Specific Gravity Sensor

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Partial Design Report

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Introduction

Clients View

During the fermentation process, it is important to know how quickly the sugars are being digested in order to get an estimate of the alcohol content. This process typically requires the brewer to open the container which adds risk of ruining the batch. This is primarily an issue in the scale of home brewing rather than on a larger industrial scale. A potential solution to this issue would be a device that can track the rate of sugar being digested by yeast in a brew without having to open the container. From our client, we were able to gather data that would further develop the need for a new solution and how to proceed in designing it. A typical way that homebrewers would measure specific gravity is by taking measurements before fermentation begins and during fermentation using a hydrometer that floats in the liquid. [2] This existing solution works well but it is limited in multiple ways such as needing to physically be read and monitored by opening the brewing container, battery life, durability, and accuracy. These factors lead to the need for an improvement upon typical hydrometer designs used by homebrewers.

Existing Alternatives

An alternative product is on the market already. It has been done by a company called Tilt. [1] Their product uses a sensor to determine how far the sensor is tilting in the liquid, and determines the density and specific gravity based on that. Their product is somewhat expensive though, priced at $135.00. Besides that product and method, there are no other digital hydrometer products that provide live data and measurements on the market. Other products in this field still require the user to take manual measurements. We hope to implement the digital hydrometer in a more cost effective and efficient manner.

Team FermenTech

Our team is FermenTech. Our team consists of Alex Weiss, Jiangyue Chu, and Michael Chestnut. This group is led by our client and advisor Dr. Kyle Winfree. Dr. Winfree is the Associate Director for Graduate Programs for the School of Informatics, Computing, and Cyber Systems at Northern Arizona University. Each team member is assigned a responsibility to ensure the team operates efficiently. Our treasurer is Alex Weiss. Alex is responsible for keeping track of the funding we have used, ordering necessary parts, picking up the delivered parts, and overseeing whatever else may involve the team's finances. Our secretary is Jiangyue Chu. Jiangyue is responsible for taking notes of the meetings, reporting what has been done so far, what is accomplished each time we meet, and keeping track of the prototypes. Our team leader is Michael Chestnut. Michael is responsible for organizing team meetings, communicating with our client Dr. Winfree, and ensuring the team is properly informed of the latest news.

Problem Statement

Statement of Needs

The problem this project is trying to solve is how to measure the specific gravity of a must or wort without opening the container to take measurements. This is a problem because when you open the container to make measurements there can be bacteria that enters the system and ruins the batch. The product to be developed will be unique in its ability to be used without opening the container and will have the ability to view real time data. The target market for this product will be homebrewer technology.

The marketing requirements include that the system must have the following qualities:

- Accuracy
- Measure specific gravity without opening the container
- Small size
- Provide real time data
- Durability (low frequency of maintenance)
- Easy to use
- Cost effective

Statement of Objectives

The project aims to design and implement a high-precision, user-friendly digital hydrometer/refractometer with the following key objectives and features:

1. The device must be capable of accurately measuring the specific gravity of the brew, with a precision of 0.0025 g/ml, ideally reaching 0.001 g/ml, essential for accurately calculating sugar content.

2. The device must measure temperature, with a precision of 1°C , and the temperature sensor works in a temperature range of 0°C -35°C (32°F - 95°F).

3. The device must be small enough to fit into a 5 gallon bucket.

4. The device must have batteries and continuously work for at least for four weeks.

5. The device must keep real-time measuring temperature and sugar content.

6. The device must be able to store real-time data.

7. Enable data transmission over common IoT protocols (e.g., Wi-Fi, Bluetooth) or include USB connectivity for manual data transfer.

8. The device should include internal diagnostics to alert if any measurement anomalies are detected.

9. The device needs to measure the battery voltage and send a low battery warning when the voltage of a battery drops to a specific value.

