Abstract- In this document is a design, build, and application of a new system to help reduce the problem of lost or tainted samples and experiments held in fridges and freezers.

I. Introduction

In the academic and scientific community there are many situations where valuable materials, projects, and research are stored and maintained in fridges and freezers. Loss of power and resulting temperature drops can lead to ruined material. A proposed solution to this possible issue is a temperature and power sensor that can enable powering from a battery when a power outlet is down. The fridge/freezer temperature/power sensor project purpose is to design and build a temperature and power sensor with a wireless communication system. The project stems from the loss of thousands of dollars’ worth of lab resources and materials from a power outage that affected faculty and student fridges units in the Cal Poly Biomedical department. Having a power system that can either use regular outlet power or a battery storage system ensures that even in the event of a power outage the system will not go down. Combining this power system with a wireless communication system, helps to make the system even more secure. The wireless communication system allows messages to be sent when the temperature drops below a certain user defined temperature, allowing for updates as soon as something goes wrong with the fridge or freezer. The whole system is designed for hands off updates and very low maintenance for reliability and consistency.

II. Background

A. General Information/Background

This section gives a description of the importance of this system and some examples and information of why this is the case.

Fridges and freezers are an important part of developing and maintaining many things from at home food storage to University and scientific laboratories across the world. One of the biggest problems for these devices however is the loss of temperature due to power outages or other events like leaving the unit open for too long. Many extremely important things from vaccines to samples of bacteria need to be refrigerated at a certain temperature for designed time periods. As the CDC requires for the Pfizer vaccine, “Once mixed, the vaccine must be used within 6 hours. Any vaccine remaining after 6 hours must be discarded.”[1] If the freezer used for storage power goes out and no one is there to check on the vaccines all of the doses would have to be discarded. The importance of a sensor and notification system for systems like this can not be understated.

As reported by The Verge, “2020 was a record-breaking year for power outages in the United States, according to an Energy Information Administration (EIA) analysis published…”[4] As time goes on more and more power outages will occur because of increasing harsh weather conditions. As these increase there is more and more likelihood that people at labs and universities with fridges with vital contents will be not in office when these outages occur, since most Americans work 9-5, including many scientists. This leads to spoiled samples and can cost thousands of dollars as seen in the Cal Poly Biomedical department. The overarching and constant need to check on sample temperature and power wastes time, money, and resources. This vital fact endangers many different industries on a quite large scale.

Most current market sensors are thermocouples, a type of temperature sensor. This project will be using the same type of sensor. As the Omega company explains them, “It consists of two different types of metals, joined together at one end. When the junction of the two metals is heated or cooled, a voltage is created that can be correlated back to the
A thermocouple is a relatively simple and easy to use, and easy to maintain system that can still accurately measure and monitor temperature.

Wireless communication is the other main point of the sensor system. As mentioned previously a huge issue of power outages is when staff or faculty is not on site when outages occur. Wireless communication with alerts through emails or text messages on system updates eliminates part of the issue. The other part of the issue is eliminated with a dual power supply. The dual power supply consists of options for power usage. A battery for power storage when there is a power outage and a plug for using when the power is on and working correctly. This eliminates issues of the device turning off when there is a power outage while not relying solely on the use of batteries which can be inconvenient to change. This whole sensor and communication system is a simple, easily maintainable, and affordable way to ensure safety and security when working with fridges and freezers.

B. Product/Project Description

This section describes the overarching design of the proposed solution and why this solution is necessary.

This temperature and power sensor system is designed to be an extremely reliable measurement system to make sure projects, materials, samples, and more are safe and protected from the dangers of power outages and temperature fluctuations. The system is a combination of 4 elements. The temperature sensor which uses a thermocouple, the power sensor, the microcontroller to interpret and send the data, and the dual power supply which can use a battery or outlet for power.

The Fridge/Freezer temperature and power sensor is similar to other temperature sensors for fridges but gives extra attention to making sure the power system is as secure as possible and making sure that there is fast wireless communication. Every year materials are getting more crucial to refrigerate like vaccines research materials. This fact combined with increasing numbers of power outages make power and communication crucial for continuing progress in the scientific community.
III. Product Planning and Research

This section describes the research done to help inspire and improve the product's design.

