EE495 Capstone Project:

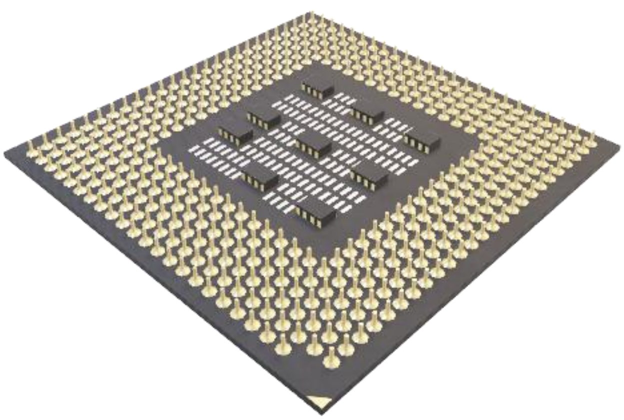
Homebrew Kegerator Monitor

Interim Project Report

Due: Monday, December 14, 2020

Team Members: Michael Coquet, Ryan Betker,

Layne Forbes, Nnamdi Emezieke



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Problem description:

The client has tasked us with building a novel solution to determine the volume of a keg of beer, without disturbing the trub that sits at the bottom. This is needed to avoid the next pour being hazy with sediment and to reduce handling of the equipment. Since the brewing process can take weeks a system is desired to help the brewer limit the time in-between batches. The system will keep a log of the volume for up to 8 kegs at a time and store at least 2 years of data with a goal of 1 sample per hour. Such a system would be especially valuable to a bar owner. The logging of this data is very helpful for determining consumption habits of the user/customers, especially helping determine which brews are the most popular. The system will also monitor the temperature of the fridge which holds the kegs but doesn't require logging with the volume. The design is not meant to be a mass manufactured solution, but an individual novel solution to this problem. Working with these sorts of electrical systems of course means special consideration to preventing electrical shock, or fire and general safety of the user must be maintained. The design must also be made to be as energy efficient as possible.

The most important objective is to accurately (+/- 500ml) measure the volume of a keg (up to 8 kegs at a time) and provide a wireless interface (up to 30ft) to be able to quickly and easily monitor the volume, temperature, and history of the kegs. This history will ideally contain logs of the volume of each keg for up to two years.

The design is meant to be external to the keg. Nothing can come into physical contact with the beer since this may introduce contaminants to the beer which will ruin the quality and pose health and safety risks. The design must also fit within the fridge that stores the kegs with the following dimensions: 48" long, 21" wide, 30" high. If something is to go under the keg, such as a scale, it must meet the clearance of at the most 3.5" above the kegs. Electronics can be put inside the fridge, but not inside the kegs, so they must function at the working temperature of the fridge which is around 4-5 ºC. There is a maximum budget for the entire design process of $250 and a working prototype should be ready in March.

Requirements Specifications:

Hardware Specifications

Identifier	Requirement Description
H.1	Device MUST have no components which come into direct contact with the beer contained in the kegs
H.2	Device MUST not disturb the contents of the kegs
H.3	Device MUST have certification from an accredited organization should it include any component with an AC outlet plug-in
H.4	Power-loss MUST NOT cause damage to either of the software, hardware, or stored memory
H.5	Device components MUST operate correctly at temperatures from 0^{o}C to 40^{o}C
H.6	Device MUST measure the volumes of beer within the 19L kegs with an accuracy of 0.5L/keg
H.7	Device MUST measure the temperature with an accuracy of 1^{o}C
H.8	All wireless connections MUST conform to any particular standards and regulations that apply
H.9	Any wireless signals to the display MUST have a power of –80dBm or greater within 30 feet of the beer fridge

H.1 As per the client's request and to maintain safety and quality of the beer, no component may contact the beer since contamination could potentially occur.

H.2 As per the client's request, the kegs cannot be disturbed as this can affect the brewing process.

H.3 In Canada, all products requiring AC outlet power must be CSA, cUL, or cETL certified. This serves to reduce risk of fire hazards and electric shock. [https://www.canada.ca/en/health-canada/services/home-safety/electrical-products.html]

H.4 Sudden power loss can affect the operation of the software and hardware. The recorded measurements must be protected to ensure that the data is not lost.

H.5 This range was based on an estimate of the possible range of temperatures in an indoors setting in Saskatchewan, Canada. The lower limit was set to 0ºC for the possibility of components inside the fridge being exposed to this temperature for brewing processes which require the fridge to approach 0ºC.

H.6 The client provided a minimum accuracy for the volume measurements.

H.7 To ensure the functionality of a temperature monitor to aid in informing the user, a 1ºC accuracy was assumed, although this was not specified by the client.

H.8 There are many alternatives for wireless communications, but most must follow a corresponding set of regulations. Approximately -80 dBm is considered a reliable connection for the relatively low amounts of data that the device is required to transmit. [https://eyesaas.com/wi-fi-signal-strength/]

H.9 The client requested that the display should be able to operate within 30 feet of the beer fridge.

Software Specifications

Identifier	Requirement Description
S.1	Device MUST collect hourly measurements of the temperature of the fridge in which the kegs are stored
S.2	Device MUST collect hourly measurements of the volumes of beer held within each individual keg
S.3	Device MUST have a minimum additional 422 kB of storage for measurement records
S.4	Device MUST maintain the required accuracies in the recorded and displayed values from H.6 and H.7

S.1: The client requested that the temperature should be taken at a minimum of once every hour, however, a higher collection rate is desired if possible.

S.2: The client requested that the temperature should be taken at a minimum of once every hour, however, a higher collection rate is desired if possible.

S.3: Based on calculations for the minimum amount of storage that it would require to practically log the measurements in S.2 for two calendar years and including the possibility of a leap year involving an additional 24 hours. A minimum one byte per character and three characters required to log each measurement was assumed.

