Specific Gravity Sensor

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Report 2

12/01/2023

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Introduction

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. The goal of our project is to develop an IoT device that accurately measures a brewing liquid's specific gravity to 0.001 g/ml accuracy during fermentation. The device will also measure the temperature of the liquid. Our device will eliminate the need to open brewing containers to check on the brew, which reduces contamination risk and manual effort. Our sensor will also display real-time data, providing brewers a convenient monitoring solution. A similar 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 very 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.

Statement of Needs

Customer Requirements

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.

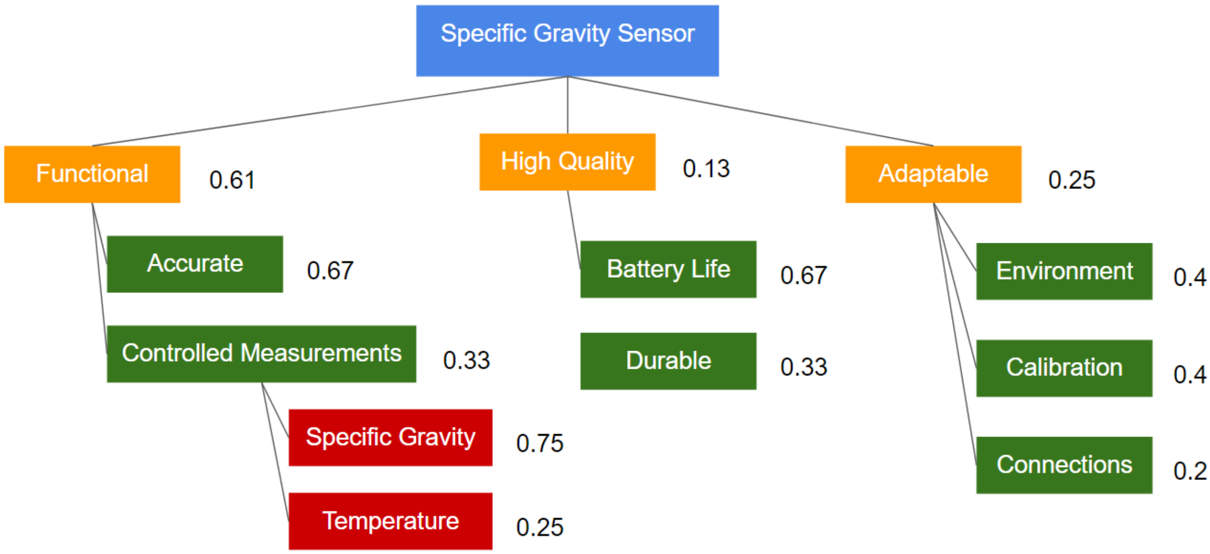
Statement of Objectives and Objective Tree

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.

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



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.

System Requirements

Engineering-Marketing Trade Off Matrix:

Engineering Requirements

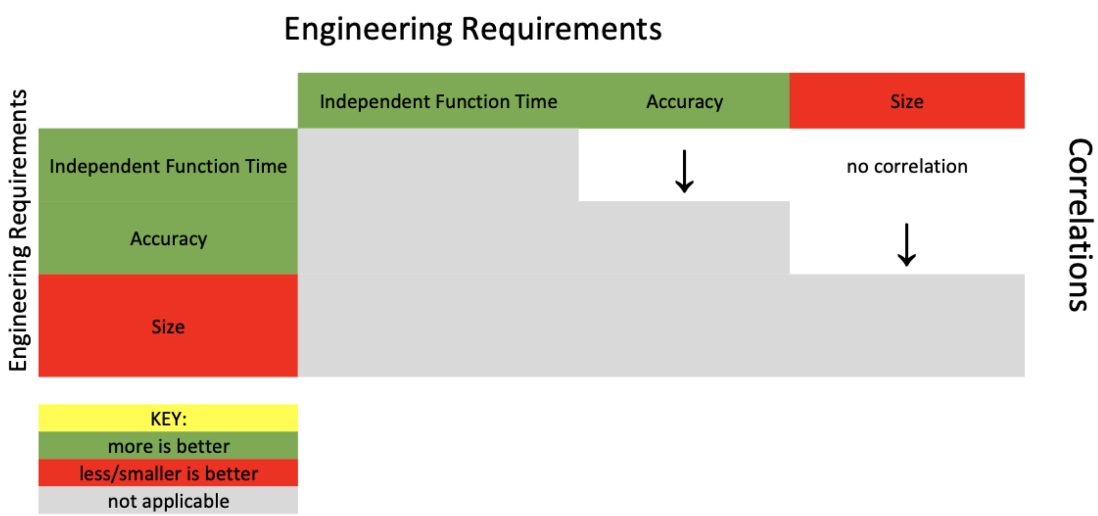
Marketing Requirements	Independent Function Time	Accuracy	Size
Ease of Use	↑	No Correlation	↑
Live Data	↑	↑	No Correlation
Accurate and Precise	↑	↑	↓
Low Cost	↓	↓	↑
Frequency of Maintenance	↑	↑	No Correlation

Correlations

KEY:
more is better (green)
less/smaller is better (red)

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.

