Project Report for Specific Gravity Measuring Device

Team Brewery Uno

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Introduction

Beyond the Pale Brewing Company is an independent microbrewery located in Ottawa, Ontario. They have recently begun expanding their personnel and facilities which has caused their previous method of measuring specific gravity, manually via hydrometer or refractometer with an extracted sample of fermenting liquid at regular intervals, to become unfeasible with the increasing scale of their process. As such, the company has contracted the GNG1103 Engineering Design class at the University of Ottawa to design a device that will allow them to precisely measure the specific gravity of their fermentation process without having to draw time and manpower away from the other stages of their brewing process. The briefing that follows will document the raw user data collected from an interview held with a representative from Beyond the Pale and how that data was interpreted, organized, and converted into a specific problem statement. It will also discuss the design criteria and specifications derived from these interpreted needs, as well as the user and technical benchmarking performed to obtain a better understanding of what this type of device may look like.

Empathize

Needs Identification and Problem Statement

First, the client specified that the device's principal purpose is to monitor specific gravity during either the in-line or fermentation processes. He repeatedly stated that fermentation is the most crucial aspect of the brewing process. As a result, this team decided to design the product to the needs of the fermentation tanks. The client's main issue was that their existing procedure for measuring the specific gravity (hydrometer) required a significant amount of liquid to be withdrawn as a test sample, which cannot be put back in for health and safety concerns. To preserve the closed system, the device must be placed into the tank using existing ports and make measurements automatically within short intervals of time. The device must also be mounted to the tank wall rather than floating in the liquid, as requested by the user, and it must work despite the presence of alcohol, unlike a refractometer. Another issue raised by the client is that time constraints result in fewer measurements being conducted throughout the day, resulting in less exact data. As a result, the device will take its automatic measurements at shorter intervals of time, collecting, displaying, and storing the data. The user indicated they want to be able to look at a display and instantly see the specific gravity of a tank. Another request is that the data must be shown both as graphs/curves and stored in a centralized system. These requirements were recognized as the most significant ones since the customer insisted on them throughout the interview, they are the key aims of the design, as they are the core requirements for functionality and improvement over current solutions. Less critical, but still significant, elements include the device being removable for cleaning which would remove the necessity for materials that can withstand the tank cleaning process, and the device being powered by the building, with a backup battery in case of emergency. Finally, the client expressed that he would like for the temperature to be measured as well, but was not insistent on this, placing that need at the bottom of our list of importance. Using the identified needs, our team has defined the following problem statement: "A need exists for Beyond the Pale Brewing Company to precisely and automatically measure the specific gravity of their fermentation process with an attached device that displays real-time data remotely, is easy to use, and can be removed for cleaning."

Question	**What he said**	**Interpreted Need**
Typical uses	I need the device to be installed into the tank to take readings and display them remotely.	The device is installed in the tank. The data is displayed remotely.
	I want a device that measures the specific gravity of the wort or the fermenting (liquid?)	The device measures specific gravity.
	I would like for the device to track temperature as well	The device measures the temperature.
	It is run on a closed system: nothing can be exposed to air. What gets taken out can't be put back in.	The device functions without breaking the closed system.
	I want to logarithmically track the curve of the fermentation process.	The curve of the fermentation is tracked/displayed.
	Ideally it can be removed and clean separately from the tanks, but it can stay in if it is easy to clean and can withstand high pressure and an alkaline solution.	The device is removeable from the tank.
Likes – Current tools	Using a hydrometer is very simple: it's more precise than a refractometer and it can be used	The device is simple to use, precise, and can function in the presence of alcohol

	even in the fermentation process.	
	I like that Plaato logs the fermentation curve.	The curve of the fermentation is tracked/displayed.
	The 3-inch ports in the fermentation tanks are always available.	The device is installed in the tank via the ports already in place.
Dislikes – Current tools	A sizeable volume of wort/fermenting liquid must be removed to perform specific gravity measurement. (Beer loss)	The device functions without breaking the closed system.
	Cannot use refractometer when alcohol is present.	The device functions when alcohol is present.
	Our current methods for checking the specific gravity just take too much time.	The device is time-efficient
Suggested improvements	I want to be able to just glance down and see (the data?). The goal is to be able to monitor the process in a real-time way.	The data is tracked and displayed in real-time.
	I want all data to be logged and stored forever.	The data is stored in a central system.
	We can't use things that are just tossed into the tank free-floating.	The device needs to be attached to the tank.
	I want the data to be visualized on a graph (curve), but also be checked individually at a certain time.	The data is tracked/displayed in real-time and stored in a central system.
	For power, wired or battery powered is fine, but we would prefer wired so that we don't have to worry about keeping track of/replacing batteries. A battery-power back-up would be great though because we don't have the money for a generator if the power goes out.	The device is powered through wires. There is a back-up battery power source.

User Need	**Importance (5-best, 1-less)**	**Why**
The fermentation data is tracked and displayed as a curve in real-time and stored in a central system.	5	This is the primary objective of the device
The device is installed in the tank using the available ports.	5	Device must function in-tank without having to remove beer

		(which is then wasted). There are already ports available.
is removeable for maintenance	3	Allows for ease of cleaning and cheaper materials that do not have to withstand the tank cleaning process
The device measures the specific gravity of fermenting liquid automatically.	5	This is the primary objective of the device
The device measures the temperature of the fermenting liquid.	2	Already somewhat of a solution in place. He did not seem too worried about it/set on this element
The device is simple to use, precise, and can function in the presence of alcohol.	5	Requirement for functionality
The device takes automatic measurements over a shorter time interval.	4	He wants the device so that the measurements are taken without needing an employee, and more often for better precision
The device is powered through wires. There is a back-up battery power source.	3	Doesn't want to have to worry about changing batteries and wire connection is easy with current set up. They don't have the money for a back-up generator, so a battery backup would be useful.

User Benchmarking

In order to conduct user benchmarking, we looked at Amazon reviews for the Plaato wireless hydrometer. From these reviews, we immediately noticed that the product is the subject of mixed reviews. Indeed, a certain number of users advocate its efficiency, its accuracy, as well as the ease of connecting it to Wi-Fi. Nevertheless, others maintain that there are problems with Bluetooth/Wi-Fi connectivity and maintaining an airtight seal on the tank. Therefore, it is important that our device has a reliable Wi-Fi/ Bluetooth connection and a proper airtight fit to the tank's available port.

Define

Design Criteria and Specifications

Using the interpreted needs that we developed from the raw data collected from the client, as well as other information from user and technical benchmarking, we created a number of design criteria and desired specifications for our final product. These criteria were broken up into three categories: functional requirements, non-functional requirements, and constraints.

Functional requirements focus on specifications related how the final product will accomplish the task that it was built to perform; how its “functions”. The primary functional requirements that we derived from our user needs were an automatic measuring system for specific gravity, a system for recording and displaying fermentation data graphically, and to use a system that can function consistently whether alcohol is present or not, unlike a refractometer. These function requirements are the highest priority as without them the device fails to accomplish what the client asked for. The other function requirements listed were not deemed necessary to accomplishing the base task specified by the client but are still deemed important to producing a higher quality and more consistent product. These include the device receiving power through direct connection to the building’s grid rather than external batteries, the device being quick and easy to use and interpret, and the interval of measurements being shorter to provide a more detailed and accurate curve of fermentation.

The second category of design criteria were the constraints. These are the particular specifications that limit or otherwise dictate what parameters the final product must exist within. The primary constraints that we listed were related to the physical dimensions of the device, as these constraints would be necessary to ensuring that the device properly fits onto the fermentation tanks at the brewery. For the on-tank installation method that we will design our product around, it must be able to fit within the 3-inch diameter of the available tank port. It must also extend at least 6 inches into the tank to reliably take measurements as the tank wall is 3 inches thick. In addition to the physical measurements of the device, the other main constraints that we are concerned with are cost and the temperature range at which the device remains effective. The maximum budget that we have been given by the client is $25,000, and the temperature range of 0 to 71 degrees Celsius to comfortably function within all possible temperatures in the fermentation process.

The final category were the non-functional requirements. These are requirements that are not related to the direct functional purpose of the final product but are still necessary considerations for the product to be successful. The non-functional requirements of our device are mostly concerned with the safety and reliability of our device. Ensuring the device is made from food-grade materials and is easily removeable from the tank for cleaning and maintenance are important for hygiene and safety. Additionally, the installation of a backup battery that can adequately power the device for an extended period of time in the event of a power outage is also key, as the client had mentioned experiences with wasted batches during blackouts.

	Design specifications	**Relation (=, < or >)**	**Value**	**Units**	**Verification Method**
	Functional Requirements				
	Easy to use	=	yes	N/A	Test

	Automatic measurements over a shorter time interval	>	2	min	Test
	Powered through wires	=	yes	N/A	Test
	Function in the presence of alcohol	=	yes	N/A	Test
	Automatic measurement of the fermenting liquid's specific gravity	=	yes	N/A	Test
	A central system tracks the fermentation data and displays it as a curve	=	yes	N/A	Test
	Constraints				
	Cost: maximum of $25000 up front, no monthly fees	=	25000	$	Test
	Must be able to attach to a tri-clover sanitary tri-clamp. 3-inch diameter for tank, 1.5-inchhome diameter for in-line	=	3, 1.5	inch	Test
	The sensor must be at least 6 inches into the tank from the inner wall, tank wall is 3 inches thick	=	6, 3	inch	Test
	Entire design must be able to function within the temperature range the fermenting beer is kept at	=	0-71	Degrees Celsius	Test
	Non-functional requirements				
1	Safety: Food-grade materials	=	Yes	N/A	Research and Analysis
2	Removeable for maintenance	=	Yes	N/A	Test
6	Back-up battery life	>	72	h	Research and Analysis
5	Back-up battery power/capacity	>	5; 2;	V; Amp;	Research/Test
3	Display Aesthetics (personalized)	=	Yes	N/A	Test
4	Measure temperature Precision	= +/-	Yes 0.5	N/A °C	Test Test

Technical Benchmarking

We reviewed the specifications of four different devices with a similar function to our design: the Homebrew Stuff Hydrometer, Triple Scale Hydrometer Kit, DiFluid Beer

Refractometer, and the Plaato Airlock Hydrometer. The Homebrew Stuff Hydrometer is the simplest and most analog of the devices we reviewed, and it represents the basic function and premise of our device. It is cheap, easy to use and clean, and measures specific gravity, but it is not very precise and requires all of the measuring and data recording to be done manually. The Triple Scale Hydrometer Kit is marginally more accurate than the Homebrew Stuff Hydrometer as it can account for up to 20% alcohol in the test sample and has easier to interpret markings. However, it is still a fully manual device which hinders its usefulness as an example. The DiFluid Beer Refractometer is the last of the manual devices that we looked at, but it offers a few more interesting features than the previous two. The device can measure specific gravity, temperature, degrees brix, and the time that the test was taken. In addition to all this, the device has its own companion app that calculates the alcohol percentage within the test sample automatically and records all the relevant data. Finally, the Plaato Airlock Hydrometer is the closest example of the type of device that we are aiming to design for Beyond the Pale Brewery. It can collect a variety of data including specific gravity, alcohol percentage, and temperature, and record it all on a companion app, and unlike the other devices we investigated it does so automatically at regular adjustable intervals. The primary shortcoming of this particular device is that the airtight seal it creates when attached to a fermentation vessel tends to break and leak air, which can potentially ruin an entire batch.