S.4: Conversion of the collected values from analog inputs to the logged and displayed digital values can cause a loss of precision that must be minimized to meet the accuracy requirements.

Display Specifications

Identifier	Requirement Description
D.1	Device display MUST update hourly with most recent measurement data
D.2	Device display MUST be capable of displaying the volume measurements in S.2 for the last two calendar years
D.3	Device MUST display the most recent temperature measurement in S.1

D.1: The client requested that there be an hourly update of displayed data.

D.2: The client requested that two years of data of the measurements in S.2 be accessible on the display.

D.3: The client requested that the temperature be displayed.

System alternatives:

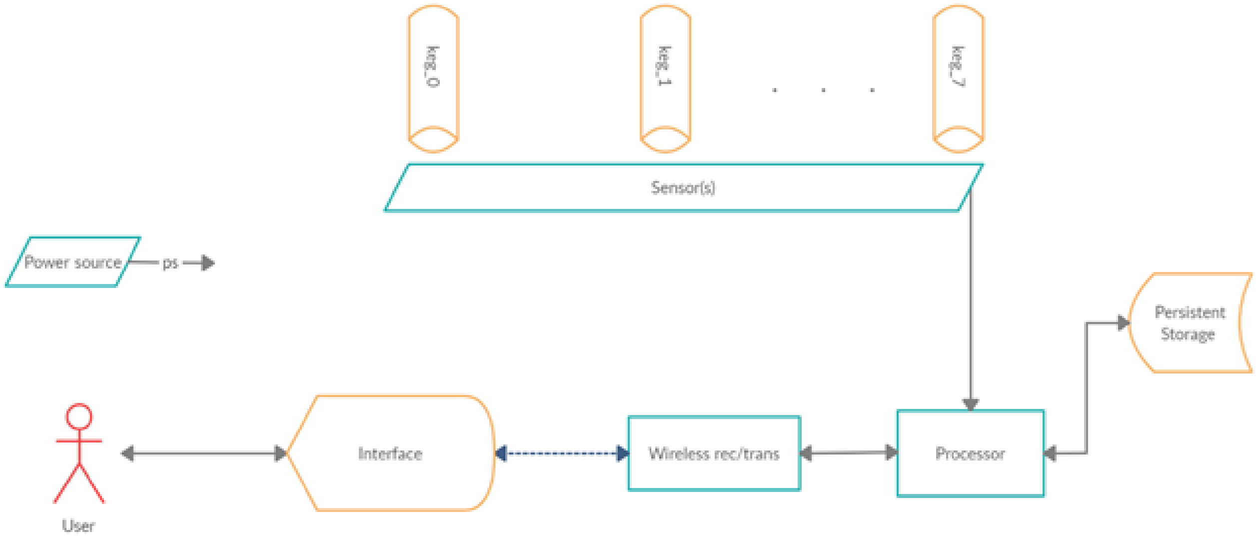
Alternative Generation Methods

We used several of the methods to generate our design alternatives. many brainstorming sessions were conducted over Microsoft teams calls between all members of the team. We found this to be the most productive method to generate design alternatives since each member of the team have such different backgrounds that can be applied to the problem. During the brainstorming sessions one of our alternative designs, the non-contact level sensor, came about from an analogy to a system in the oil & gas industry to measure the level inside gas tanks from the outside of the tank. Since the actual system used in the oil industry greatly exceeded our current budget this led to researching and finding these non-contact level sensors and learning that they only detect the barrier of gas and water and we would need some means of moving it up and down the keg. We also used the example from the text book in a session to come up with the strain gauge, and co2 flow, and line of sight alternatives by brainstorming the various scientific principles that we could relate to the problem such as:

A. You can determine the remaining volume of liquid in a tank given the mass and density of the liquid
B. You can determine the remaining volume of liquid in a tank by tracking the flow of input and output of the liquid
C. You can determine the remaining volume of liquid in a tank by tracking the displacement of the liquid by the gas in the tank
D. If the volume of the inside of the tank is known, then you can determine the remaining liquid in the tank by measuring the distance from the top of the tank to the surface of the liquid

Then we tried to identify the high-level component blocks that would be common to all options and break down the various alternatives for that specific block (see Diagram 1). For example, we identified a major block as the “sensor” block which will be whatever collects the actual volume data. What we called the “microcontroller” block is the main processing block that takes the data from the sensor block, processes it to be sent to the “interface” block. A more detailed block diagram was then generated for each of the alternative design candidates. We identified the “sensor” block as the major key to the alternative designs since this is the major variable in how our system achieves the requirements so each of the design alternatives are based on the sensor block. We also broke down the individual component block alternatives available, for instance the processor block could be any number of microcontrollers like an Arduino or a or series of smaller components.

