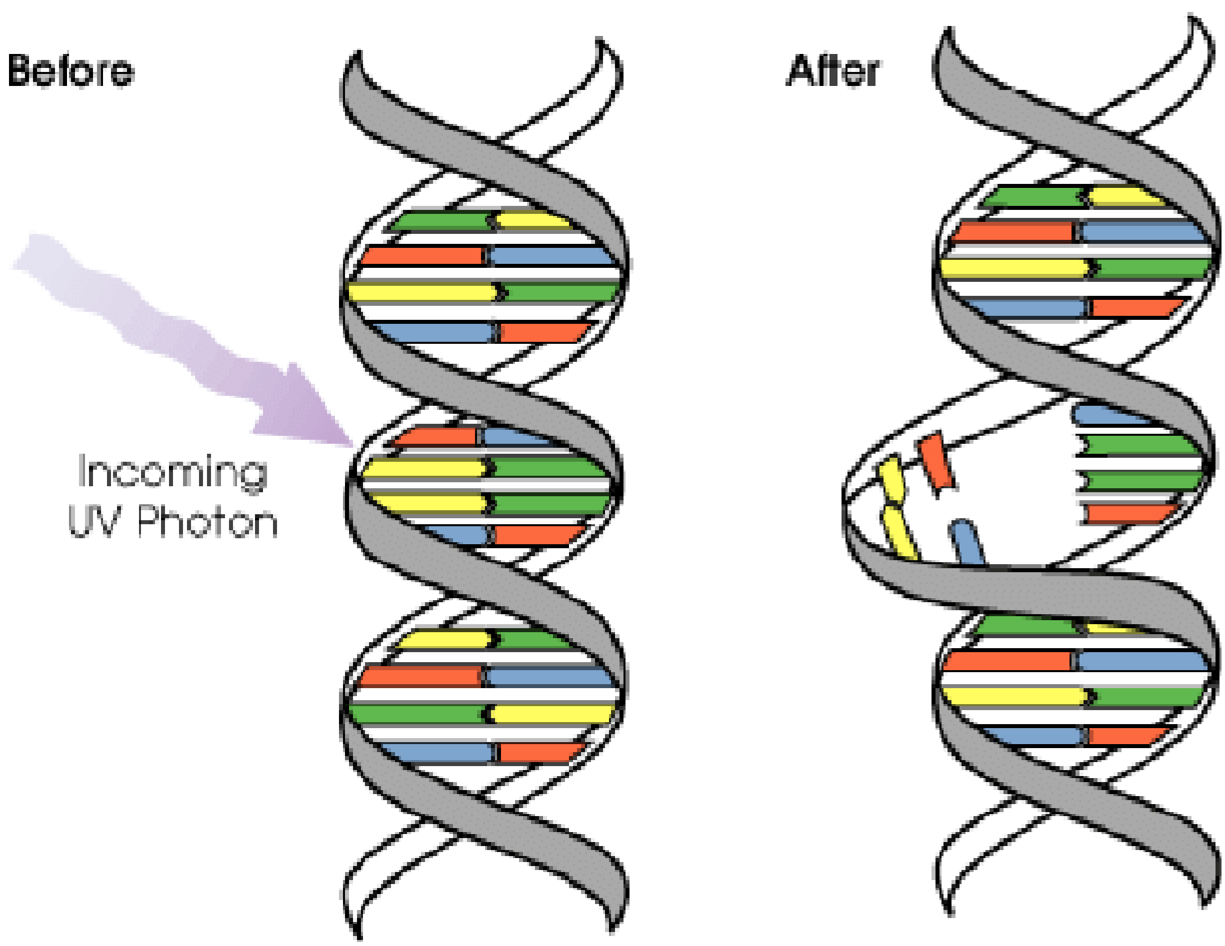


Figure 11: Figure taken from [17]

Safety and Precautions of Ultraviolet Light

We all know and have heard about UV light not being good for our health in the long run and it is completely true. Most of the UV light is blocked by the ozone layer keeping us safe but now as the industry has started building UVC lights for its usefulness for killing microorganisms we need to be careful and take the necessary precautions. Following are the risks caused by UVC radiation and they all depend on the wavelength, duration of exposure and dose:

- It affects the skin and eye and can cause painful eye injuries and skin burns.
- “Some UVC lamps generate ozone. Ozone inhalation can be irritating to the airway” [18]. These ozone gases can cause several health complications like coughing, chest pain, lung damage, throat irritations, asthma, and more.
- As we know it interrupts the DNA and RNA in the cells and same could happen in human cells and cause many health issues. If UV light is not exposed correctly, it might just modify the virus and hence causing mutations of the virus that might be difficult to kill later.
- “High-exposure to radiation promotes the formation of cancerous tumors that can prove fatal if not detected in time” [15].