Device	Accuracy and precision	Measurement update	Ease of use	C O S T	Personalized software and graphing of data	Measures specific gravity/ temperature	Liquid waste And maintenance
 **Home Brew Stuff Hydrometer**	Not very precise: accurate at ±2 % which is huge for a 5% measurement	Manual updating: the beer must be measured by the worker each time	Easy to use but the reading demands a certain knowledge	24$	Since the specific gravity is measured manually, the different densities are not automatically inserted into a software. It will be necessary to create one upstream and add the density values after each test.	Measures specific gravity before the presence of alcohol. Can't measure temperature.	10 times 250 ml per day in each tank = 2,5 l in each tank/ Knowing that there are 16 tanks, 40L are wasted daily The hydrometer can be washed and re-used.

 **Triple Scale Hydrometer Kit**	Not very precise because it measures liquids at 60°C maximum. Unfortunately, our client clearly stated during the interview that the liquid is at 65°C till 77°C	Manual updating: the beer must be measured by the worker each time.	This device is easy to use and to understand because it comes with detailed markings for each drink (beer, wine etc.)	48$	Since the specific gravity is measured manually, the different densities are not automatically inserted into a software. It will be necessary to create one upstream and add the density values after each test.	Can measure potential Alcohol 0%-20%. If it exceeds 20%, the hydrometer is useless. But the beer's amount of alcohol won't exceed 5%, the device is therefore functional for our case. Can't measure temperature.	10 times 175 ml per day in each tank. In 16 tanks: 28L per day which is much better than 40 ml per day Easy to clean and re-usable.
 **DiFluid Beer refractometer**	Moderately accurate: ±1% which is pretty good but not ideal as the specific gravity is measured within 3 significant digits (1.005-1.015)	Manual updating: the beer must be measured by the worker each time.	It must be calibrated by pure water, place one drop of sample onto the refractometer, a short press the button then the result will display within 2s.	294 $	There is an app: Companion App, that can calculate the alcohol automatically and stores all the data: time of testing, temperature, brix and are displayed in graphs	Can measure all the important data: specific gravity, temperature, brix, time of testing etc.	10 drops a day for one tank. 16 ml a day approximately.
 **Plaato Airlock Hydrometer**	Very precise but a gas leak can occur, which leads to a catastrophe because the liquid must be in a closed system	The measurement can be within each hour or each second according to the need. It is smart and automatic, therefore very useful	It must be plugged in to a tri-clover sanitary tri-clamp. using a valve	170 $	The device is paired with a personalized app that gives all the required information.	**Collects the following information:** • Fermentation activity • Specific Gravity • Alcohol percentage • Ambient temperature	No liquid is wasted as the device is plugged in the tank directly.

						But it needs to be constantly electrically powered.	

Ideate

Subsystem Design and Organization into Three Final Products

Using the design criteria, specifications, and technical benchmarking our group performed in the previous phase, we decided to split our final solution into five subsystems: the device for measuring specific gravity, the device for measuring temperature, the method of installation onto the tank, the method of collecting and displaying data, and the back-up power source. Each group member created one conceptual design for each subsystem, which would then be compared and chosen to make up three final designs. These conceptual designs can be viewed in Appendix A, and a table summarizing how these subsystem options were organized into three final products can be found at the end of this section.

For the data display, we narrowed it down to three variants: a monitor installed on-tank that only displays data for that tank, central app that receives data via Bluetooth or Wi-Fi from all the tanks and displays them remotely on one computer, and a combination of the two. On-tank display makes the data easier to read and is simpler to set up but requires each tank to be checked individually. A central wireless display places all the data in one place for viewing but is more complex and may be prone to network errors or slower connection. Combining the two will grant the widest coverage of data display but will be the most complex and costly to install.

Three concepts were highlighted for the installation of the device onto the tank: a sheath installed into the port on the side of the tank that facilitates insertion of sensor probes, a metallic shell that attaches to the port with individual sensors already installed in it, and simply inserting the device into the tank through the port at the top. The sheath would provide the most flexibility in installation as it would allow individual sensor probes to be removed or added without having detach the entire apparatus but would be the most complex to design. The metallic shell would be simpler but would need to be completely removed for cleaning or to replace probes. Finally, installing through the top of the tank would be the easiest method but does not use the ideal port, and therefore would likely have to be taken out more frequently.

Regarding the device to measure specific gravity, two primary options were highlighted by the team. The first was a submersible hydrometer, this type of device is familiar to the client and known to provide exactly the service they asked for, and would be easier to work with, but it requires the hydrometer to be oriented upright when in the tank. The other device has no requirements on positioning but is more experimental. It would be a vibration sensor that detects vibrations in the water and converts that data into specific gravity. This would require knowledge of the algorithms and formulas required to calculate specific gravity from that data.

The temperature sensor is likely the simplest part of the final device and was a decision between simply installing a separate temperature probe into the apparatus or including a temperature sensor directly into the specific gravity probe. Keeping them separate simplifies the design and allows for individual replacement of sensors but involves more working parts than having both functions in one removeable sensor.

Finally, there was the question of a back-up power source. This largely came down to whether or not the group decided a back-up power source was necessary to the final product. We decided that both options would be explored in our three final products. If included, it would take the form of a rechargeable lithium-ion battery installed with the device on the tank, with a protective cover and an automatic transfer switch.

Subsystems	**Device 1**	**Device 2**	**Device 3**
Display	On-tank only	Centralized wireless system	Hybrid: On tank and wireless system
Back-up Power	No back-up battery	No back-up battery	Back-up battery
Installation	Top port of tank	Side port of tank with sealed shell	Side port of the tank with a sheath
Specific Gravity	Submersible hydrometer	Vibration sensor	Submersible hydrometer
Temperature	Included with Hydrometer	Separate probe	Separate probe

Selection of Final Design Components

After organizing our chosen subsystems into three different final designs, we then moved to deciding which of the three designs we would choose as our main design to move worth with and prototype. In order to determine which design to move forward, we listed out the pros and cons of each design, which can be found in a table at the end of this section.

The first option, “Device 1”, is composed primarily of the simplest design features and shaves off most unnecessary features, it still accomplishes the basic task of measuring specific gravity and would easily be the cheapest option for installation. Sacrifices, had to be made for such a streamlined design, however, so it would not be suitable as the primary design but rather a back-up one.

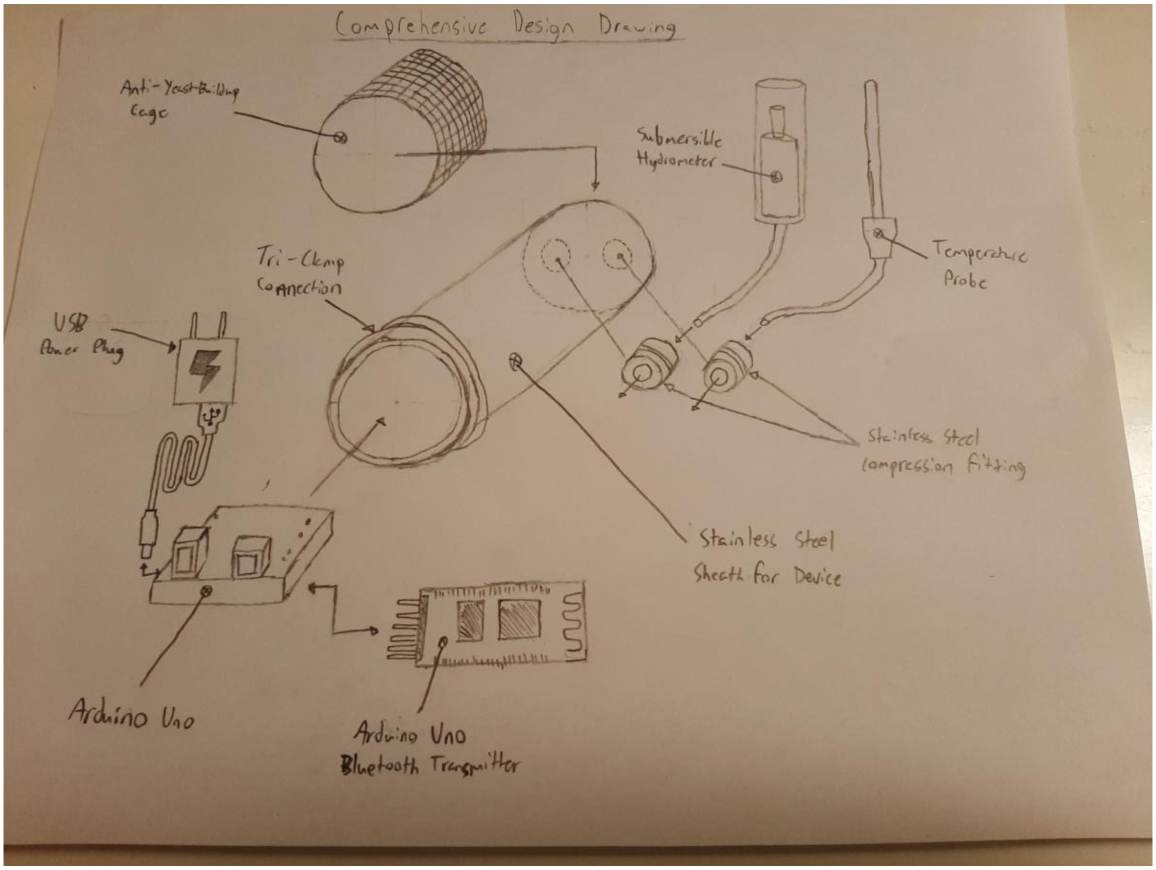
“Device 2” is the most technically complex as it utilizes the more experimental vibration sensor and a centralized wireless data display. It accomplishes the primary objective of the client, uses the more desirable side port, and allows remote access to data, but uses the less flexible installation method and uncertain vibration sensor.