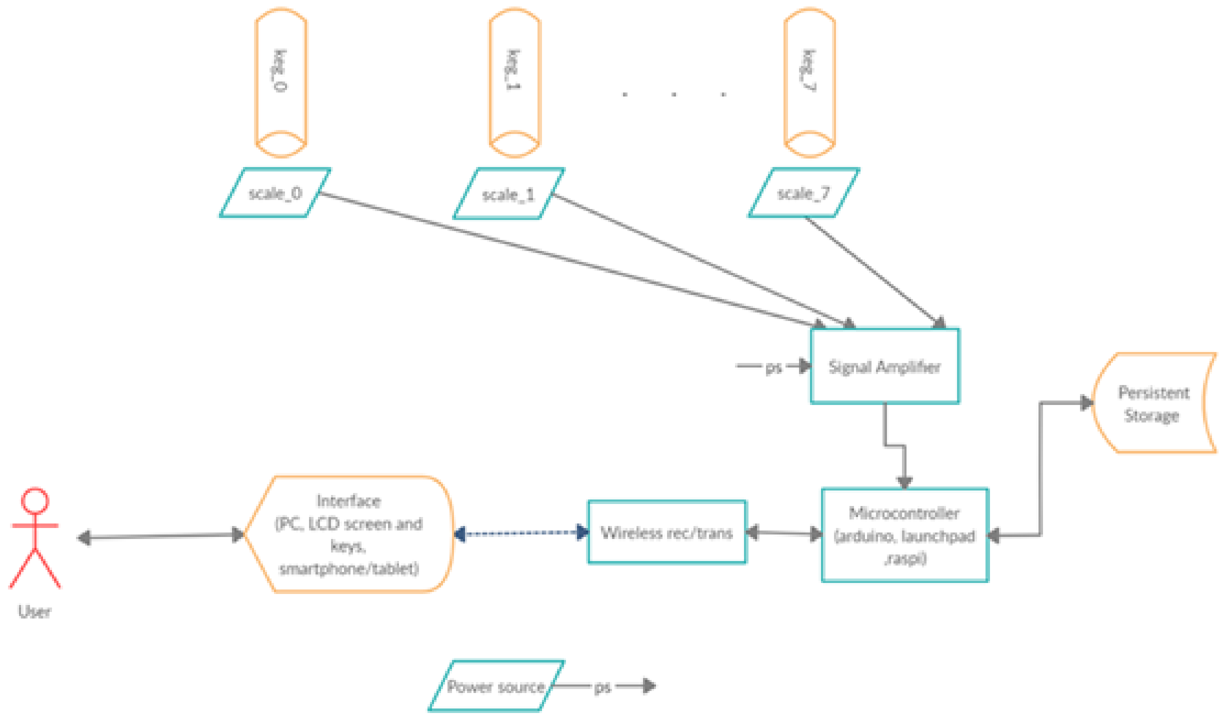
Diagram 1: High-level component diagram for the system



Alternative Analysis

The strain gauge alternative uses the same sensor found in most bathroom scales. Each sensor can measure up to a maximum of 50kg, and we estimate that a full keg would weigh about half that so we would need 1 sensor per keg. These analog signal from the strain gauge also would need to be amplified before the processor could read it and depending on the choice of microcontroller could need external ADC to convert it to a digital signal. There is a lot of information on this concept available and is the most common way option for this type of system in commercially available products. This should easily be able to meet the technical specifications, and the only potential issue we concluded was that the error may be too large. If the accuracy was an issue however, we could simply increase the number of strain gauges per tank to increase the accuracy to an acceptable level, since these sensors are extremely cheap this means the accuracy would not be much of an issue here. Since the sensors are so cheap this is also a good option in economic terms and this was given a higher score for this alternative in our decision matrix (see Chart 1). Since each member of the team is familiar with these sorts of sensors, we also gave this high score for project timeline considerations in our matrix. Since the amount of power to run this system is extremely low and fire hazards are almost nonexistent we scored the safety category metrics here high as well.