Therefore, proper safety precautions are very necessary when using a UVC light. Do not come in direct exposure to it and never look right into the path of it.

For these safety concerns we will have a sensor in the bottle that will not let the UVC light radiate when the cap is open for the safety purpose of the user. UVC light will only work when the bottle cap is sealed.

Sanitization Methods Comparison

	Boiling	**Chemical Treatment**	**Ultraviolet Light**
Effectiveness	Very High	Very High	99.9% pure
Time	1-3 min	15-20 min	10 sec – 2min
Cost	<$25	<$20	<$30
Residual Left	None	Yes	None
Electric Components feasibility	Not feasible due to heating and cooling	No electronic components required	Feasible
Implementation	Hard	Hard	Medium
Power	High	Low	Medium
Safety	Medium- can get too heated	Medium – because of the residuals left	Medium – UV light can be harmful for humans
User friendly	Low – water gets too heated	Low – User needs to keep refilling the chemicals	High – no user interaction needed
Portability	Hard	Medium	Easy

Table 16

It is clear after looking into all three sanitization methods that ultraviolet light is the best approach to go forward with, due to its everyday use and portability. Boiling system and the chemical treatments are not feasible methods for our product due to its lack of portability and everyday use as our audience is travelers and hikers. UV light requires more safety precautions due to its ability to harm humans with potential exposure but that is just a minor issue and can be taken care of. Seeing the table and detailing everything we feel it will be easier and a better approach for our project to go with UV light.

Analysis

Methodology

Water quality can be analyzed by a variety of chemical, optical, and electrical means. For the purposes of this project chemical methods are an inherently poor choice due to their disposability- a water bottle that requires monthly refills of obscure compounds and potentially toxic solutes is a poor choice for a hydration vessel.

This leaves optical, electrical, and opto-electrical methods.

Raman Spectroscopy

Raman spectroscopy appears to be the most relevant technology for the project as it is a non-destructive, contactless optical method capable of detecting minute concentrations of dissolved materials. This methodology exploits a non-linear effect of light knows as Raman Scattering, which involves a small portion of incident light shifting from the characteristic wavelength due to interactions with the vibration of atomic bonds [19]. This method, while first discovered using the broad spectrum of sunlight, needs its pump source to be monochromatic to obtain usable data [19]. This method is non-destructive but is observed in the UV range, which necessitates special care for imaging sensors to avoid ablation [19]. While most usages involve infrared or near-infrared pumps, it is unclear whether a UV pump is simply less efficient or altogether unusable [20].

Fluorescence Spectrometry

Fluorescence spectrometry involves the stimulation of a sample with UV light, whose frequency-shifted response is shifted by contained fluorescent materials (primarily present in micro-organisms) [21]. This system, while experimentally demonstrated to be effective at determining the quantity and type of micro-organism present in a sample, is not of particular importance for this project’s design, as our product will destroy living contaminants. This methodology could potentially be useful for demonstration purposes, however, to provide a rapid means for showing the efficacy of the sanitization process.

Inductively Coupled Plasma

Inductively Coupled Plasma (ICP) is a method by which a sample is stabilized to a desired PH using bases or acids before introduction to a plasma source generated by electromagnetic inductors [22]. The process results in of several thousand Kelvin while drawing multiple kilowatt-hours of electricity and destroying the sample- despite its effective and reliable spectral output, the system is not low-cost, low-power, simple, nor compact [22].

Impedance Analysis

Impedance analysis detects and identifies the presence of metallic ions by registering the impedance among an array of electrodes of differing compositions [23]. The impedances are collectively compared to known, contaminated scores for similarity analysis- a similar response indicating the presence of the contaminant in question [23]. While impedance analysis is a reliable means of detecting dissolved heavy metals, the method requires submerged electrodes which would be an undesirable departure from the project's modularity (as the electrodes would need to be in the bottle rather than in the cap to ensure contact with the sample) while also introducing new surfaces that require sanitization and cleaning. Under ideal circumstance these electrodes would undoubtedly add a slight, metallic flavor to the bottle contents- a process which would be accelerated by a UV sanitizer.