The final design, “Device 3”, is the option that the team settled on as our primary design. It offers the most flexibility in data display, most flexible installation method, includes a back-up power source, and uses the more familiar hydrometer. The primary obstacle of this design is creating a functional sheath and allowing the hydrometer to sit upright once in the tank, but this is something the team is more confident it can overcome.

	Pros	Cons
Design 1	-Easier to install and use hydrometer because of use of top port -No back-up battery means less cost and weight -Likely the cheapest design -Most feasible -Can glance down at tank to see info (simpler)	-No wireless system (more manpower to check each tank individually) -2-in-1 temp is more complicated to make -Does not use the preferred tank port -No back-up battery
Design 2	-Preferred tank port -Separate temp probe is easier -No back-up battery means less cost and weight -Data easily accessible via central wireless system	-Vibration is the most difficult/complicated specific gravity sensor (lots of math to figure out) -No back-up battery -Requires Bluetooth/Wi-Fi connection
Design 3	-Preferred tank port -Separate temp probe is easier -Back-up power -Both display options are available	-Back-up battery means more cost and weight -More complicated requirements for display

Final Design Layout

The final envisioned design for our device centers around a stainless-steel metal sheath that fits snugly into the 3-inch port on the side of the fermentation tank, this sheath will house and the electronics of the device while sealing the inside of the tank from the exterior. Inside the sheath on the side that faces the exterior of the tank, there is the Arduino Uno that will power all of the other components of the device as well as run the code that enables the sensors to measure specific gravity and temperature and the transmitter to send the data to the software component on the client's computer. The sensors themselves are located on the side of the sheath facing the interior of the tank. They are protected by a mesh cage that prevents yeast buildup and their wires feed into the sheath to the Arduino through a pair of stainless-steel compression fittings. The Bluetooth transmitter will be attached to the exterior of the tank near the port so that its transmission remains unobstructed. The Arduino itself draws power directly from an outlet using a USB power plug. The comprehensive design drawing and bill of materials for the final product can be found directly below.



Bill of Material for Final Design

Materials needed		**Cost ($)**
1	Arduino Uno	9.00
2	Temperature Probe	14.00
3	Jumper Wires	0.10
4	Bluetooth Module	22.09
5	USB Cable A-B	7.00
6	Fluid Pressure Sensor	10.99
7	Ultrasonic Range Finder	4.00
8	Circuit Breadboard	2.50
9	3D Print Material	10.00
10	3" sheet metal tube	0
11	Plastic wire mesh stand-in	0
12	Cardboard	0
13	Scotch tape	0

14	Plastic Specific Gravity sensor stand-in	0
15	Webpage visualization software	0
Total		79.68

1. https://edu-makerlab.odoo.com/shop/product/arduino-5#attr=5
2. https://edu-makerlab.odoo.com/shop/product/grove-temperature-sensor-47#attr=
3. https://edu-makerlab.odoo.com/shop/product/jumper-wires-44?search=jumper+wires#attr=46
4. https://edu-makerlab.odoo.com/shop/product/bluetooth-module-9#attr=254
5. https://edu-makerlab.odoo.com/shop/product/usb-cable-68?search=USB+cable#attr=80
6. https://www.canadarobotix.com/products/2760?variant=39439020294193&currency=CAD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic
7. https://edu-makerlab.odoo.com/shop/product/ultrasonic-sensor-60#attr=
8. https://edu-makerlab.odoo.com/shop/product/breadboard-53?search=breadboard#attr=58

Prototype

Prototype 1 and Test Plan

Tables listing the required materials and the test plan for prototype 1 can be found at the end of this section. For the first prototype of the project, we wanted to start looking at the device from a general standpoint and determine whether or not the overall look of the device could feasibly accommodate the tasks we required it to fill. Having a physical object that we could look at in order to better visualize how the device fits together and possibly how might interact with the tank at the brewery would help focus the efforts of our future prototypes on what needs to be changed or what we are uncertain of. Both a low fidelity physical model and a higher fidelity model created with CAD would beneficial; the physical model would allow us to interact with it and the CAD model would provide us with a more detailed picture of it.

Prototype 1

Materials needed	**Cost** ($)
3" sheet metal tube	0
Plastic wire mesh stand-in	0
Cardboard	0
Scotch tape	0
Plastic Specific Gravity sensor stand-in	0
Webpage visualization software	0

Arduino Uno	9.00
Temperature Probe	14.00
Jumper Wires	1.20
USB Wire A-B	7.00
Bluetooth Module	22.09
Total	52.19

Test ID	**Test Objective**	**Description of Prototype used and of Basic Test Method**	**Description of Results to be Recorded and how these results will be used**	**Estimated Test duration and planned start date**
1	Analyze system integration (Stays sealed, mesh stays in place without affecting sensors, parts all connect)	Prototype: Physical (low fidelity) and/or analytical (high fidelity) comprehensive model Materials needed: 3' diameter tube, mesh/metal wire, sensors (models), seal, and/or CAD 3D model Test method: Build the model(s) and analyze the feasibility of the connections/motion	Results: Written notes taken of challenges and changes made to the design Stop criteria: All parts connect and can move as needed	Test duration: 3 hours Start date: November 1, 2022
2	Verifying feasibility of physical requirements (Wires and other hardware must fit in a 3" diameter, 6-18-inch-long shell)	Prototype: Physical comprehensive model of the shell and internal parts. Materials needed: Physical prototype from Test 1, wires and internal hardware or correct dimensions Test method: Place the internal	Results: Notes taken on design challenges and changes to be made to the design Stop criteria: All internal components fit in 3" cylinder	Test duration: 3 hours Start date: November 1, 2022
3	Analyze system integration (Easy to remove)	Prototype: Prototypes from Test 1 Materials needed: Physical model of the tank wall, CAD, or other testing platform Test method: Perform digital and manual tests of insertion and removal of the device	Results: Notes taken on challenges and changes to the design Stop criteria: Device is easy to remove	Test duration: 3 hours Start date: November 1, 2022

4	Get feedback for ideas (Data display system aesthetics and ease of use)	Prototype: Low/mid fidelity focused model of the data display interface Materials needed: Software Test method: Show to client and get feedback	Results: Notes taken of feedback and changes made because of it Stop criteria: Client is happy with the aesthetics, ease of use and function of the display	Test duration: 3 hours Start date: November 1, 2022

Prototype 1 Test Results

Our first prototype test plan focused on trying to visualize the overall shape and layout of the physical prototype, as well as a mock-up design of the data display that the device will be connected to. The overall low fidelity of the model prevents it from being accurate for more intensive and complex tests such as testing the seal or anything related to the function of the sensors, but it works perfectly as a preliminary real-world design that gives both the team and the client something to study and adjust if necessary.

A number of challenges and requirements presented themselves during the process of building the first prototype. The most noticeable and important challenge was the size and length of the wires required to connect all of the electronic components to the Arduino. The inside of the device's shell is a tight space, so the long rubber wire of the temperature probe was difficult to fully insert into the shell and took up a lot of the space. This will be a problem in the final design if left unchanged as there will not be enough room for other wires, especially from the specific gravity sensor. To fix this issue, all the wires used in the final design should be cut to around the minimum size needed for the necessary connects in order to reduce wasted space and improve the cleanliness of the design.

The second most prominent challenge presented during the prototyping process was fitting the wire mesh to the front of the device shell to protect the sensors from yeast buildup. Our attempt to use the wire mesh of a sieve did not work as it was not possible to shape the mesh properly to the shell, as it was likely to break open and unfurl after attaching and left some jagged edges that could be unsafe. As a result, the prototype used a plastic stand-in to emulate the look and purpose of the mesh, and the final design will likely require a custom piece to be designed to the measurements of the device shell in order for it to be successfully integrated.

Another requirement uncovered by the build process was the minimum length of the shell to comfortably accommodate the Arduino Uno, sensors, and wiring inside. This minimum length is 5 inches. This potentially poses an issue if the thickness of the fermentation tanks is significantly less than 5 inches. If this is the case, then the general layout of the device will have to be reformatted to accommodate this incompatibility. If the thickness of the tanks is larger than 5 inches however, then it should not be a problem to lengthen the device's shell, creating even more space for the electrical components inside. This concern will be brought to the client and addressed based on information provided by them.

Finally, the least consequential requirement discovered was how the Arduino Uno would realistically be inserted comfortably into the shell. the interior of the sheath is a curved circle, but the Arduino is a single flat piece. To allow the Arduino to sit properly inside the shell, a piece of cardboard was cut to fit inside, and the Arduino was placed on top of it with some scotch tape to hold it in place. This requirement was easily solved in the prototype itself, and a similar solution could be used for the final design.

Aside from the physical prototype, a mock-up of the data display was created to give an example of what the layout may look like. The general design that our team aimed for was perfectly achievable in the mock-up, with the specific gravity and temperature of each tank displayed on one page, which each tank being selectable to bring up a more thorough list of data and a graph. Images of the physical prototype and data display mock-up can be found in Appendix B: Prototype 1.