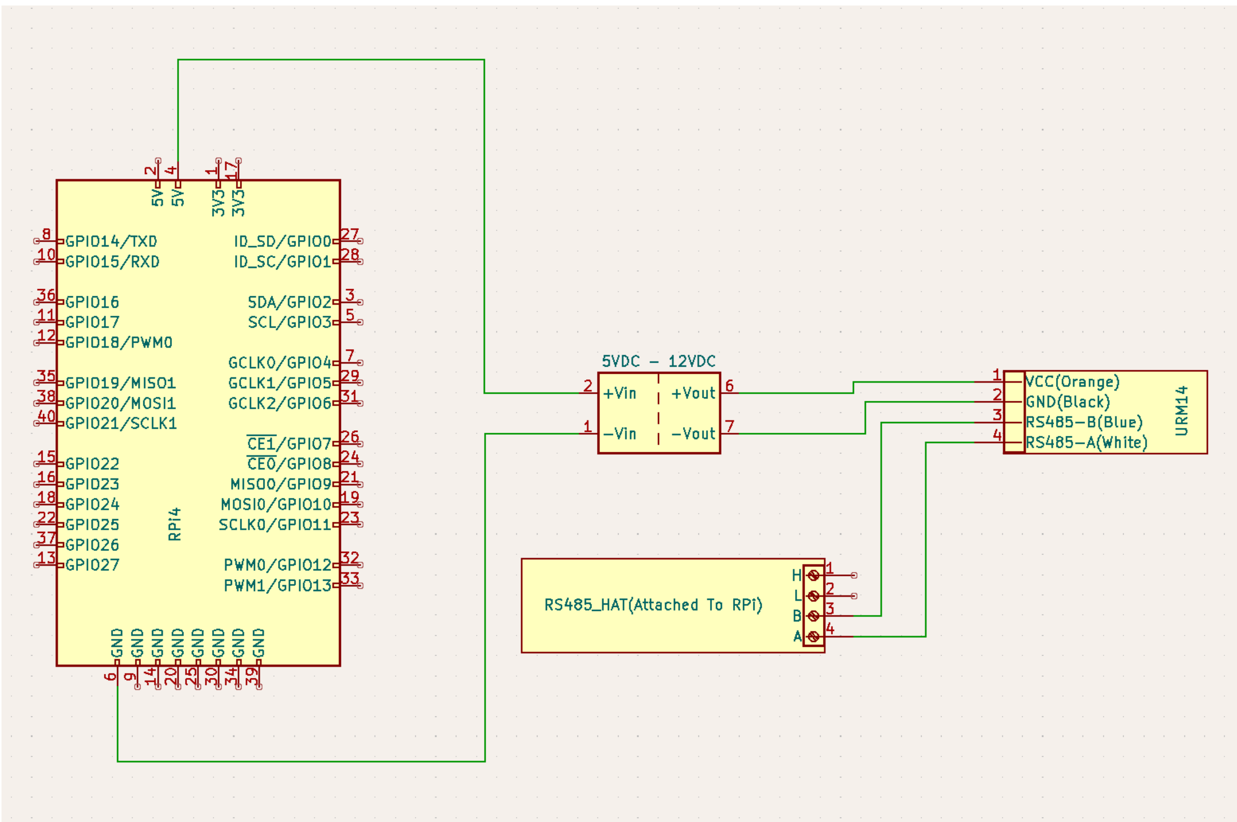
11. The device must allow user calibration to accommodate various specific brewing conditions and requirements.

Concept

About Our Solution

Our solution to the problem at hand involves the use of a precision ultrasonic sensor. The plan for our team is to use the ultrasonic sensor to measure the distance to a bobber floating in the brewing liquid. The bobber will shift slightly in height as the density increases, just as a physical hydrometer does. The ultrasonic sensor will then measure the distance to the top of the bobber. As the height shifts, the raspberry pi will be able to interpolate the shift in height and provide a respective shift in specific gravity. Our ultrasonic sensor also includes a built in thermometer. This means we will be able to satisfy both the specific gravity measurement and temperature measurement with one sensor. The raspberry pi will then take the data and store it into InfluxDB using a client called telegraf. Telegraf simply parses the outputted data and stores it into the database. Once the data is stored into the database, our team will create a live display of the data using Grafana. Grafana is an open source graphing software that we can use to give users a live view of the temperature and specific gravity.

Schematics



In the figure above, we can see the wiring schematic for our sensor. This sensor uses minimal components. The components involved are the RaspberryPi, the DC to DC converter, the RS485 HAT, and the URM14 ultrasonic sensor. 5v is taken from the raspberry pi and runs through a 5v to 12v DC to DC converter. This voltage is then supplied to the URM14. The URM14 is connected to the RS485 HAT, which is connected to the RaspberryPi via header pins. The RS485 HAT handles all RS485 to TTL (UART) communication. Ideally we can convert the

DC to DC converter into another HAT for the RaspberryPi. This would compact the design even further.

