Specific Gravity Sensor

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EXECUTIVE SUMMARY:

Brief Overview

In the brewing of mead, wine, or beer, monitoring the rate at which yeast digests sugars is crucial as it directly relates to the alcohol content and quality of the final product. Currently, this process typically involves manually opening the fermentation container periodically to measure the specific gravity of the must, a process that is not only tedious but also poses a risk of contamination each time the container is opened. In addition, although there are some products on the market that calculate changes in sugar content during brewing by measuring gravity using inclination angles, these products have certain issues.

The innovation of this project lies in the development of a new type of IoT device capable of accurately measuring the specific gravity of the brew to a precision of 0.001 g/ml without the need to open the fermentation container. This significantly reduces the risk of contamination while providing brewers with a convenient, real-time method to monitor the brewing process, ensuring yeasts are properly nourished for ideal fermentation results.

Furthermore, the successful development and implementation of this device will bring about revolutionary changes in the brewing industry, especially in the realm of small-batch and craft brewing. In the long run, this technology has the potential to be integrated with automated nutrient dosing systems, further optimizing the precision and convenience of the brewing process.

Proposed Solution

During this week and earlier experimental processes, we initially proposed several solutions to achieve this experimental goal and attempted to conduct early data collection. We preliminarily put forward the following two solutions:

1. Utilizing the principle that different sugar contents in liquids lead to different refractive indices, we use a laser to determine the refractive index of the fermenting liquid, thereby measuring the liquid's sugar content.

2. Utilizing a principle similar to that of a hydrometer, the sugar content is determined by measuring specific gravity through the resistance values measured when immersed.

STATEMENT OF NEEDS:

Marketing Requirements

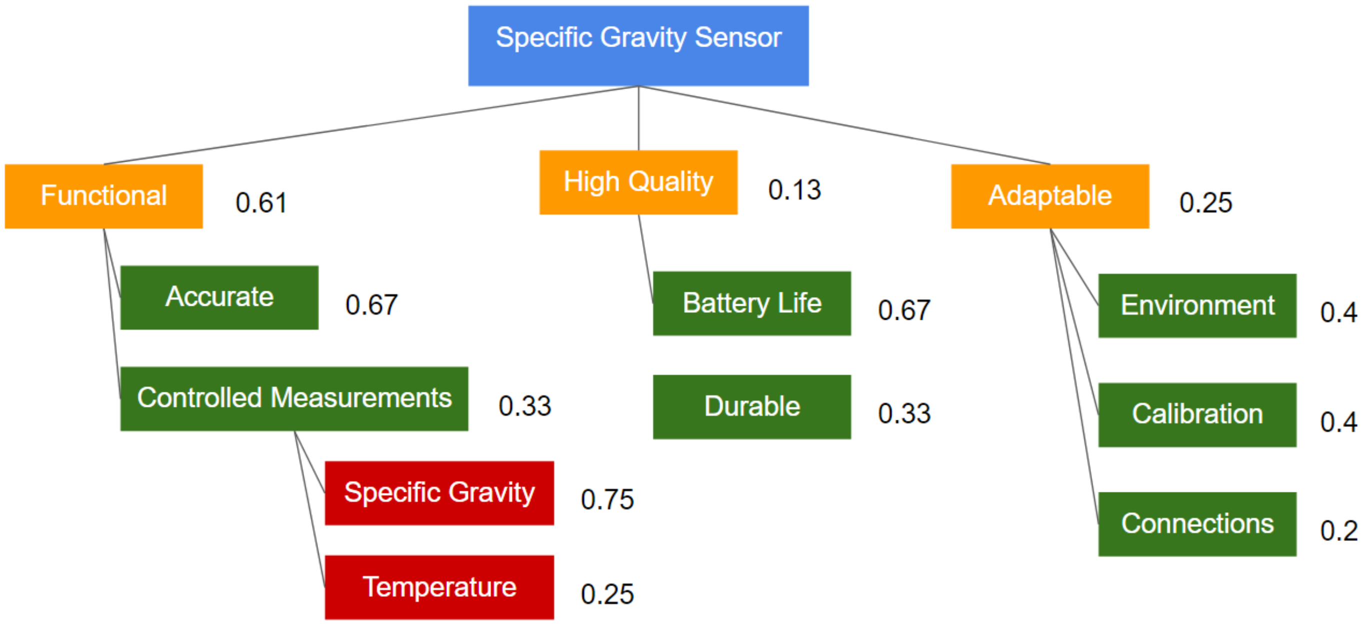
The problem this project is trying to solve is how to measure the specific gravity of a must or wort without opening the container to take measurements. This is a problem because when you open the container to make measurements there can be bacteria that enters the system and ruins the batch. The product 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. Current alternatives to this product include hydrometers and refractometers that take individual measurements every few days by opening the container to estimate the specific gravity. The success of this project will be determined by meeting both the qualitative marketing requirements and specific technical requirements.