Feedback from Client

Preliminary feedback from the client based on pictures of the prototype and overall design concept was mostly positive. The client approved of the concept of a full remote data display that provided easy access to the basic data of all tanks with the ability to quickly access more detailed information on a particular tank of interest. The design's use of the 3-inch side port was also positively received as it was in keeping with what the client stated was the most preferred method of entrance into the tank. Additionally, the concept of the wire mesh was a new addition not specifically asked for by the client that he approved of, as it solves an issue that was not immediately apparent, that of yeast build-up. This feedback is based primarily off of images of both basic prototype and conceptual designs. More detailed and accurate feedback will likely be gathered from the client when he is able to access our prototype in-person in the next meeting with him.

Prototype 2 Test Plan

Test ID	Test Objective	Description of Prototype used and of Basic Test Method	Description of Results to be Recorded and how these results will be used	Estimated Test duration and planned start date
1	Analyze critical subsystem (Does it measure SG, and how accurately)	Prototype: Physical focused mid/high fidelity model of the specific gravity probe Materials needed: Test method: Compare sensor's data with	Results: Comparison of sensor data with theoretical results Stop criteria: Sensor gives an accurate reading (+/- 0.005)	Test duration: November 7-13 Start date: November 8

		calculated densities (3 minimum) with an experiment (measuring the mass and volume of a liquid, calculating density)		
2	Reduce uncertainty (How accurate is temperature measurement) **May not need to be tested	Prototype: Arduino temperature probe Materials needed: Arduino, temperature probe, thermometer (digital and reliable) Test method: Place probe and thermometer in same liquid. Heat or cool the liquid.	Results: Accuracy of the probe compared to the thermometer Stop criteria: Accuracy no more than +/- 0.5°C	Test duration: November 7-13 Start date: November 8
4	Analyze critical subsystem (Data from SG and temperature sensors displays as graphs and tables)	Prototype: Focused digital prototype Materials needed: Coding Test method: Visual test and feedback from user	Results: Written notes and feedback Stop criteria: Data is successfully collected. Data displays in correct format.	Test duration: November 7-13 Start date: November 8
5	Reduce risk of material failure in conditions of use (Functions in presence of alcohol, required temperature, stays sealed, mesh stays in place without affecting sensors)	Prototype: Analytical comprehensive model Materials needed: MATLAB or other test software Test method: Digital test using software	Results: Predicted problems, artifacts, etc. (data from the software) Stop criteria: Materials fit technical requirements	Test duration: November 7-13 Start date: November 8

https://support.rollsbattery.com/en/support/solutions/articles/4347-measuring-specific-gravity : source for SG sensor preferred accuracy

Prototype 2 Changes and Results

Due to the delay of our pressure sensor arriving for testing, we have postponed the practical sensor tests to prototype 3. Instead, we have chosen to focus prototype 2 on the digital aspect of our project in anticipation for the final practical sensor tests over the coming two weeks. The new procedure for prototype 2 consists of two aspects: developing and testing the code used to export data from the sensors to the display and developing early versions of the sensor code and CAD models based on more accurate measurements of the fermentation tank and pressure sensor. The data display code can be written and tested now as it involves only the digital aspect of the project. The sensor code and CAD models are early versions made to prepare ahead of time for the tests conducted in prototype 3. Once all the sensors have been received, we can refine the code by testing the functionality of each sensor, and the CAD models can be 3D printed to test how effectively they seal the electronics off from liquids.

Regarding the development and testing of the data display code, the data collected by our sensors needs to be exported to an external system, where it will take the shape of a data set and graphs in a user interface. As a stand-in for the pressure sensor and temperature sensor, the ultrasonic sensor was used to test the Arduino software's functionalities. (Code from two sources was edited together to get the sensor functioning, and experimental estimations showed that the sensor was decently accurate, but this testing was not pursued further because of its irrelevance to the actual test). Research confirmed the observation that Arduino's Serial Plotter function does not allow the graphs it produces to be exported. So, by modifying open-source Python code found through research (SerialChart), the Arduino program was run through Python and the data was converted by the code into an output of a graph; a PNG saved automatically in a designated file. In short, Arduino's software does not suffice to create the data display interface as designed. Therefore, this test (by method of research-based trial and error) has produced a prototype of the code required to export the data in the desired format.

In regard to the CAD models and sensor code, these were created off of data we had researched rather than off of the components themselves. The CAD model for the device shell was based off the design of prototype 1, but with more precise measurements relative to the fermentation tank. The waterproofing case for the pressure sensor was similarly designed using the dimensions listed its website where it was purchased from and will likely be modified once the sensor has been received. The sensor code is based off of research into examples of code used to run pressure sensors and will be altered and refined once it can be tested practically with our sensor. Images and links to the CAD models and code can be found in Appendix C: Prototype 2.

Feedback From Client

Feedback from the client on our first prototype was unfortunately minimal, so we are hoping to gain more insight on this prototype during our next meeting. The feedback we did receive from the client from the first prototype was still useful, however. We confirmed that the client wants the specific gravity measured by the device converted to degrees Plato, so a formula for that conversion was researched. This conversion formula will be presented to the client for confirmation of its authenticity. Additionally, we confirmed that the thickness of the fermentation tanks is 5” and that the sensor should reach from 1” to 1.5” into the tank at minimum, which allowed us to model the device shell more accurately in CAD. In our next meeting with the client, we hope to present what we have developed in this prototype and receive feedback so we can prioritize what needs changing in our final prototype.

Prototype 3 Test Plan

For the third and final prototype, a number of tests will be performed to confirm the viability and reliability of our sensors and waterproofing cases, as well as our data display code. One these tests have provided satisfactory results, the subsystems of the device can then be combined into the final, refined comprehensive prototype to be demonstrated at Design Day. The full test plan for Prototype 3 can be seen below.

Test ID	Test Objective	Description of Prototype used and of Basic Test Method	Description of Results to be Recorded and how these results will be used	Estimated Test duration and planned start date
1	Analyze system integration	Prototype: Physical mid/high-fidelity comprehensive model of the device Materials needed: Prototype 2, 3D printing, Arduino kit, Test method: Build the prototype. Note any design challenges	Results: Written notes, final prototype, feedback. Stop criteria: Prototype satisfies selected design requirements.	Test duration: November 14-21 Start date: November 15
2	Analyze system integration	Prototype: Mid/high-fidelity model of the data display interface Materials needed: Arduino software, data software	Results: Written notes, final prototype, feedback. Stop criteria: Prototype satisfies selected	Test duration: November 14-21 Start date: November 15

		Test method: Get user feedback. Note any design challenges	design requirements.	
3	Analyse critical subsystem (Does it measure SG, and how accurately)	Prototype: Physical focused mid/high fidelity model of the specific gravity probe Materials needed: Test method: Compare sensor's data with calculated densities (3 minimum) with an experiment (measuring the mass and volume of a liquid, calculating density)	Results: Comparison of sensor data with theoretical results Stop criteria: Sensor gives an accurate reading (+/- 0.1°P)	Test duration: November 14-21 Start date: November 15
4	Reduce uncertainty (How accurate is temperature measurement)	Prototype: Arduino temperature probe Materials needed: Arduino, temperature probe, thermometer (digital and reliable) Test method: Place probe and thermometer in same liquid. Heat or cool the liquid.	Results: Accuracy of the probe compared to the thermometer Stop criteria: Accuracy no more than +/- 0.5°C	Test duration: November 14-21 Start date: November 15
5	Reduce risk of material failure in conditions of use (Stays sealed)	Prototype: Focused physical model Materials needed: 3D printing, CAD models	Results: Notes on problems and their solutions, artifacts, etc. Stop criteria: Sensors will stay dry in the casing	Test duration: November 14-21 Start date: November 15

		Test method: Test if objects of equal size to the sensors stay dry when encased in the 3D printed sensor shells		

Conclusion

Following our meeting with the client from Beyond the Pale Brewing Company, we have determined that the device needs to attach to the fermentation tank and automatically take measurements of the specific gravity at regular intervals and display them remotely for easy interpretation by the brewing team. it should be easy to remove from the tank for cleaning and maintenance, and should function reliably in the environment it will spend extended periods of time in. From these needs, we have determined a range of design criteria that will direct the team in the direction of fulfilling these needs and perhaps designing beyond what is strictly necessary. The user and technical benchmarking have given us examples of what the device might look like, and either reinforcing the seal on the Plaato or making the DiFluid Refractometer function automatically are good challenges to keep in mind for developing a successful final product.

Current Wrike Snapshot

https://www.wrike.com/frontend/ganttchart/index.html?snapshotId=Gj7eI4TruC9zWOWxsouOx7FZPfRydGg0%7CIE2DSNZVHA2DELSTGIYA

Bibliography

Amazon.com: Customer reviews: PLAATO Airlock V3 - WiFi Fermentation Analyzer for Homebrewing. Retrieved October 2, 2022, from https://www.amazon.com/PLAATO-Airlock-Fermentation-Analyzer-Homebrewing/product-reviews/B07KQPKSG5.