Summary of Methodologies

	Raman	Fluorescence	ICP	Impedance
Senses	Atoms	Micro-organisms	Atoms	Atoms
Rapidity	Rapid	Rapid	Slow	Rapid
Cost	Mid-range	Low-cost	High cost	Mid-range
Destructive	No	No	Yes	Partially
Feasibility	Feasible	Feasible for demonstrations	Unfeasible	Feasible but undesirable

Table 17

Spectral Isolators

While the function of this component is the same for both options, the different implementations result in key differences for the overall system.

Prism

Prisms are the most basic means for separating incident light into its spectral components. Light of differing wavelengths is refracted at different angles in the prism due to the wavelength-dependence of the material's refractive index. While prisms made from ice, plastic, candy, and resin are all usable in a high-school science demonstration, it is worth noting that many materials used to produce prisms absorb UV radiation and/or are outright destroyed by it, while tailor-made glass (such as THORLAB's UV fused silica) is somewhat expensive [24].

Diffraction Grating

Diffraction gratings use grooves in a reflective or transparent sheet/panel to separate light into its spectral components [24]. While lighter and potentially smaller than prisms, diffraction gratings experience worse efficiency rates than prisms [24]. Additionally, the materials used to construct more economical gratings are likely vulnerable to ablation in intense UV.

Summary of Isolators

	Prism	Diffraction Grating
Cost	Low	High*
Compactness	Moderate	Moderate
Efficiency	Moderate	Moderate-Low

Table 18

*The cost for diffraction gratings will vary significantly based on scale.

Sensor

A sensor is required to convert the spectral bands into data, which is accomplished by shining the beam onto an array of receptors. If the beam is separated in a horizontal fashion then the resultant image on the sensor will vary in wavelength based on its horizontal location.

CCD

Charge-coupled devices (CCDs) consist of an array of metal oxide semiconductors (MOS) in parallel to an array of illumination-shielded semiconductors[26]. CCDs operate by collecting optical energy and passing said energy as an electric charge into their respective semiconductor cell, which is shifted toward a readout cell every clock cycle. This results in a constant stream of individual cells outputting charge, which can be formed into an image.

CMOS

Complementary metal-oxide semiconductors (CMOS) are similar to their CCD predecessors, but contain readout cells on every pixel [26]. This added complexity is beneficial for some purposes but until relatively recently was a substantial engineering hurdle resulting in increased cost, although manufacturing techniques have improved significantly.

Photodiode Arrays

Photodiode arrays are the simplest of the researched technologies, consisting of an array of photodiode pixels, all of which are continuously active [26]. These devices are attractive for spectrometers due to their large pixels and narrow gaps, reducing the quantity of light (and thus information) lost. Photodiode arrays are industrially available which are tailored to specific spectral ranges (such as UV or IR), which is generally lacking in commercially-available CCD and CMOS chips [27].

Summary of Sensors

	CCD	CMOS	Photodiodes
Cost	Low-Medium	Low-Medium	Low-High
Availability	Hobby-Industrial	Hobby-Industrial	Industrial
Compactness	Medium-High	Medium-High	Low-High
Ablation	Possible	Possible	Unlikely

Table 19

Analysis Investigation Summary

Of the technologies investigated, the combination which appears most compatible with the project goal is Raman spectroscopy using a prism to isolate the spectral bands, and either a photodiode array or CMOS chip for imaging.

Embedded Hardware

Controller Selection

The controller for the product will most likely be one of the following: FPGA, DSP, ASIC, or a microcontroller. The following controller technologies were investigated and compared, to determine which option would be a suitable choice for the project.

FPGA

FPGAs are a very capable choice, they typically have a faster release to the market, and they allow for flexibility and re-programmability when writing code. But they also require a significant amount of software/coding overhead in HDL, and they are not the best option when it comes to power consumption. Both electrical engineers in this project do have some preliminary experience in the Verilog coding language; however, the programming process would be much simpler if it were to be performed in another language that is more abstracted beyond logic gates [28][29]. This project will require a sophisticated level of firmware and software that can handle wireless communication, interface with sensors, and report quality data to the user. Because of the aforementioned reasons, an FPGA would not be a suitable choice for this embedded system.

DSP

DSP chips excel in both real-time processing and quick arithmetic computation. They also typically have a simpler coding process, and are easily reconfigurable since the data is digital, instead of analog. Since this project may determine water quality based on images represented as parallel output bits, a DSP would be suitable for this application. However, DSP chips, due to their high-speed processing, have a higher power consumption compared to a microcontroller. They also require additional filtering and IC's such as an ADC and DAC. Lastly, DSP chips are typically costly, and the electrical engineers on this project do not have a lot of experience on DSP programming. For these reasons, a DSP would not be a suitable choice [28][30].