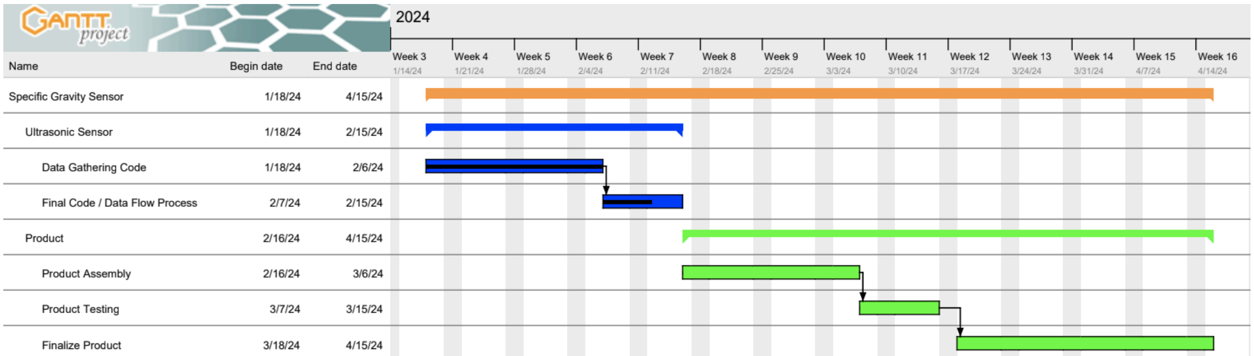
Bill Of Materials

Phase	Item	Qty	Cost
Prototyping			
	Raspberry pi 4	1	$ 65.00
	D1 Mini Pro	1	$ 15.00
	Hall effect sensors (20pc)	1	$ 9.00
	Neodymium magnets (60pc)	1	$ 9.00
	Flex sensor	1	$ 14.00
	lm358 op amps	1	$ 8.00
	Flex sensor	1	$ 12.00
	Wireless Charging Receiver	1	$ 16.00
	RS485 to TTL adapter	1	$ 10.00
	IR sensors	1	$ 10.00
	Other IR sensors	1	$ 16.00
	Voltage Step Up	1	$ 6.00
	Precision Ultra Sonic Sensor	1	$ 110.00
	Wireless Charger	1	$ 16.00
	RS486 CAN HAT	1	$ 17.00
Testing			
	10 ft 1" PVC Pipe	1	$ 13.98
	1" PVC Male Adapter	1	$ 1.17
	1" PVC Female mdapter	1	$ 1.54
	1" PVC Cap	1	$ 1.17
	taxes on above materials	1	$ 2.00
	Sandpaper	1	TBD
	Rubber Gaskets	1	TBD
		Total Cost:	$ 352.86

The table above shows our team's current bill of materials. It can be observed that a majority of the funds were spent in the prototyping phase. This is because our team had many different ideas on how to approach the problem. We finally found a solution that we felt was best. This solution involves the ultrasonic sensor, the RS485 CAN hat, the voltage step up, and all of the testing materials. Our bill of materials shows the many different avenues of prototyping our team took.

Project management

Gantt chart



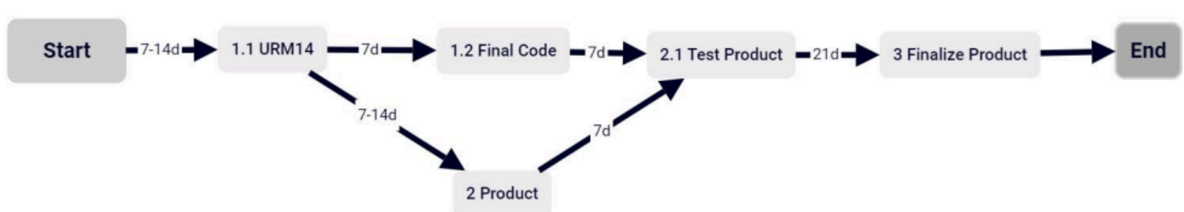
The Gantt chart shown above shows the various tasks that need to be completed to have the specific gravity sensor done on time. The time frame in the Gantt chart is from 1/18/24 to 4/15/25 and begins at that point as that is the time when the ultrasonic sensor was received. Before completing any assembly of the product we must first complete the code for gathering and displaying data. For the product section of our timeline we must first assemble before testing and finalizing the product as shown by the dependencies in the chart.