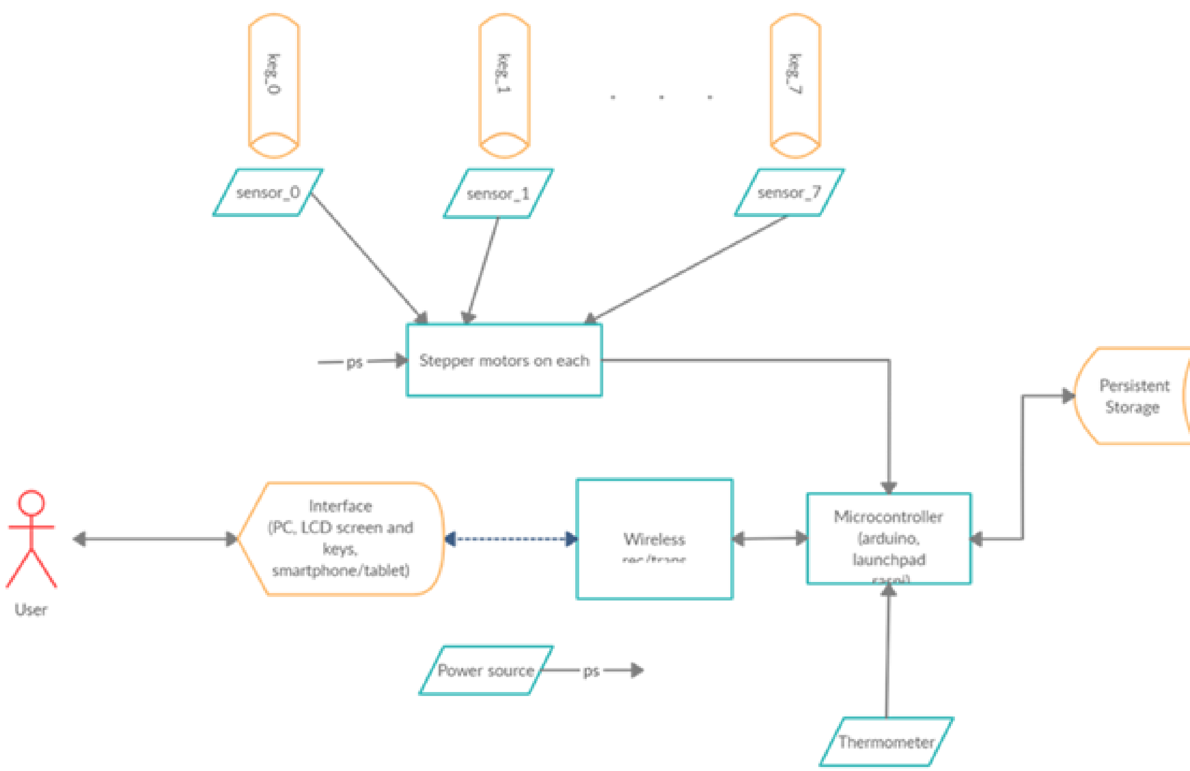
Diagram 2: Alternative 1 - Strain gauge



This alternative would use a sensor which detects the barrier between gas and liquid (see the example in Diagram 3). For this to work for measuring remaining liquid in the tank a mechanism would need to move the sensor up and down the outside of the tank until the level is found, the distance that the sensor moves from the bottom of the tank to the level of the liquid would then be used to measure the volume of the remaining beer. The biggest issue with this option is we are uncertain how sensitive these sensors are, and if they would be able to sense the liquid level through the metal keg as well as how the curvature of the keg would affect the sensors ability to detect the level of the liquid so in our matrix, we scored this lower than the other options the ability to meet the tech specs categories of the decision matrix. Next in terms of economics the individual sensors are nearly as cheap as the strain gauge option, but there would be added cost in the mechanical apparatus needed to move the sensors so we scored the economics of this option lower. Environmental considerations for this option are similar to the other options in that the sensors need to be recycled after their useful lives like all the other options, however since there are more components the environmental scored lower than the other candidates. The safety of this option also is much lower than the other options for a few reasons; there are moving parts that present pinching or crushing hazards, as well as increased power usage to run the stepper motors. The project timeline would also be at greater risk with this option since there is more components that need to be designed and implemented which increased complexity.

Diagram 3: Alternative 2 – Non-contact Level Sensor Example

Diagram 4: Alternative 2 - Non-Contact Level Sensor



The next alternative would use a co2 flow sensor on the co2 line that flows to each keg. The co2 flows into the tank and displaces the liquid in the tank when a beer is poured. So, in theory you could measure the amount of co2 that flows into the tank to determine the amount of liquid that flow out and then use that to determine the remaining beer in the keg. The accuracy and feasibility of this option is uncertain since there is little information on this novel solution, as far as our research revealed it has never been used for this purpose or any similar purpose, so the ability to meet tech specs section was scored lower. The cost to build this is the single least attractive feature of this candidate since 8 co2 flow sensors would be required, and each of those is around $50 according to our research so this was scored very badly in economics categories. The safety of the system is nearly identical to the strain gauge alternative except that it requires more power so electrical safety was scored lower. Project timeline was also score low here since a great amount of research would still be required to have a system that functions.

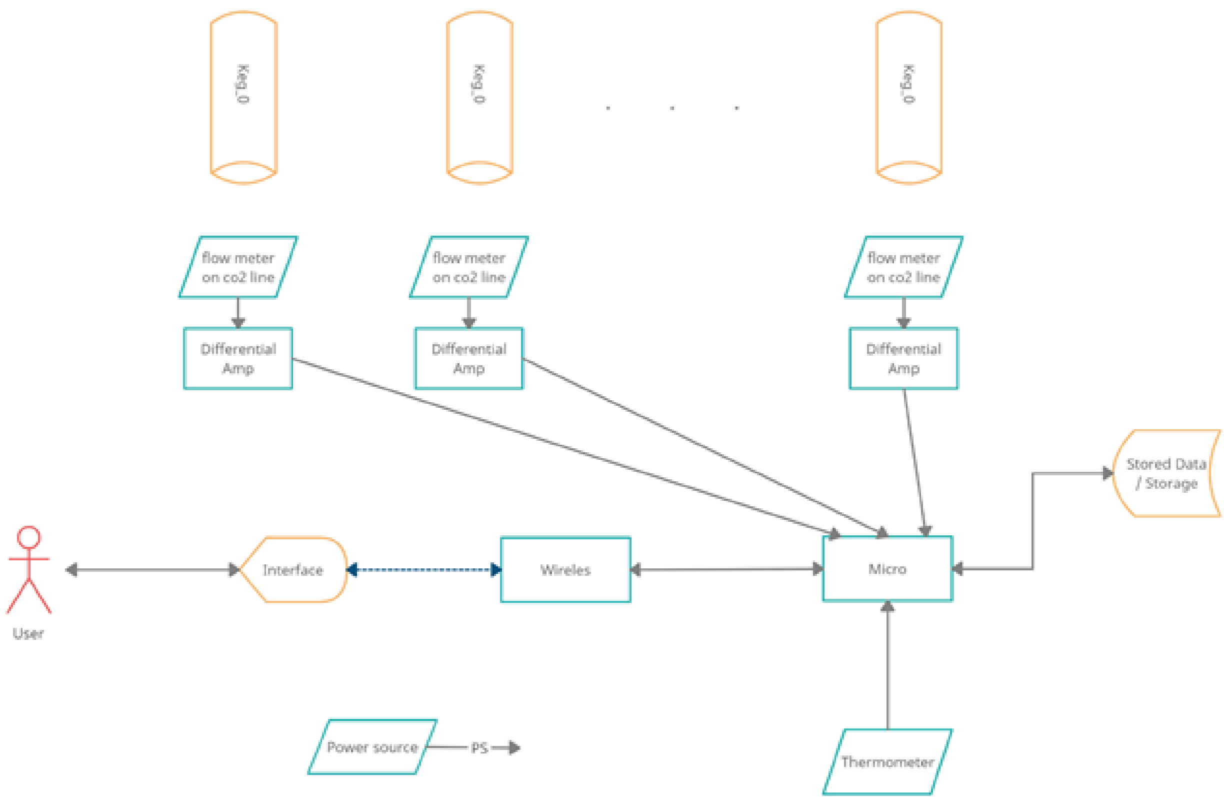


Figure 5: Alternative 3 - CO_2 flow

Alternative Final Decision

We compiled a decision matrix with a list of metrics (see list below) and assigned weights representing importance of the metric to each and placed them into the following categories: ability to meet tech specs, economic, Environmental, Safety, project timeline, and project risks. We then took a weighted sum of all the metrics for each of the alternatives and used this to come to our final decision on which alternative we would pursue move to the next step with (see Chart 1). The results of this showed that the strain gauge alternative is the best alternative all around according to our importance weightings and scorings.