Engineering-Engineering Trade Off Matrix:



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.

House-Of-Quality:

No Correlation

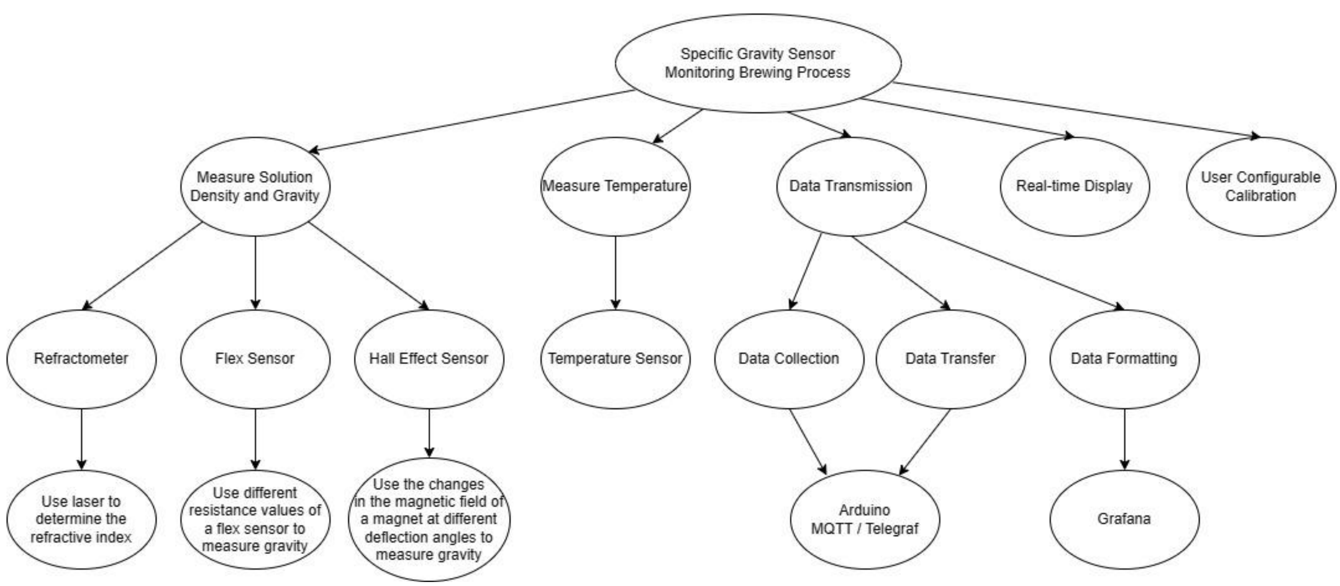
↓ ↓

	Independent Function Time	Accuracy	Size
Ease of Use	↑	No Correlation	↑
Live Data	↑	↑	No Correlation
Accurate and Precise	↑	↑	↓
Low Cost	↓	↓	↑
Frequency of Maintenance	↑	↑	No Correlation
	Can operate for 4 weeks at a time	Accurate to .0025g/ml	< 11 inches in diameter (Fits in a 5 gallon bucket)

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.

Functional & Behavioral Analyses

Functional Decomposition



In the functional analysis of our project, the primary function of the system is the precise measurement of the specific gravity and temperature of the liquid during brewing, with real-time transmission and display of this data to the user. To achieve this goal, here is the functional decomposition.

1. Measuring the density and gravity of the solution is a primary sub-function, we tried three methods to achieve this goal:

- A refractometer measures the solution's density through the refractive index of light, a traditional method for specific gravity measurement. [3]
- A flex sensor determines gravity by its variable resistance value, offering a direct physical indicator for measurement. [4]
- Hall effect sensor uses variations in the magnetic field to measure the liquid's gravity, relying on the magnetic field changes at different deflection angles of a floating magnet.[5] [6]

2. Temperature measurement, which continuously monitors the solution's temperature via a temperature sensor, is crucial for ensuring the accuracy of the specific gravity measurements.
3. Data transmission includes three key steps:

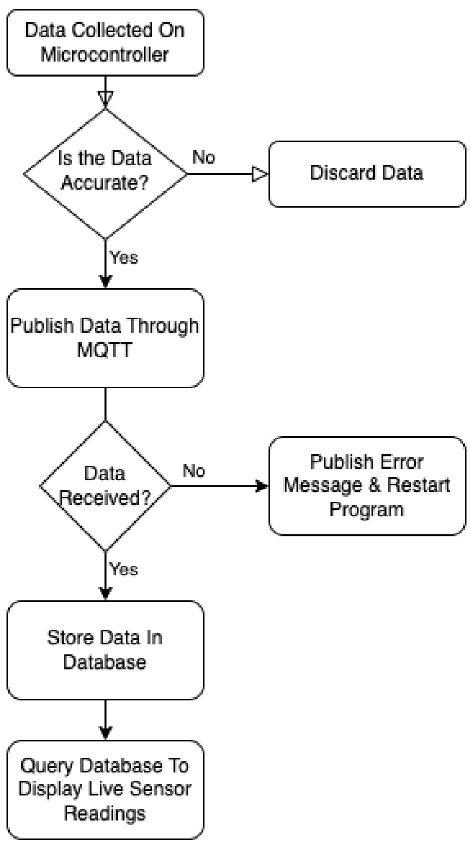
- Data collection, and gather measurement data from various sensors.
- Data transfer, transmitting data to a processing destination through microcontrollers like Arduino and protocols such as MQTT/Telegraf.
- Data formatting, using tools like Grafana to format the data for subsequent analysis and visualization.

4. Real-time data display feature, allowing users to visually monitor real-time data to make swift decisions when necessary. In order to ensure accuracy, we plan to collect data once

per second, then calculate the average of the data within one minute, and display the data as well as plot concentration curves.

5. User-configurable calibration feature, enabling users to adjust sensor calibration settings according to specific conditions, offering additional flexibility and ensuring long-term measurement accuracy.

Behavioral Analysis - Data Flow Model



This flowchart shows the process of how the data will go from the sensor to the user. We begin with taking a measurement with the sensor on a microcontroller. The data will be filtered and checked to ensure there are no abnormalities in the data. If the measurement provides accurate data, the data will be sent to the database for storage. We are currently proposing using MQTT, a remote message telemetry service. Another potential option is to use an application called Telegraf. Both accomplish the same objective of storing data into a given database. There should be another data check at this stage, to ensure data is properly transmitted and stored. If not, there should be an error message for the user and an automated reboot of the program. However, if the data is successfully stored in the database, we will then be able to set up an automatic query (fetching data) that will display the previous data trends as well as the most recent data to a live graphing service such as Grafana. Another potential way to display data is through using google sheets. Both the database and live data display method are yet to be determined.

Conclusions

In the fall semester of EE476C, our group has made significant progress. We began with thorough research, gaining an understanding of the physics behind brewing, the steps of the brewing process, and how fermentation affects the density and specific gravity of the liquid. We then spent a few weeks in the brainstorming phase, sketching ideas and prototypes, researching parts to be used, and identifying possible problems that need to be addressed in the prototype design. We eventually came to a decision to pursue 3 different prototypes. We chose to further test laser refraction, a flex sensor, and the use of hall effect sensors. We further tested the laser refraction idea by acquiring materials to shine a laser through a clear vase, with a sugar solution inside of it. The laser would be marked on a ruler where it refracted with just water. Sugar would then be added to the solution in small increments and the resulting refraction would be marked on the same ruler. We found an average refraction rate of .5908 degrees per gram of sugar added to the solution. This was promising, however we also found that as more sugar was added to the solution, the laser would have a harder time passing through the liquid. This posed a huge issue because oftentimes, the fermenting liquids are quite dark, which would likely prevent the laser from passing through the liquid adequately.

After this realization, we ordered parts for both the flex sensor prototype and the hall effect sensor prototype. We constructed a 3D printed enclosure to house the electronics, and then attached a floating bobber to a flex sensor. This bobber was placed into water and a similar method of testing ensued. We submerged the bobber in the water using fishing weights, and then took measurements of what value the flex sensor would read. We then added sugar in small increments to increase the density of the solution, hoping to observe the change in the height of the bobber. The idea was that if the bobber floated more in the solution, the flex sensor would be under less tension and read a new value. Unfortunately, the flex sensor is severely inaccurate, constantly reading new values even though no movement is incurred. We attempted to then add extreme amounts of sugar to the solution, and even then the flex sensor would read values indicating no relationship between the amount of sugar and the tension on the flex sensor. Due to this finding, we will now move onto prototyping and testing the hall effect sensor prototype. More research and testing will be our primary focus in the 486C semester. Once we have a functional prototype, we will move onto the data transmission, database, and data display aspects of the project. Those aspects should be very easy, and only take a week at most. We will use the bulk of the 486C spring semester to improve and construct our final prototype.

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