ASIC

Since ASIC's are mainly comprised of fixed logic gates and digital circuitry, they are very affordable. They also are highly optimized in terms of power consumption and clock cycles. However, since they are designed for one purpose only, they are not re-configurable. Due to their specific functionality, they also typically have a high development overhead [28][29]. For this project, an ASIC would not be a good choice because the device needs to be able to interface with sensors, process data, and wireless communicate via Bluetooth. All of these concepts are too individualistic and therefore an ASIC does not currently exist with all the necessary capability for this project. So, an ASIC (during early/prototype phases) would not be a suitable choice for this project.

Microcontroller

Microcontrollers are relatively affordable and easy to re-configure. They are a great controller to implement for GPIO functionality, which would be favorable for the sensors necessary in this project. They typically support wired communication protocols such as UART, I2C, and SPI. They also often offer low power modes which would drastically improve the overall battery lifetime. Typically, the architecture of the chip can optimize the clock cycles, which helps to improve the overall efficiency of the device [28]. They also have memory storage, which will be helpful with the digital processing necessary for predicting water quality. Microcontrollers are also more cost effective than other aforementioned options. But they do have limitations on the tasks that they can perform [29]. However, this project appears to have a reasonable scope for implementing a microcontroller. In addition to this, the electrical engineers have the most experience in programming a microcontroller and implementing it into various embedded systems.

Prior to senior design, the electrical engineers on this project have previous experience on working with TI microcontrollers. Both the MSP430FR6989 as well as the MSP430G2553 were utilized in previous embedded programming classes. Due to this familiarity, it would be beneficial (as far as time constraint) if the project sought to implement a microcontroller from the TI family. Other microcontrollers would require a significant amount of time to understand the user manual and become familiar with the device architecture and software interface. Currently, our team has access to MSP430 development kits. So, this would also decrease the project budget if we decided to go with one of the MSP430 microcontrollers.

Bluetooth Technology Comparisons

Bluetooth 2.1

Bluetooth 2.1 is an earlier version, but still appears to be very popular in the industry today. It is a low-cost option, with enhanced data rates up to 3 Mbps. Version 2.1 also improved device pairing procedure (and security); this decision drastically helped to improve user operation. This particular version has a range of 33 meters [31]. Due to the larger power consumption of this version of Bluetooth, it most likely would not be a suitable choice for the project.

BLE

Also known as Bluetooth 4, this version of Bluetooth is the first version to drastically improve device power consumption. BLE has a data rate of 1Mbps. It also approximately has the same range as Bluetooth Classic (depending on throughput). This version of Bluetooth would implement lower power consumption and therefore improve the overall battery life of the device. Although this version has a lower throughput, it should be enough bandwidth to push through all of the necessary data for this project. Additionally, a pairing range of 10 feet is more than achievable with this version of Bluetooth. Since this version is intended for devices that only need to send periodic data, this would also indicate that this version would be a great choice for the project [32].

Bluetooth 5

This is the newest version of Bluetooth that is available today. It still has a focus on low power features, but also increases the data rate and device range. This version offers speeds up to 2Mbps, but also has a high-range option of 125 kbps. If this version were to be used, most likely the high-speed option would be selected. Since, the range for this product is intended for proximity. This version was developed for an industry that is heavily based in IoT, which has some relevancy with the goals of this project [32]. Bluetooth 5, due to its new arrival, is the most expensive option, and appears to be more than capable for the project. Therefore, it appears unnecessary to go with this version, since BLE seems to already be capable enough for this project.

App Software

iOS App Development

Upon investigation, it appears that the common development environment for creating iOS apps is called Xcode and can be downloaded for free on any machine running macOS 11 or later. The coding language for iOS apps that was developed by and endorsed by Apple is known as Swift, and one can begin developing an app in this language using the SwiftUI interface within Xcode. Unfortunately, there is limited support for macOS 11 on Apple computers released before 2013 [34], and this is a direct limitation on our ability to use Xcode for iOS app development.

Android App Development

The official Integrated Development Environment for creating Android Apps is known as Android Studio [35]. This IDE provides a lot of flexibility for developers because it is available for Windows, macOS, and Linux. The official programming language for developing Android apps used to be Java, but it was replaced by a newer language known as Kotlin in 2019 [36]. Kotlin is considered to be easier for beginners to code in compared to Java, and this is a promising feature for this project when considering that none of the group members have experience in programming an app for smartphones.

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