Canada, P. S. (2022, August 4). *Power outages - what to do?* Public Safety Canada. Retrieved October 9, 2022, from https://www.getprepared.gc.ca/cnt/rsrcs/pblctns/pwrtgs-wtd/index-en.aspx

Digital Pressure Sensor– Arduino Workshop. (n.d.). Arduino Project Hub. https://create.arduino.cc/projecthub/sarful/digital-pressure-sensor-arduino-workshop-0e43ae

FAQs hardware - plaato airlock. Plaato Help Center. (n.d.). Retrieved October 9, 2022, from https://intercom.help/plaato/en/articles/5004647-faqs-hardware-plaato-airlock#:~:text=No%2C%20the%20Plaato%20Airlock%20needs,provides%20minimum%205V%20and%202amps

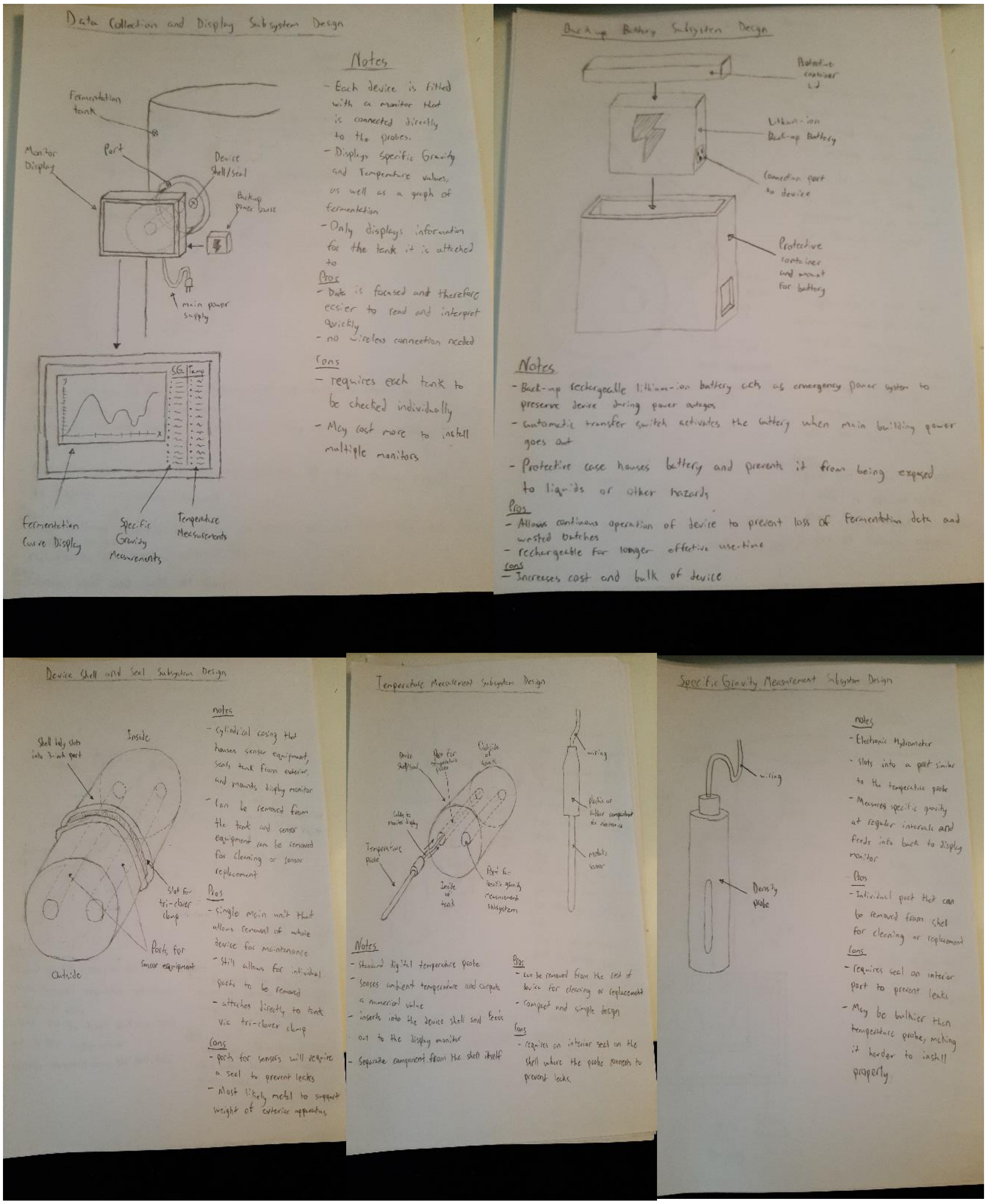
Jabbaar, A. A. (2019, September 17). *Ultrasonic Sensor HC-SR04 with Arduino Tutorial*. Arduino Project Hub. https://create.arduino.cc/projecthub/abdularbi17/ultrasonic-sensor-hc-sr04-with-arduino-tutorial-327ff6

Kazarinoff, Peter D. *Reading a Sensor with Python - Problem Solving with Python*. (n.d.). Problemsolvingwithpython.com. Retrieved November 14, 2022, from https://problemsolvingwithpython.com/11-Python-and-External-Hardware/11.04-Reading-a-Sensor-with-Python/

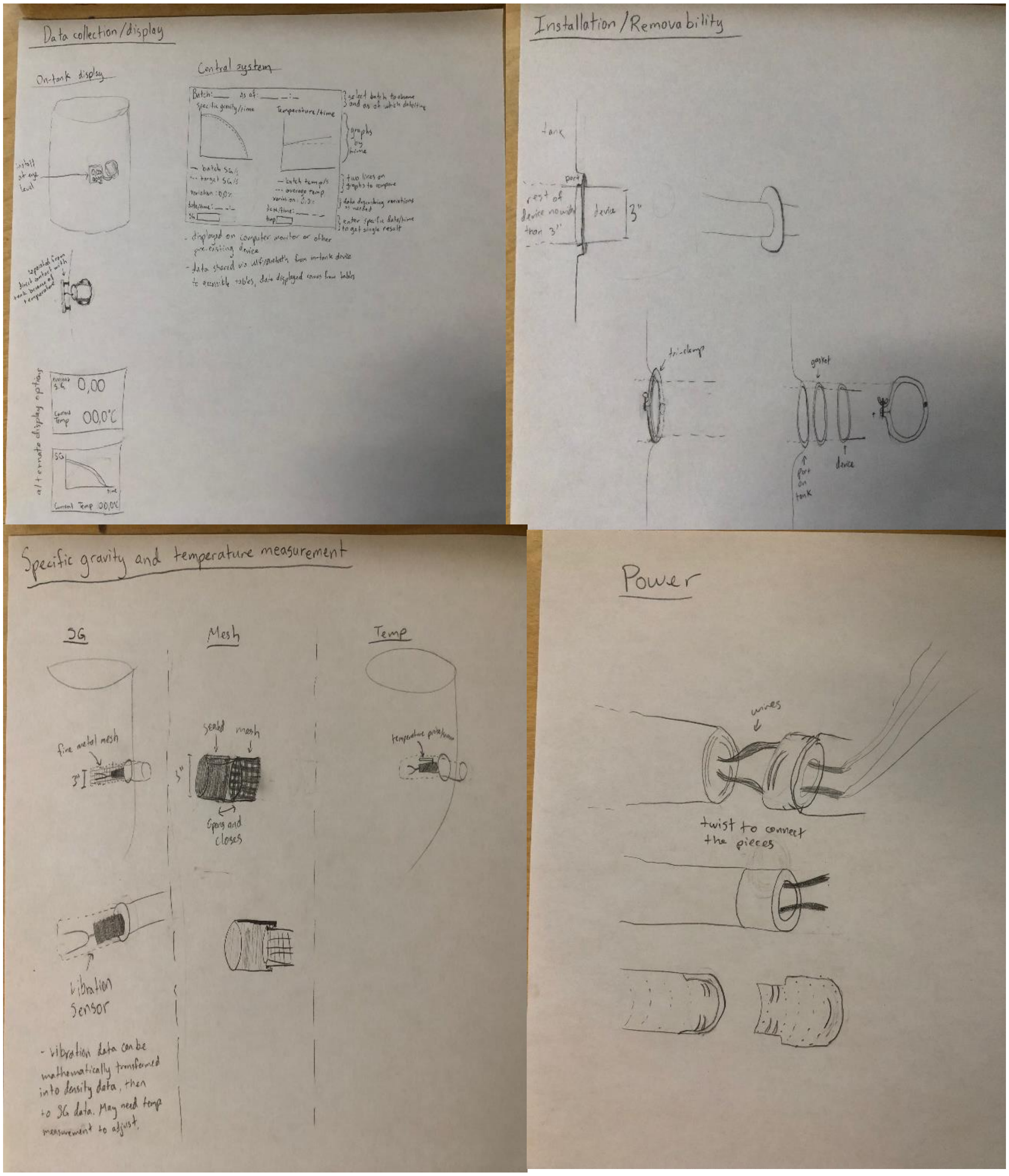
Probert, Brad. (2020, December 28). *Hands on review: Plaato Digital Airlock – WIFI fermentation analyzer for homebrewing*. Homebrew Finds. Retrieved October 2, 2022, from https://www.homebrewfinds.com/2019/02/hands-on-review-plaato-digital-airlock-wifi-fermentation-analyzer-for-homebrewing.html