List of decision metrics:

- Ability to meet tech specs
  - Accuracy – The error in the measurement of the volume of remaining beer in the kegs, this should be one of the most important metrics
  - Feasibility – How possible the idea is to design and implement, also one the more important metrics.
- Economic
  - Cost to build – Cost of the entire system; components, labor, etc.
  - Cost to run - Cost of the electricity to run the system
  - Cost to maintain – Eventually some of the sensors or processor or any of the components will wear out, how fast will they wear out and how much will it cost to replace?
  - Cost to dispose – Some electronics need to be recycled or disposed of in an environmentally friendly way, like batteries, how much does this cost?
- Environmental
  - Manufacturing – The environmental impact of the manufacturing of the components involved in the system
  - Power usage – how much power does the system use, is it an efficient way to do this?
  - End of life disposal – how much of an impact will the disposal of the product have on the environment
- Safety
  - Fire safety – This is clearly the most import section and each of these should be assigned the highest importance weighting since its critical the system doesn't hurt anybody
  - Electrical safety – how likely is this to be able to electrocute the user?
  - Potential physical harm to user – Other things, like pinching or kegs falling could cause harm to the user as well, how likely is this?
- Project timeline

- Design and implementation difficulty – related to team skill is how difficult it will be to make something like this?
- Manufacturing/Shipping times for components – how much will the shipping times affect our project timeline?
- Team skill level – how knowledgeable is our team in terms of working with each of these sensors or systems?

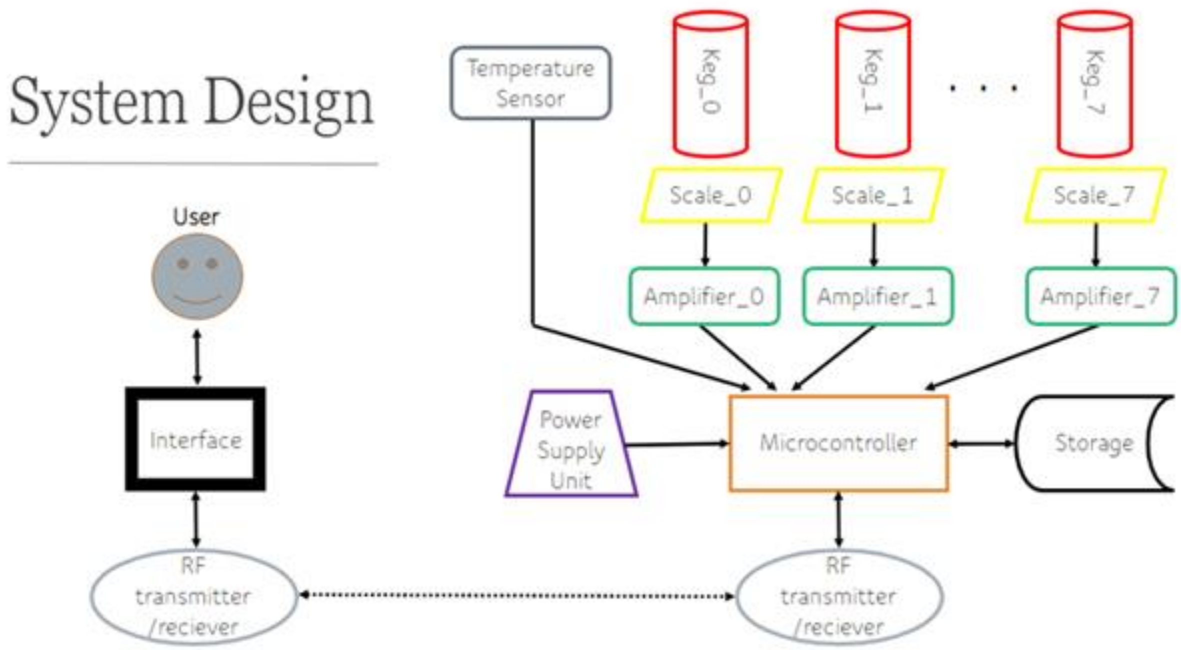
– Project risk

Chart 1: Design Alternatives, Decision Matrix

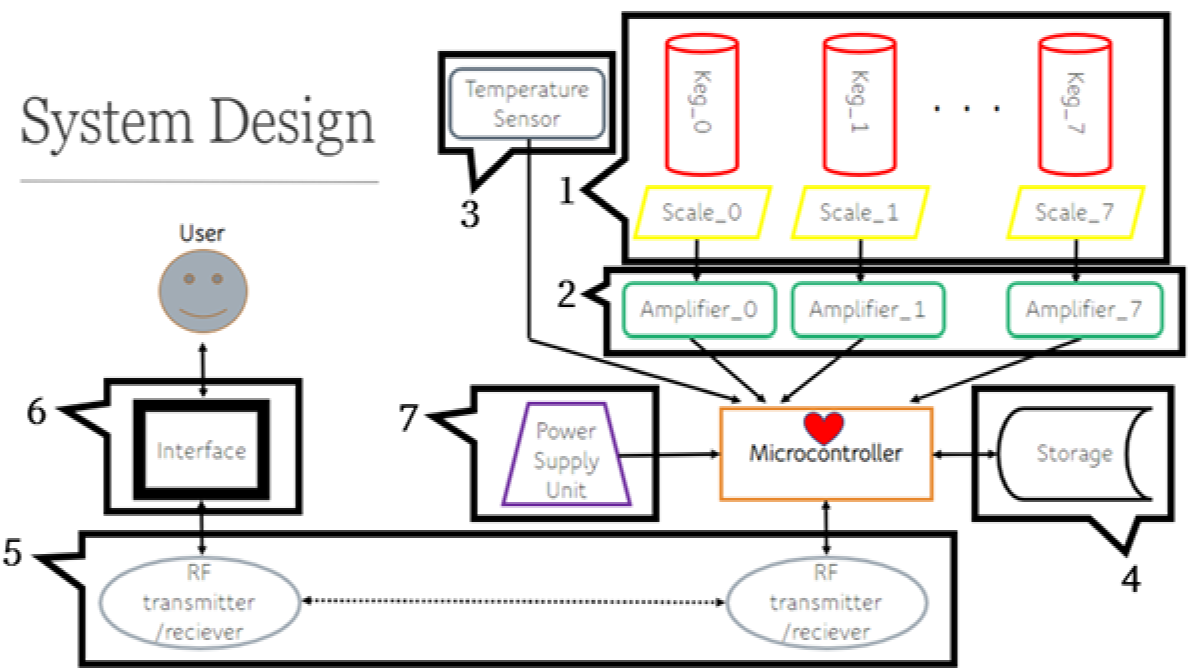
			Design Alternatives		
Category	Metric	Importance weight	Strain Gauge	Non-contact Level Sensor	CO2 flow
Ability to meet tech specs	Accuracy	0.8	7	4	8
	Feasibility	0.8	10	4	1
Economic	Cost to build	0.8	7	8	1
	Cost to run	0.6	6	5	8
	Cost to maintain	0.2	9	2	6
	Cost to dispose	0.2	10	9	10
Environmental	Manufacturing	0.1	10	9	9
	Power usage	0.6	8	4	9
	End of life	0.2	10	9	10
Safety	Fire safety	1	10	9	10
	Electrical safety	1	10	9	9
	Other potential harm to user	0.5	9	8	10
Project timeline	Design and implementation difficulty	0.3	10	6	2
	Team skill level	0.2	8	5	2