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

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

Objective Tree

This objective tree outlines the requirements of our project, a specific gravity sensor. The tree goes from general to specific from top to bottom starting with the final product, the specific gravity sensor. The three qualitative objectives for this project include functionality, quality, and adaptability. The device being functional is the most important out of those three because if it cannot accurately measure the specific gravity and temperature of a must or wort then the device will have failed entirely. Measurement of the specific gravity is also more important than measuring the temperature because that is the most important requirement of the customer. The next most important objective is to have the device be adaptable. This includes adaptability to the environment it is put in, calibration, and connections. The device must be adaptable to different liquids that could have fruits floating at the top or sediment at the bottom. The calibration of the sensor needs to be configurable by the user and the connections whether they are USB, network, or both must be adaptable and easy to use by the user. The device also needs to be high quality which includes its battery life and durability. Specific battery life was one requirement of the customer so it is weighted heavier than durability, but it still needs to be durable or the device could break and require repair or replacement.



Pairwise Comparisons

	Functional	High Quality	Adaptable	Sum	Weight
Functional	1	4	3	8	0.61
High Quality	0.25	1	2	3.25	0.25
Adaptable	0.33	0.5	1	1.83	0.14
				13.08	

	Accurate	Controlled Measurements	Sum	Weight
Accurate	1	2	3	0.67
Controlled Measurements	0.5	1	1.5	0.33
			4.5	

	Battery Life	Durable	Sum	Weight
Battery Life	1	2	3	0.67
Durable	0.5	1	1.5	0.33
			4.5	

	Specific Gravity	Temperature	Sum	Weight
Specific Gravity	1	3	4	0.75
Temperature	0.33	1	1.33	0.25
			5.33	

	Environment	Calibration	Connections	Sum	Weight
Environment	1	1	2	4	0.4
Calibration	1	1	2	4	0.4
Connections	0.5	0.5	1	2	0.2
				10	

Expectations of Stakeholders

The primary stakeholder for this project is the client who provided the project description. The expectation of the client is to provide a sensor that is able to measure both the specific gravity and temperature of a brew with a software that records and displays those measurements. The timeframe for these expectations will be to have multiple prototypes and a strong understanding of the physics used before the spring and by the end of the spring to complete these prototypes and show results with an actual brew.

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, ideal reaching 0.001 g/ml, essential for accurately calculating sugar content.

2. The device must measure temperature, with a precision of 0.1°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.

SYSTEM REQUIREMENTS:

Technical and functional requirements:

- Sensor must be able to measure specific gravity of a liquid
- Sensor must be able to measure temperature
- Must be able to send data to a recording source
- Project must provide real time data viewing
- Sensor must be able to function independently for a given time period
- Calibration of sensor must be configurable by the user

Hardware, software, and performance requirements:

- Sensor must be accurate within .0025 - .01 g/ml (Ideally .001 g/ml)
- Sensor must be able to function independently for 4 weeks at a time
- Hardware must be small enough to fit into a 5 gallon bucket
- Software must aid in the computation of specific gravity
- Software must be used to store data
- Software must be able to give users access to live data

Engineering trade-off matrix (include some discussion):

Engineering Requirements

Engineering Requirements	Independent Function Time	Accuracy	Size
Independent Function Time		↓	no correlation
Accuracy			↓
Size			

Correlations

KEY:
more is better
less/smaller is better
not applicable

In the above engineering tradeoff matrix, we can see the Engineering requirements for this project compared against each other. The three criteria are independent function time, accuracy, and size. For independent function time, we can see that the longer the sensor can go without being checked on, maintained, or charged, the better. For accuracy, we can see that it is better for the sensor to be more accurate. For size, we can see that the sensor being smaller is better. The tradeoff matrix shows a negative correlation between independent function time and accuracy. This is because if the sensor constantly needs to be serviced or adjusted, that may impact the accuracy of the sensor. Likewise, if the accuracy of the sensor is not up to par, the sensor will need to be adjusted. For independent function time and size, we can see that there is no correlation between these two requirements. When looking at accuracy compared with size, we can see another negative correlation. This could be due to the tolerances of the sensor or the size of the components used. For this project, it is projected that a larger sensor with more complex components will perform better than a smaller sensor composed of simpler components. As size increases, so too will the accuracy of the sensor.

Engineering-marketing tradeoff matrix (include some discussion):

Engineering Requirements

Marketing Requirements	Independent Function Time	Accuracy	Size
Ease of Use	↑	No Correlation	↑
Live Data	↑	↑	No Correlation
Accurate and Precise	↑	↑	↓
Low Cost	↓	↓	↑
Frequency of Maintenance	↑	↑	No Correlation