Appendix A: Ideate Sketches

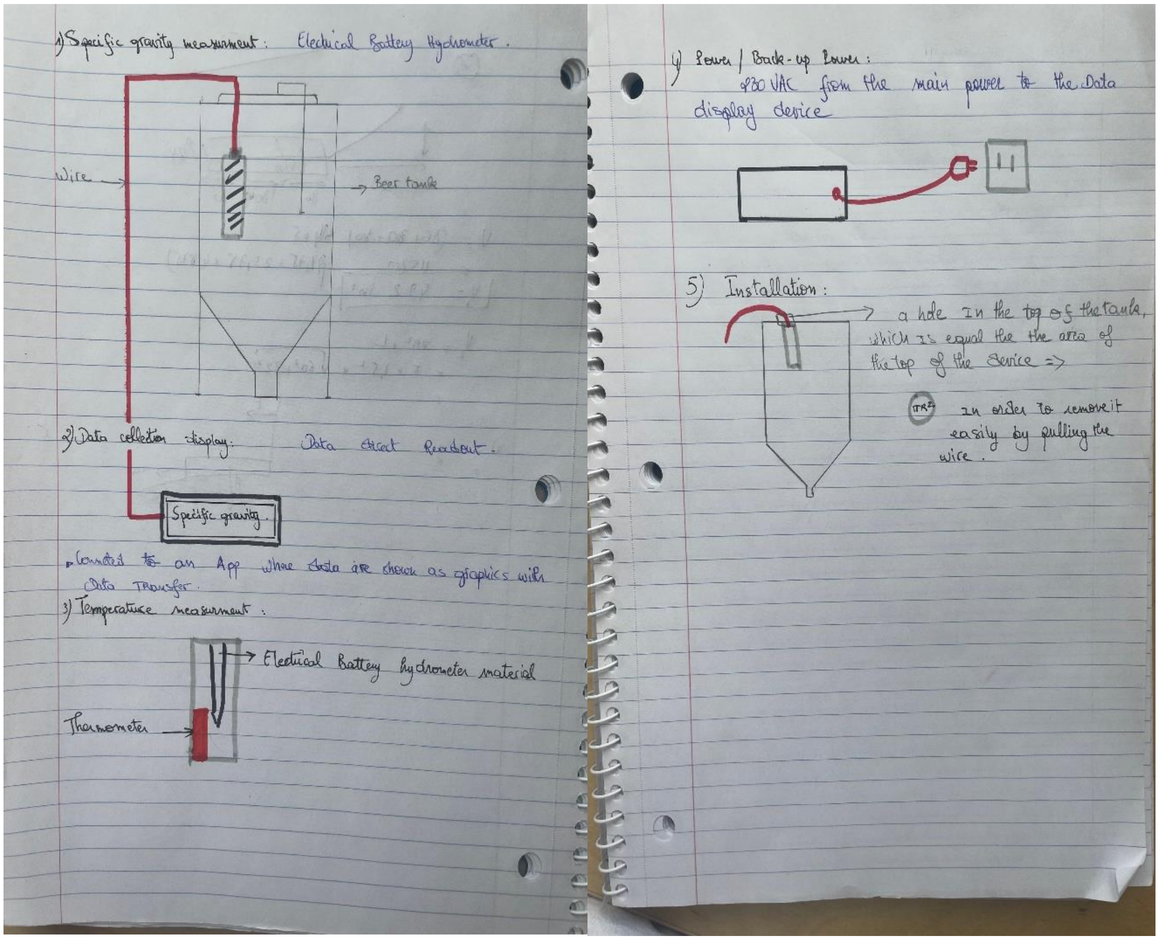
Designs by Patrick Feraday



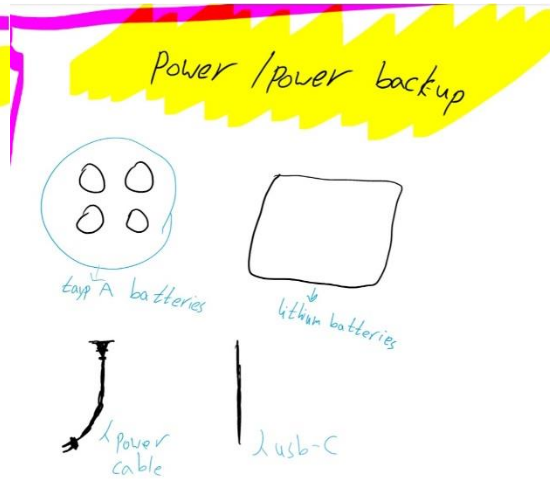
Designs by Juliana Barbieri

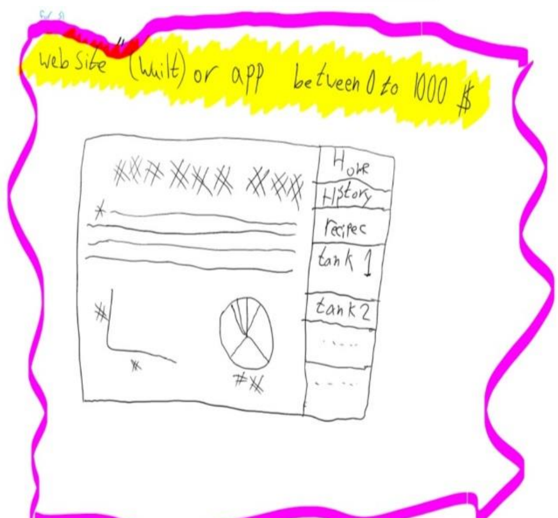


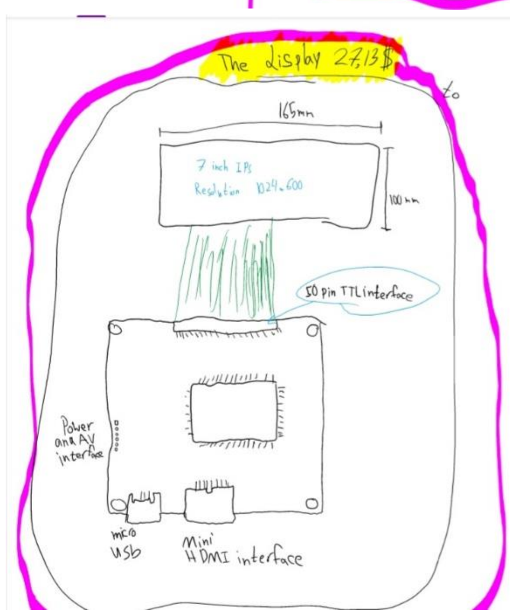
Designs by Hiba Dahrabou



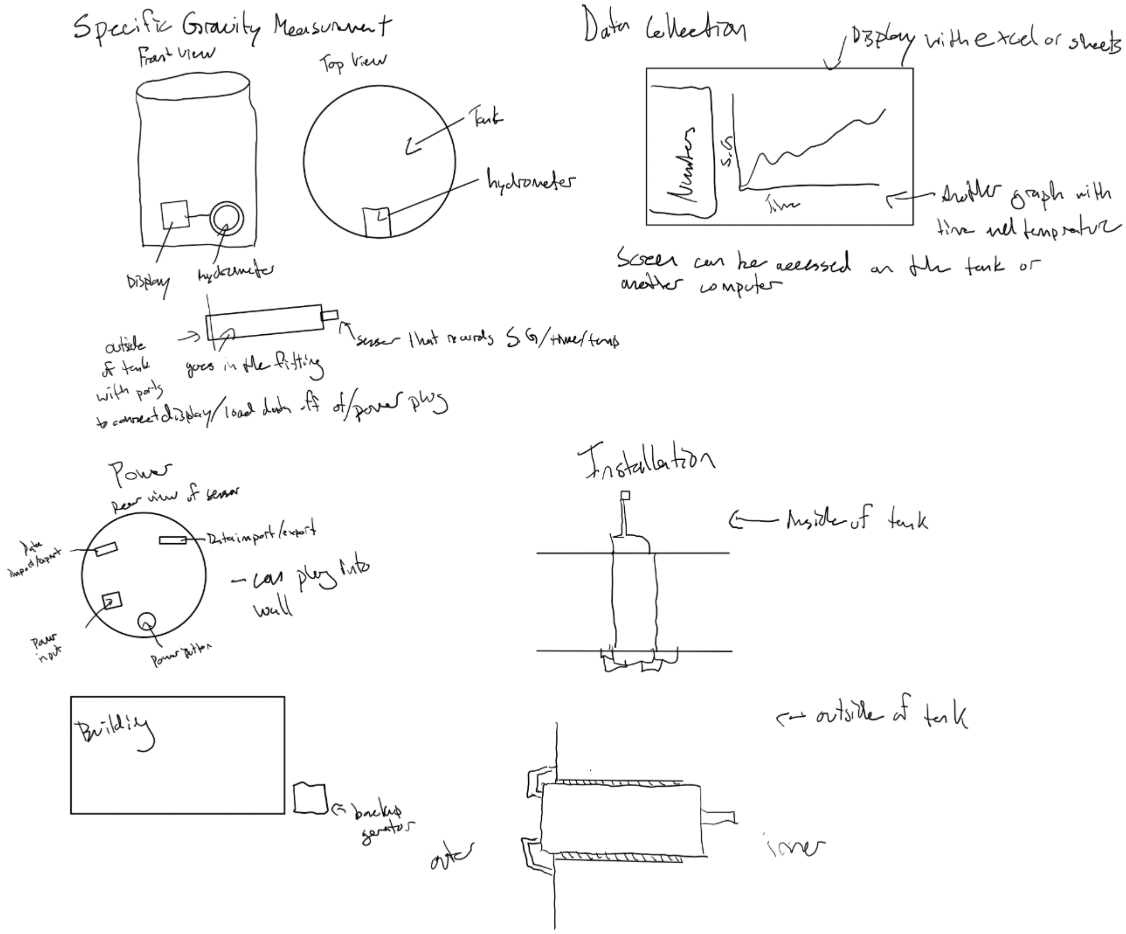
Designs by Jasem Alenezi



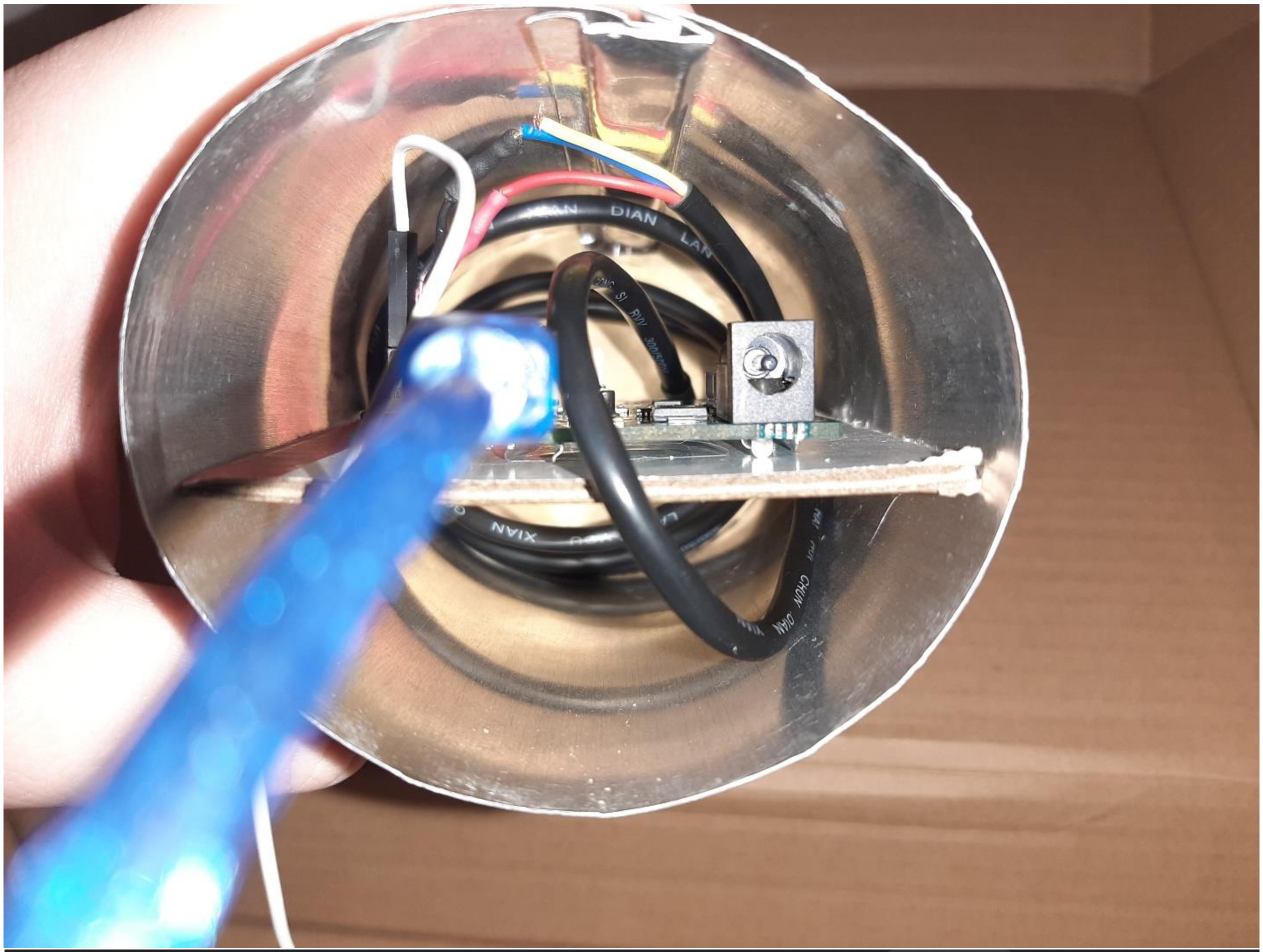


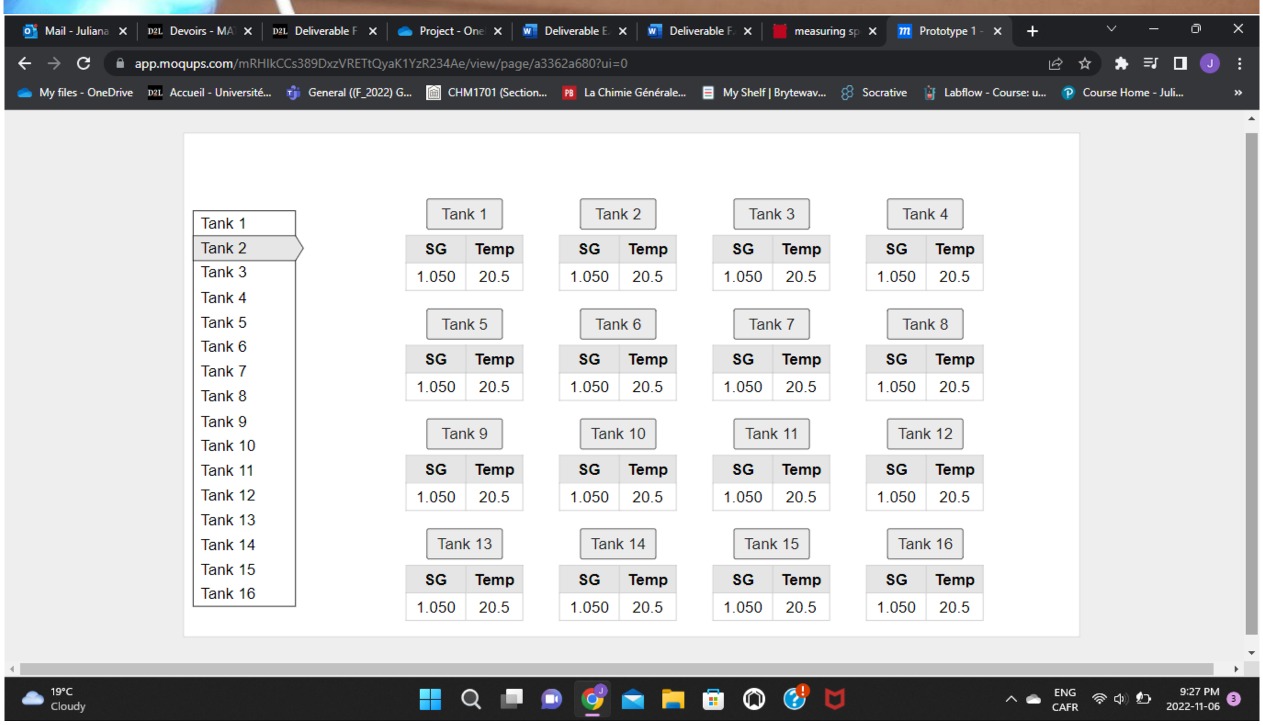


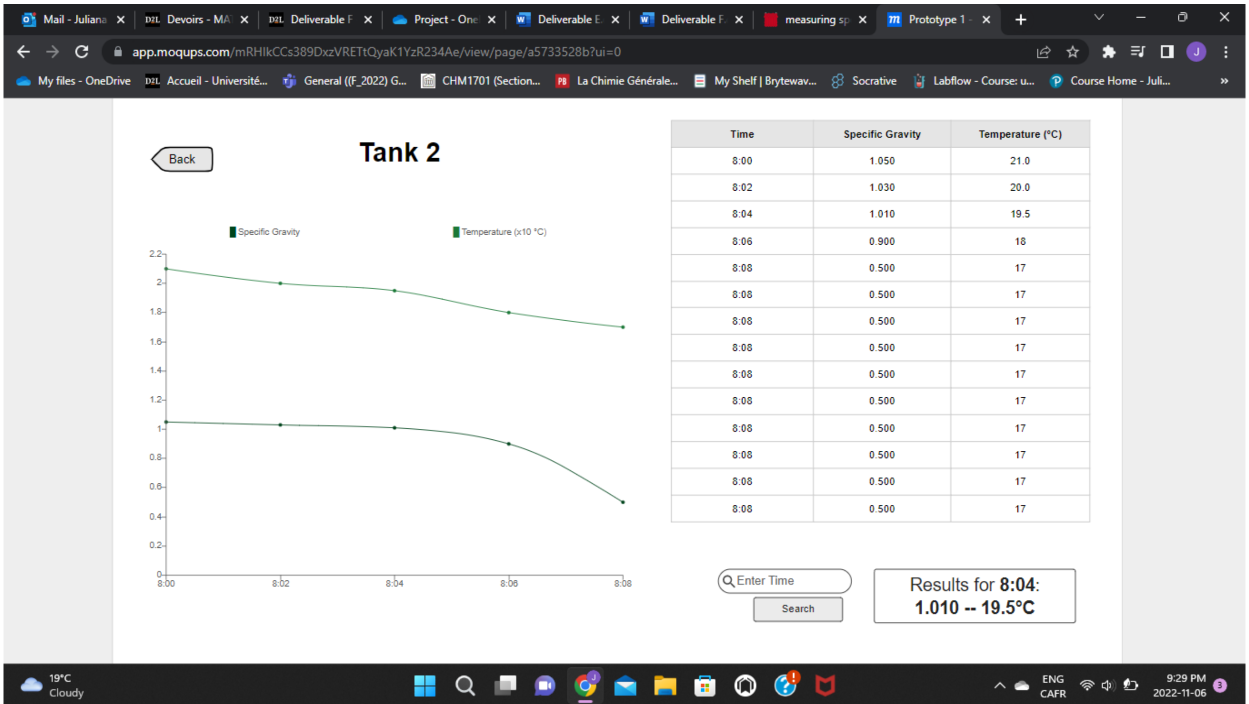
Designs by Keenan Yiptong

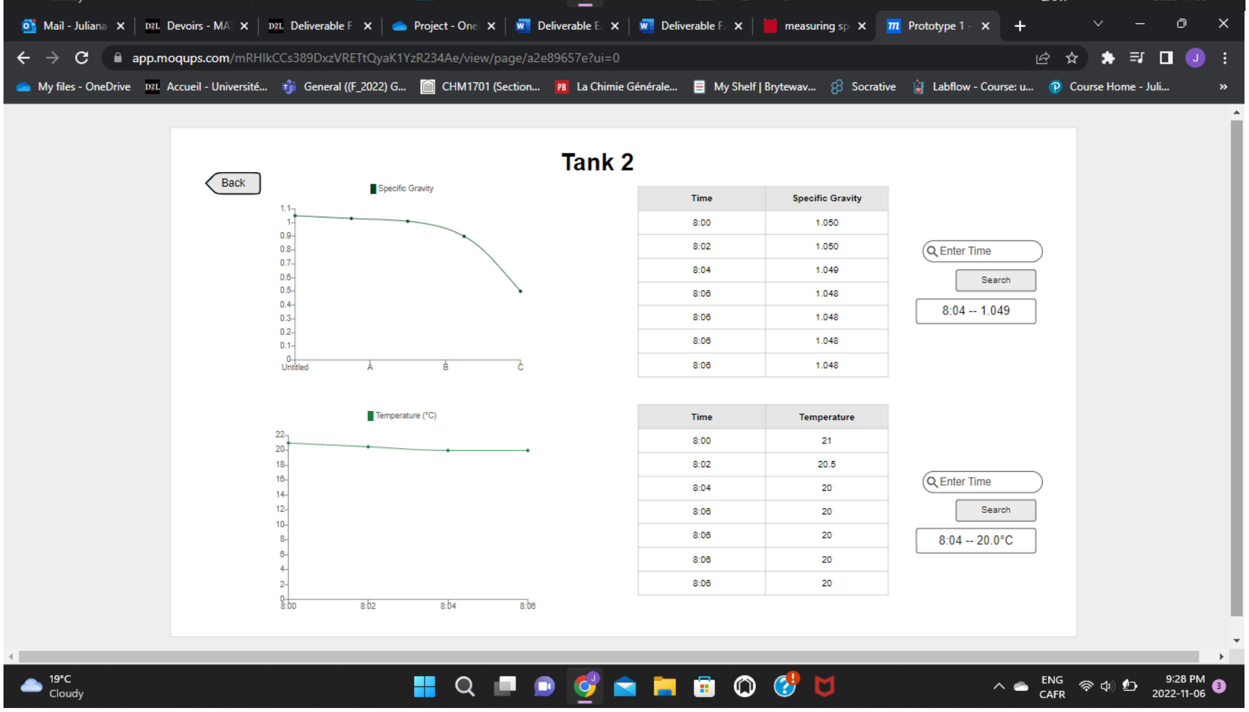


Appendix B: Prototype 1

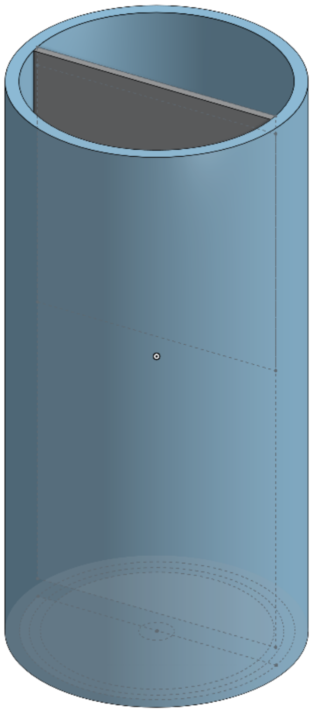


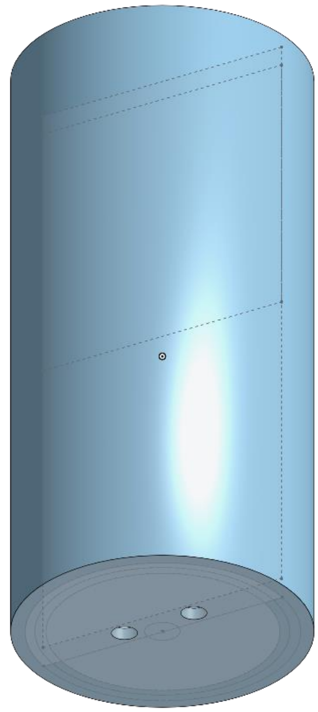

app.moqups.com/mRHlkCCs389DxzVRETtQyaK1YzR234Ae/view/page/a3362a680?ui=0
Tank 1
Tank 2
Tank 3
Tank 4
Tank 5
Tank 6
Tank 7
Tank 8
Tank 9
Tank 10
Tank 11
Tank 12
Tank 13
Tank 14
Tank 15
Tank 16
Tank 1 SG Temp 1.050 20.5
Tank 2 SG Temp 1.050 20.5
Tank 3 SG Temp 1.050 20.5
Tank 4 SG Temp 1.050 20.5
Tank 5 SG Temp 1.050 20.5
Tank 6 SG Temp 1.050 20.5
Tank 7 SG Temp 1.050 20.5
Tank 8 SG Temp 1.050 20.5
Tank 9 SG Temp 1.050 20.5
Tank 10 SG Temp 1.050 20.5
Tank 11 SG Temp 1.050 20.5
Tank 12 SG Temp 1.050 20.5
Tank 13 SG Temp 1.050 20.5
Tank 14 SG Temp 1.050 20.5
Tank 15 SG Temp 1.050 20.5
Tank 16 SG Temp 1.050 20.5
19°C
Cloudy
ENG
CAFR
9:27 PM
2022-11-06

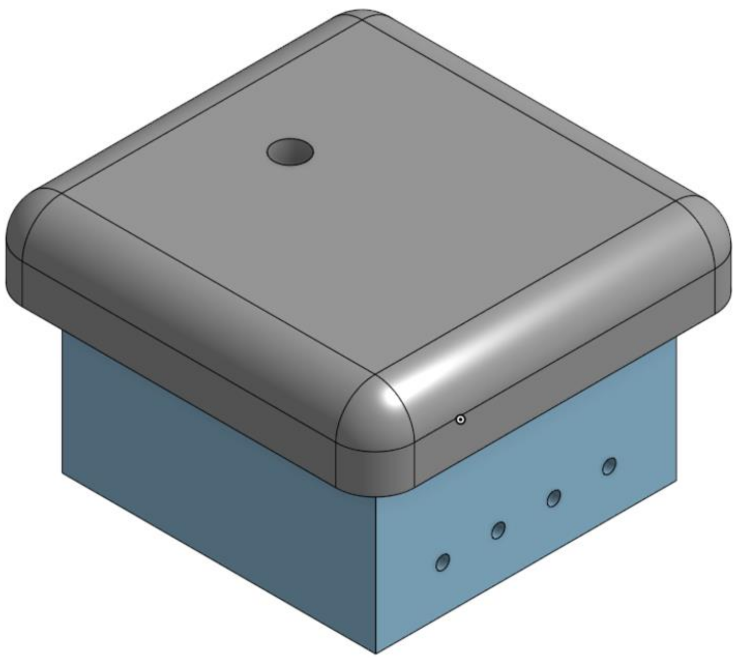

app.moqups.com/mRHIkCCs389DxzVRETtQyaK1YzR234Ae/view/page/a5733528b?ui=0
Back
Tank 2
Specific Gravity
Temperature (x10 °C)
Time | Specific Gravity | Temperature (°C)
8:00 | 1.050 | 21.0
8:02 | 1.030 | 20.0
8:04 | 1.010 | 19.5
8:06 | 0.900 | 18
8:08 | 0.500 | 17
8:08 | 0.500 | 17
8:08 | 0.500 | 17
8:08 | 0.500 | 17
8:08 | 0.500 | 17
8:08 | 0.500 | 17
8:08 | 0.500 | 17
8:08 | 0.500 | 17
8:08 | 0.500 | 17
8:08 | 0.500 | 17
Enter Time
Search
Results for 8:04:
1.010 -- 19.5°C
19°C
Cloudy
9:29 PM
2022-11-06