Project Risk	Project risk	0.3	10	10	10
		Weighted Total	66.5	50.9	52.3

System design:



Here you will see our system level block diagram. It is a relatively straight forward design but let us investigate each section more closely.



1. Starting inside the kegerator. We will be using weight sensors that will be placed under the kegs. One weight sensor bundle per keg, up to a total of 8 kegs. The part number of this sensor is WD1802AX4. We chose this item because of the low cost and its ease of use, while meeting our 0.5L error objective. These sensors will output an analog voltage signal depending on the volume of beer that is left in the keg. However, the raw output signals from these sensors are not sufficient to be processed by the microcontroller.

2. We need to connect a voltage amplifier to each weight sensor bundle, so that the data can now be analyzed by the microcontroller. The part number for the amplifier we chose is HX711. We chose this item because it works well with our weight sensors, its cheap, and readily available. This device inputs the analog voltage signal from the weight sensors, amplifies the signal, then converts it to a digital signal. This digital signal is outputted and can now be read by the microprocessor. One weight sensor bundle will be hardwired to one amplifier and each amplifier will be hard wired directly to the microcontroller located on the outside of the kegerator.

3. The other sensor needed, is the temperature sensor. The part number we chose is TMP36. This sensor has a temperature range of -40°C to 125°C so it is well within the range of fridge temperatures. Also, it has a low voltage operation (2.7V to 5.5V) which makes it ideal for our microprocessor design. This sensor will output an analog

voltage signal directly to the microprocessor. This sensor is to be placed inside the fridge just for temperature monitoring purposes.

4. One requirement, is that we need to provide a history of the volume in each of the kegs for up to 2 years. As well as, date, time, keg number, and temperature. 24 samples of each per day for 2 years, we are estimating a storage capacity of roughly 1.8Mb. The amount of memory needed for this data exceeds the microcontrollers internal memory. Thus, we are connecting additional memory via SD card directly to the microcontroller.

5. One of our constraints is that the interface must be wireless (up to 30ft). To achieve this, we have narrowed it down to two possibilities. Either by using RF transmitters and receivers from the microcontroller to the user interface or by Bluetooth to a smart phone/computer. Either method will wirelessly send the data for the date, time, keg number, volume of beer remaining in each keg, and the temperature inside the kegerator every hour. Both methods would work for our constraint because it does not require a line-of-sight connection and it has adequate range (long enough for our constraint).

6. Now the user interface, the user interface is where the user can view all the required data in a comprehensible way. This interface has not yet been chosen at this time, but it will consist of either an LCD screen as well as a few keys for navigating through the displayed information or a smart phone/computer. We need more time to decide what option is the most feasible for this project based on time and money.

7. The PSU or the power supply unit will be used to power the entire system. It will be a DC power source in the form of a battery pack connected to the microcontroller. We chose a DC power source because it is a low power design and unnecessary to have it running 24/7 when it only needs to sample every hour. Based on the capacity rating for a standard AA battery (2400mAh), the current consumption during sleep and wake (0.1mA and 20mA respectively), the number of wakeups per hour (one per hour), and duration of wake (20s). We calculated that 2 AA batteries will last roughly 767 days or 2.1 years. All values used were conservative to show that even in worst case scenarios the batteries will last at least 2 years to meet our data storage constraint.

8. Now the microcontroller, the microcontroller is the heart of this system. For this project, it will input the signals from the weight and temperature sensors, analyze them and output the data to memory. Also, to communicate back and forth between

the user interface via Bluetooth or RF transmitters/receivers. We have chosen the microcontroller for this project to be the Tiva™ TM4C123GH6PM. We are using this microprocessor because it is relatively cheap, we all have experience working with it, and it can handle all the tasks for the design of this project.

System test plan:

Requirement

H.1, Device MUST have no components which come into direct contact with the beer contained in the kegs.

Test

Set up the system in the kegerator and obverse that no components come into direct contact with the beer in the kegs.

Requirement

H.2, Device MUST not disturb the contents of the kegs.

Test

Set up the system in the kegerator and obverse that the device does not disturb the contents of the keg.

Requirement

H.3, Device MUST have certification from an accredited organization should it include any component with an AC outlet plug-in.

Test

If at any point, an AC outlet plug is included in the design, the process to secure a certification must be followed. A certification must be acquired before any production. As we are not using any AC components, we will observe that our working system will operate entirely from DC power using a DC power source.

Requirement

H.4, Power-loss MUST NOT cause damage to either of the software, hardware, or stored memory.