Correlations

KEY:
more is better
less/smaller is better

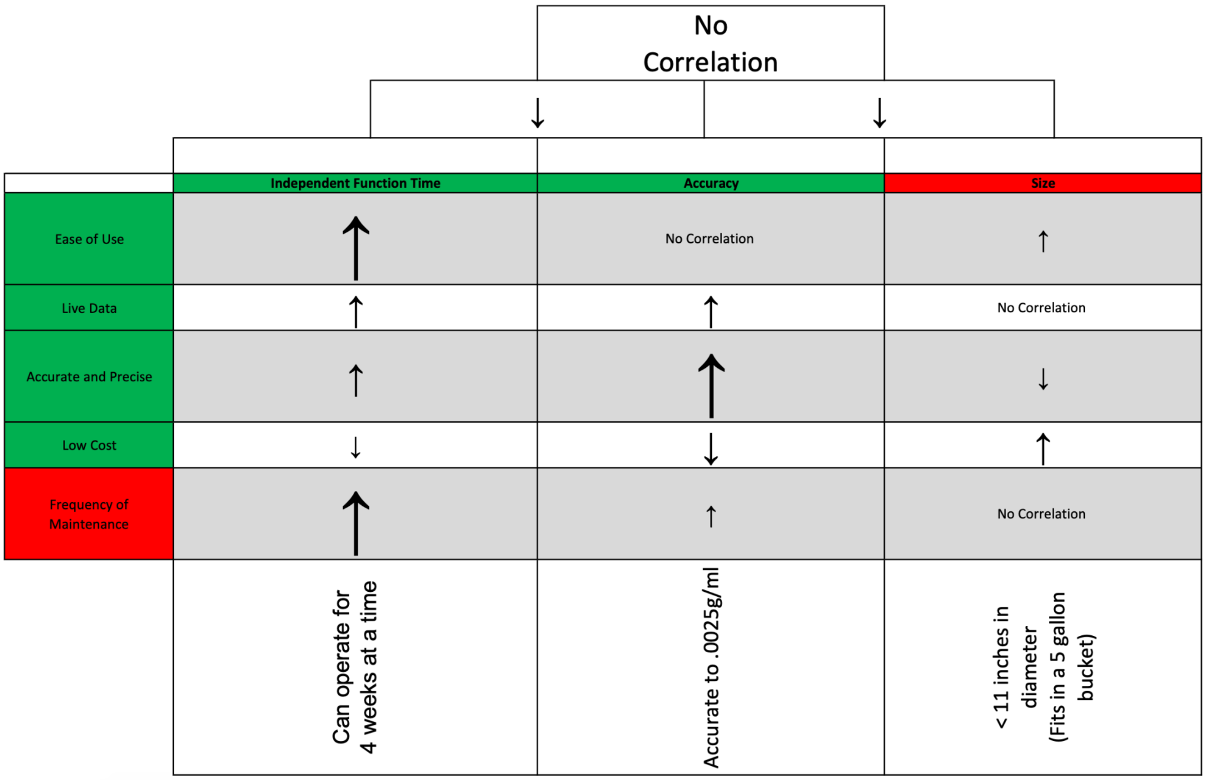
The above figure shows the engineering-marketing tradeoff matrix. Here we can see a positive correlation between independent function time and ease of use, live data, accuracy/precision, and frequency of maintenance. This is because as the sensor independence increases, the sensor will be easier to use, live data will be more accessible, the sensor will be more precise and accurate, and the frequency of maintenance will surely decrease. However, a negative correlation is shown with low cost because it will likely cost more money to implement methods of sensor independence. Accuracy shows no correlation with ease of use, but positive correlations with live data, precision and accuracy, and frequency of maintenance. An accurate sensor will provide better live data, better precision and accuracy, and require less maintenance. Another negative correlation is shown between accuracy and low cost, because a more accurate sensor will likely be more expensive. The matrix shows that size has no correlation with live data and frequency of maintenance, but a positive correlation with ease of use and low cost. A smaller sensor will be easier to handle/use, and a smaller sensor will likely cost less to produce because there is less material involved. Finally, it can be seen how a smaller sensor can impact the accuracy and precision negatively.

Benchmark comparing existing options:

	Tilt hydrometer	EasyDens	Our project
Accuracy	+ - 0.002	+ - 0.001	+ - 0.0025
Live Data	Yes	No	Yes
Cost	$135	$399	$100
Battery Life	12-24 months	40 hours	4 week minimum

The table above compares two digital hydrometer options available on the market today with our own design. Four criteria are used to compare these; Accuracy, capability of live data, cost, and battery life. We can see that our sensor is the least accurate of the three, but by a very small margin. It is shown that both Tilt and our project are capable of live data, but EasyDens is not, as you must take measurements every time you want to gather your data. We can see that our project is projected to be the cheapest of the 3, being slightly cheaper than Tilt, and a quarter of the cost of EasyDens. Finally, our project has a 4 week minimum battery life, putting it ahead of EasyDens, but very far behind Tilt's year long battery life.

House-of-quality:



The figure above displays the house of quality for this project. This compares the engineering requirements of the project with themselves and shows their correlation. This figure simultaneously compares the engineering requirements with the marketing requirements and displays their correlation as well. The top pyramid shows the correlations between each engineering requirement. The central box compares the engineering and marketing requirements. The bottom 3 boxes further describe the engineering requirements. The color coding has meaning as well. Green means that more is better, and red means that less is better. The size of the arrows also signify the strength of the correlation, meaning a larger arrow represents a stronger correlation.