app.moqups.com/mRHIkCCs389DxzVRETtQyaK1YzR234Ae/view/page/a2e89657e?ui=0
Back
Tank 2
Specific Gravity
Time | Specific Gravity
8:00 | 1.050
8:02 | 1.050
8:04 | 1.049
8:06 | 1.048
8:06 | 1.048
8:06 | 1.048
8:06 | 1.048
Enter Time
Search
8:04 -- 1.049
Temperature (°C)
Time | Temperature
8:00 | 21
8:02 | 20.5
8:04 | 20
8:06 | 20
8:06 | 20
8:06 | 20
8:06 | 20
Enter Time
Search
8:04 -- 20.0°C
19°C
Cloudy
9:28 PM
2022-11-06

Appendix C: Prototype 3







Device Shell:
https://cad.onshape.com/documents/9a6a28fe057df15eedbfc6b2/w/8ff7cb299f0972b69154a065/e/595c3ed12ae9a00e2dd3374f?renderMode=0&uiState=6371253318aa6a57015d2148
Pressure Sensor Waterproofing Case:
https://cad.onshape.com/documents/f66c45a13b4e952344df35f0/w/04ebf9d462e65628db7ac986/e/bcd8487e93806d4a20628324?renderMode=0&uiState=637142b933f5595edf299fdf

- In Python:

```python
import serial

import time

ser = serial.Serial ("COM5",9600)


data =[]                # empty list to store the data

for i in range(10):

   b = ser.readline()        # read a byte string

   string_n = b.decode()  # decode byte string into Unicode

   string = string_n.rstrip() # remove \n and \r

   flt = float(string)      # convert string to float

   print(flt,time.time())

   data.append(flt)        # add to the end of data list

   time.sleep(0.1)         # wait (sleep) 0.1 seconds
```

- Code for Digital Pressure Sensor (the CAD's):

```cpp
#include <Wire.h> // so we can use I2C communication
#define MYALTITUDE 262 //define altitude at your location to
calculate mean sea level pressure in meters
// Register addresses
const int SENSORADDRESS = 0x60; // MPL3115A1 address from the
datasheet
#define SENSOR_CONTROL_REG_1 0x26
#define SENSOR_DR_STATUS 0x00 // Address of DataReady status
register
#define SENSOR_OUT_P_MSB 0x01 // Starting address of Pressure
Data registers
float baroAltitudeCorrectionFactor = 1/(pow(1-