Test

Experiment with removing our DC power supply (i.e., Remove a battery) and turning it back on again. Afterwards, observe to make sure the system works as intended and check the hardware for noticeable damage. Also take the SD card out of the system and observe on the computer that the pre-power loss data is still stored.

Requirement

H.5, Device components MUST operate correctly at temperatures from 0°C to 40°C.

Test

Requirement

H.6, Device MUST measure the volumes of beer within the 19L kegs with an accuracy of 0.5L/keg.

Test

The sensing mechanism for each keg will be tested, to ensure correct operation for every keg in the kegerator. Ideally, these could all be tested simultaneously, however, due to budget, it may be necessary to test each keg's sensing mechanism individually. A test keg canister will be filled with a measured amount of beer or for cost reasons a similar liquid which will be used to test each of the sensors. The proposed experiment is outlined below.

1. Choose a completely empty test keg and set up as it would be for storage in the refrigerator.
2. Using the device as intended by the design, take a reading of the keg's content volume and use this as a baseline volume.
3. Add exactly 1L of the testing liquid (ie. beer) to the test keg.
4. Perform another measurement to determine the new volume of the keg's contents.
5. The change in the sensor's measurement MUST correspond to the total volume of testing liquid added to the keg up until this point ±0.5 L.
6. Repeat steps 3-5 until 19L have been added or until the keg is filled.

Requirement

H.7, Device MUST measure the temperature with an accuracy of 1°C.

Test

Experiment by setting up the system and comparing the systems temperature sensor to various thermometers to verify the 1°C accuracy.

Requirement

H.8, All wireless connections MUST conform to any particular standards and regulations that apply.

Test

Analyse all datasheets used in wireless connections to make sure that they conform to the standards and regulations of our region.

Requirement

H.9, Any wireless signals to the display MUST have a power of –80dBm or greater within 30 feet of the beer fridge.

Test

Because of our cost constraint, we will use an app on a smart phone to determine the signal strength at various locations and distances to verify that we have a signal strength of at least –80dBm within 30 feet of the system.

Requirement

S.1, Device MUST collect hourly measurements of the temperature of the fridge in which the kegs are stored.

Test

Record the time and temperature every hour for a few hours then increase/decrease the temperature of the kegerator while continuing to record the time and temperature changes. Then verify that the data stored on the SD card corresponds to the time and temperatures that we recorded.

Requirement

S.2, Device MUST collect hourly measurements of the volumes of beer held within each individual keg.

Test

Record the time and starting volumes of beer held within each keg. Every hour, dispense some beer from random kegs for a few hours. Then verify that the data stored on the SD card corresponds to the time and volumes of beer held within each keg that we recorded.

Requirement

S.3, Device MUST have a minimum additional 422 kB of storage for measurement records.

Test

Temporarily store a “dummy” file that is a minimum 3 mB in size to verify that our additional storage has enough storage capacity for measurement records.

Requirement

S.4, Device MUST maintain the required accuracies in the recorded and displayed values from H.6 and H.7.

Test

Requirement

D.1, Device display MUST update hourly with most recent measurement data.

Test

Record the time, temperature, and starting volumes of beer held within each keg every hour. After a few hours, start to increase/decrease the temperature of the kegerator as well as dispense some beer from random kegs while continuing to record the time, temperature, and volume changes. Then verify that the data displayed corresponds to the most recent time, temperatures, and volumes of beer that we recorded.

Requirement

D.2, Device display MUST be capable of displaying the volume measurements in S.2 for the last two calendar years.

Test

Requirement

D.3, Device MUST display the most recent temperature measurement in S.1.

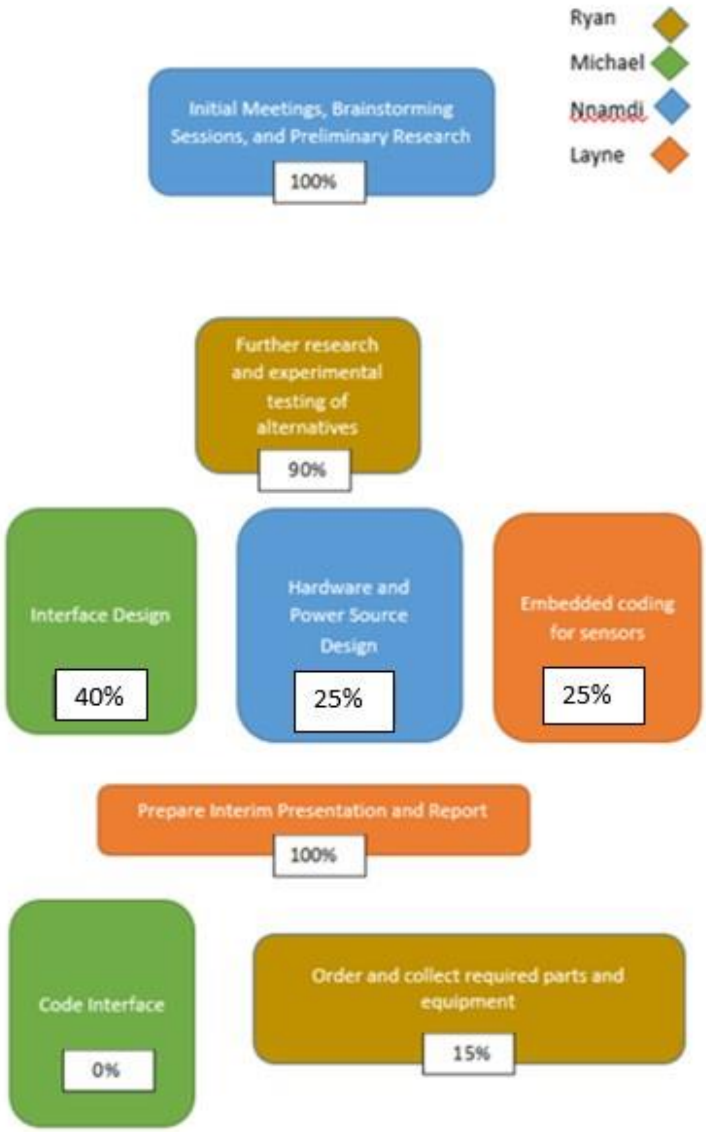
Test

Record the time and temperature every hour for a few hours then increase/decrease the temperature of the kegerator while continuing to record the time and temperature changes. Then verify that the data displayed corresponds to the most recent time and temperatures that we recorded.