WBS

ID	Activity	Description	Deliverables	Duration (Days)	People	Resources	Dependencies
1	Specific Gravity Sensor						
1.1	URM14	figure out how to get data off URM14	None	14 Days	Michael	None	None
1.2	Final Code	Finish code and data flow process	None	7 Days	Michael	None	1.1
2	Product	gather parts and assemble product	"prototype"	14 Days	Alex, Jiangyue	None	1.1, 1.2
2.1	Test Product	Test reliability, accuracy, functionaility	improved product	7 Days	Alex, Jiangyue	None	2
3	Finalize Product	Make final improvements	Final Product	21 Days	Michael, Alex, Jiangyue	None	2.1

The work breakdown structure table shown above includes the same tasks as in the Gantt chart, however includes descriptions of each activity, who will complete them, and the deliverables. The coding section is assigned to Michael and is to be completed over three total weeks. The product section is assigned to Alex and Jiangyue and is to be completed over 6 weeks with the main deliverable being the finalized specific gravity sensor.

Pert Network

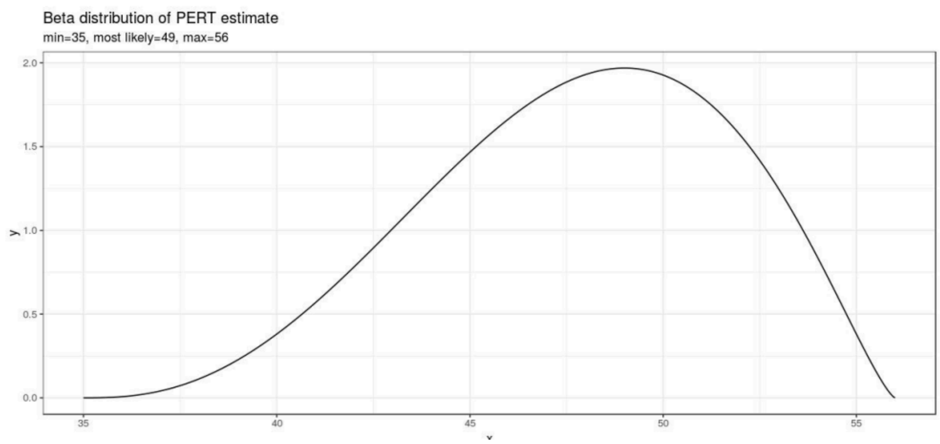


Optimistic time: 35 days

Pessimistic time: 56 days

Most Likely Estimation: 49 days

Pert Distribution Plot:



In the PERT network analysis, we have detailed our project flow and the time required for each part. Specifically, we pointed out that throughout the project process, completing the final code and product assembly can be done in parallel, which significantly increases our adaptability to project changes, allowing us to flexibly adjust the code to deal with emergencies. Additionally, we mentioned the detailed work breakdown from February to April 15th, including the optimistic time, pessimistic time, and the most likely estimation time. These time estimates help us assess the possibility of completing the project under different circumstances and provide us with a data-based method to prepare for the best and worst scenarios. Moreover, according to the PERT distribution plot, this chart visually shows the possible distribution of time required to complete the project, enabling us to better understand the uncertainty and range of variation in the project completion time.

Testing

Preliminary Testing Data

water (mL)	sugar (g)	bobber measurement (mm)	no bobber measurement (mm)	spec grav (g/ml)
210 ml	0	189.7	242.3	1
210 ml	0	189.9	242.5	1
210 ml	0	190.1	242.7	1
210 ml	0	189.9	242.7	1
210 ml	0	189.9	242.5	1
210 ml	4	183.5	242.1	1.01904
210 ml	4	184	241.1	1.01904
210 ml	4	184.2	240.9	1.01904
210 ml	4	184.2	240.9	1.01904
210 ml	4	183.8	240.9	1.01904
210 ml	8	176.2	239.4	1.038095
210 ml	8	176.4	239.1	1.038095
210 ml	8	176.4	238.9	1.038095
210 ml	8	176.2	239.2	1.038095
210 ml	8	176.2	239.2	1.038095
210 ml	12	169.3	236.8	1.057143
210 ml	12	169	236.8	1.057143
210 ml	12	169.1	236.8	1.057143
210 ml	12	169.3	236.5	1.057143
210 ml	12	169.1	236.5	1.057143
210 ml	16	161.7	233.4	1.07619
210 ml	16	161.2	233.4	1.07619
210 ml	16	161.2	233.2	1.07619
210 ml	16	161.6	233	1.07619
210 ml	16	161.4	233	1.07619
210 ml	28	142.9	226.3	1.1333333
210 ml	28	142.9	226.1	1.1333333
210 ml	28	142.7	226.3	1.1333333
210 ml	28	142.9	226.3	1.1333333
210 ml	28	142.6	226.1	1.1333333