MYALTITUDE/44330.77,5.255877));
byte I2Cdata[5] = {0,0,0,0,0}; //buffer for sensor data
void setup(){
Wire.begin(); // join i2c bus
Serial.begin(9600); // start serial for output at 9600 baud
Serial.println("Setup");
I2C_Write(SENSOR_CONTROL_REG_1, 0b00000000); // put in standby
mode
// these upper bits of the control register
// can only be changed while in standby
I2C_Write(SENSOR_CONTROL_REG_1, 0b00111000); // set oversampling
to 128
Serial.println("Done.");
}
void loop(){
```

```python
   data.append(flt)        # add to the end of data list

   time.sleep(0.1)        # wait (sleep) 0.1 seconds


ser.close()


for line in data:

   print(line)


import matplotlib.pyplot as plt

# if using a Jupyter notebook include %matplotlib inline


plt.plot(data)

plt.xlabel('Time (seconds)')

plt.ylabel('Potentiometer Reading')

plt.title('Potentiometer Reading vs. Time')

#plt.show()


plt.savefig('myplot.png')

plt.close()
```

```cpp
Serial.println("Done.");
}
void loop(){
float temperature, pressure, baroPressure;
Read_Sensor_Data();
temperature = Calc_Temperature();
pressure = Calc_Pressure();
baroPressure = pressure * baroAltitudeCorrectionFactor;
Serial.print("Absolute pressure: ");
Serial.print(pressure); // in Pascal
Serial.print(" Pa, Barometer: ");
Serial.print(baroPressure); // in Pascal
Serial.print(" Pa, Temperature: ");
Serial.print(temperature); // in degrees C
Serial.println(" C");
delay(1000);
}
// Read the pressure and temperature readings from the sensor
void Read_Sensor_Data(){
// request a single measurement from the sensor
I2C_Write(SENSOR_CONTROL_REG_1, 0b00111010); //bit 1 is one shot
mode
// Wait for measurement to complete.
// One-shot bit will clear when it is done.
// Rread the current (sensor control) register
// repeat until sensor clears OST bit
do {
Wire.requestFrom(SENSORADDRESS,1);
} while ((Wire.read() & 0b00000010) != 0);
```