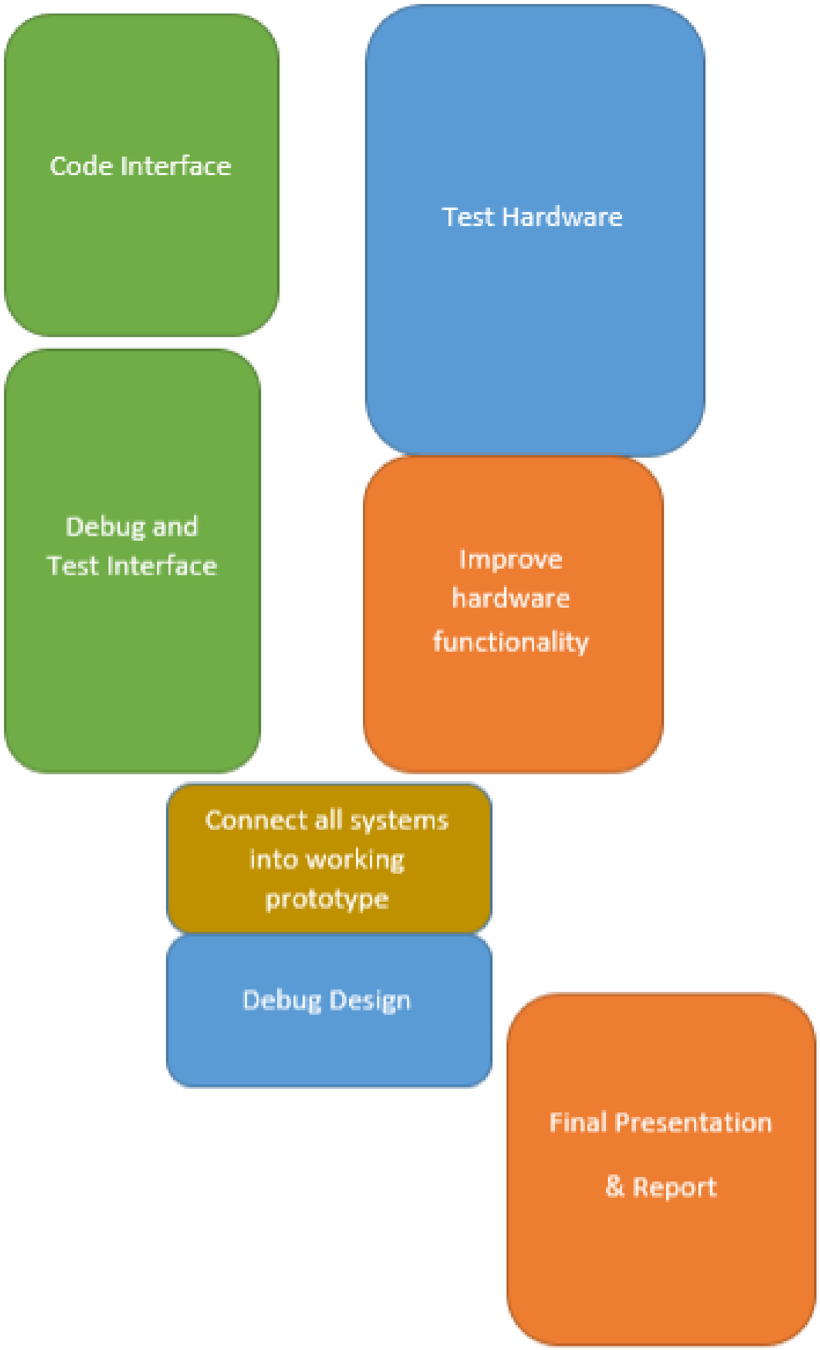
Project planning:

Gantt Flow Chart:

Gantt Flow Chart for First Term with Percentage Complete



Gantt Flow Chart for Second Term:



Part Lists and Budget:

Parts	Quantity	Budget (CAD$)

weight sensor package	8	87.6
temp sensor	3	4.5
microcontroller	1	30
RF Trans/Receiver	1	20
SD card with adapter	1	25
DC battery pack	2	10
Interface	1	30

Table : The list of parts needed required to complete the project and their budget

Number of Hours for Each Member:

Each member of the team was scheduled to spend at least 6 hours on the capstone project in a week. But, due to the pandemic, some member will spend more time on the building part than other as agreed by the whole team. There was 25 weeks from the start of the project (2nd October 2020) to the approximate ending date 31st March 2021. Below you will find in the list of each task, the lead and the approximate time to complete each task. Also, the time spent so far with each task can also be found in the table.

Tasks	Lead	Scheduled Hours	Hours Spent so Far
Research on various ways to approach the task	Nnamdi	10	10
Decide in the group what methods we prefer to approach the task.	Nnamdi	3	3
Continue research further on the chosen method of approach the task.	Ryan	10	10
Proof of Concept and update project description.	Michael	13	13
Interim project Presentation	Layne	18	18
Interim project report	Ryan	16	16

Power Source Design	Nnamdi	54	13
Embedded coding for Sensor	Layne	54	13.5
Interface display design	Michael	44	18
Code an interface	Michael	54	0
Final Project Presentation	Layne	7	0
Project Demonstration	Ryan	13	0
Final Project Report	Layne	12	0
Lessons Learned and Peer Assessment	Everybody	2	0

Table : Breakdown list of tasks showing both the lead of each task and the approximate time on each task.