In the initial data testing phase, we conducted our first test with an ultrasonic sensor. We utilized a hydrometer as a floating object, placing a 3D-printed cap on top of the hydrometer to facilitate measurements by the ultrasonic sensor. We altered the solution's density by adding sugar, measuring the change in the cap's height due to differences in buoyancy caused by the varying densities. In adding sugar, we adopted a strategy of incrementally adding 4g of sugar starting from 0g up to 16g, then directly increasing to 28g. In terms of code design, we measured once per second and calculated an average every sixty seconds as the final value. For each sugar addition, we collected data five times to ensure accuracy, gathering and analyzing the original experimental data. To ensure data was accurate, each time a measurement was taken, the sensor and testing materials were disassembled and then reassembled before the measurement was taken. This ensured that no unknown variables were influencing the results.

Test Matrix

Tester: Michael Chestnut					
Test case: URM14 sensor					
Set up: measure bob float height with URM14 and observe change in specific gravity					
Test	**Total Sugar Added**	**Expected change in bobber height**	**Obtained**	**Pass**	**Fail**
1	4	> 6mm	~6 mm	✔	
2	8	> 6mm	~8mm	✔	
3	12	> 6mm	~7mm	✔	
4	16	> 6mm	~7.5mm	✔	
5	28	> 18mm	~19mm	✔	

The table above shows our test matrix, showing that we expected a change in bobber height of at least 1.5mm per gram of sugar added. This change in height would ensure that the sensor is accurate enough to detect a small change in specific gravity. As the table shows, we observed changes in bobber height greater than expected on all tests conducted. This indicates a passing grade for all tests.

Testing Results

Change in bobber distance per gram added (mm/g)
1.682142857
Change in water height per gram added (mm/g)
0.578571429
Change in specific gravity per mm change in distance (0-4g) (g/ml)
0.003227119
Change in specific gravity per mm change in distance (4-8g) (g/ml)
0.002610274
Change in specific gravity per mm change in distance (8-12g) (g/ml)
0.002682817
Change in specific gravity per mm change in distance (12-16g) (g/ml)
0.002411013
Change in specific gravity per mm change in distance (16-28) (g/ml)
0.002991796
Change in specific gravity per mm change in distance (0-28g) (g/ml)
0.002830856

Average Change In Specific Gravity Per mm of Bobber Height Difference (g/ml): 0.002792313

Through our preliminary testing we were able to extract some valuable information including the smallest change in specific gravity we can measure, change in bobber distance per gram of sugar, and change in water height per gram of sugar. We found that the average change in specific gravity per mm of bobber height difference was approximately 0.0028 g/mL. This information tells us that we still have some work to do on improving the accuracy to the clients expectation of 0.0025 g/mL. By finding the change in bobber distance per gram of sugar that was added we are able to determine how much of a change in height we can expect in real application which will impact our overall design including the height of the tube required. The change in water height per gram of sugar added that was measured without the bobber will tell us how much we can expect to offset our distance measurements by accounting for sugars or fruits that are added to the liquid. Overall, our preliminary results will guide our next steps in designing our product to meet requirements.

Conclusions

As we enter the critical phase of project development and testing, we have made significant progress this semester. So far, after experimenting with various possible solutions for the project last semester, we have decided to ultimately use an ultrasonic sensor for measurement of the specific gravity during the brewing process. Initial testing data shows that the average change in specific gravity per millimeter of bobber height difference was approximately 0.0028 g/mL, which is very close to the client's requirement of 0.0025 g/mL. Additionally, we are in the process of assembling the model and debugging the final code to meet the client's demands.

Timeline

1. Product Assembly and Improvement: Our project's progress is largely in line with our Gantt Chart. We have attempted to assemble the product but found that improvements are needed in selecting the final floating object and the measurement range of the ultrasonic sensor. Therefore, we plan to select a more suitable floating object within the next 1 week and complete the product assembly, aiming to maintain more stable data measurements from the ultrasonic sensor.

2. Product Testing and Data Analysis: After assembly is complete, we will test the product again and collect data, anticipating that this process will take about one week. Through this phase of testing, we hope to validate the key functions and performance indicators of the product, providing data support for improving measurement accuracy.

3. Code Finalization and Accuracy Enhancement: After completing data analysis, we will finalize our code and product design to achieve the measurement accuracy expected by Dr. Winfree. We estimate that this process will take 2-3 weeks. The goal of this phase is to ensure that the product is not only technically feasible but also capable of providing accurate and reliable data in practical applications.