A. Product Research

This section describes the current products available in this technology area.

Temperature sensors have developed over the years. From only potential differences of heating metals into full models with displays and communication abilities. Many electronic companies like Acurite, MOCREO, and Govee have developed the technology to make more and more complex systems paralleling other electronic technology developments.

![Figure 5: Acurite Temperature Sensor](image)

These systems have grown using wireless communication between sensors, displays, and even customers' phones and computers. As the technology has developed there are still problems that need to be addressed, like what happens when the power of the sensor system runs out. This is a crucial aspect that has been dealt with slightly but not as rigorously as it should be. Most products are for lower stake systems like household fridges and freezers which mostly store food. However, working with more scientific materials and samples the need for this becomes more and more obvious.

B. Technology Research

This section describes the research and technology that has gone into the temperature sensor and battery backup.

For this temperature/power system the temperature measurement can be done in a variety of ways with pros and cons to each way. From Maximum Integrated [8], there are 4 main temperature sensors, thermocouple, RTD’s, thermistors, and IC temperature sensors. The sensor for this project will be a thermocouple which is described as, “A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming an electrical junction. A thermocouple produces a temperature-dependent voltage…” [9] This type of sensor is simple to understand, use, maintain, and it is not very expensive.

![Figure 6: Thermocouple](image)

Another technological aspect of the product is the dual power system that incorporates lithium ion batteries and outlet power. Outlet power is used for day to day power consumption while the batteries will be used for circumstances when there is a power outage so the sensor does not fail. The dual power ensures that no matter what the sensor can get crucial data to the consumer.

C. Market Research

This section describes the types of products available and their main group they focus on.

When comparing the temperature and power sensor to other similar products on the market this proposed solution has similar aspects but also a few key differences. Popular products from AcuRite and Amir have slightly less complex devices with two part systems, one sensor in the fridge and one display on
the outside. Other competitors have slightly more complicated systems that have a wireless communication system and apps. The less intricate devices are less expensive than the app and wireless communication devices. The solution and product being proposed from this report offers a cheaper alternative with wireless communication, a more reliable power system, and a design that is mainly outside the fridge instead of inside. The main problem when dealing with fridge and freezer systems is when the power goes out and materials get ruined. The main difference in market devices and this proposed one is the power supply to the devices. This new temperature and power sensor will be powered by a combination of regular outlet power and battery power. What this product lacks in not having a phone application, like the more expensive products on the market, is made up by having a more reliable power source. Another aspect that other competitors have is that most of the system goes inside the fridge or freezer which takes up valuable space when it comes to lab equipment and materials. Most outside products are designed for regular at home fridges or freezers which usually have space to house a device comfortably. This proposed design has a very small sensor inside while the rest of the system that interprets the data and sends alerts sits outside.

D. Customer Archetype

This section describes the type of customer this solution would be marketed towards.

This temperature and power sensor system has a few established competitors in the same industry. However, the competition’s systems lack a few key features that this system addresses. By emphasizing the reliability of the dual power system and how everything but the thermocouple goes outside the fridge or freezer, ensuring max space inside the unit, the temperature and power sensor is tailored to a slightly different market. These types of customers will be University departments and faculty, scientific researchers, and medical centers.

<table>
<thead>
<tr>
<th>Type of Customer</th>
<th>Description</th>
<th>Reason</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>University Departments and Faculty</td>
<td>These customers are people who have student/faculty projects and materials</td>
<td>This new sensor system will attract those looking to protect materials and projects that are being used for educational/research purposes while being a relatively cheap option</td>
<td>They will use this product to ensure and have piece of mind knowing they will be alerted of any problems that could damage their work</td>
</tr>
<tr>
<td>Scientific Researchers</td>
<td>These customers are those who professionally need the materials in their fridges and freezers to stay in tact for their job and research sake</td>
<td>Very reliable power system and wireless communication gives a solution to the problem of power outages</td>
<td>They will use this system to monitor their work materials and samples needed to conduct research and sell products</td>
</tr>
<tr>
<td>Medical Centers</td>
<td>These customers who need materials or products safe to save lives</td>
<td>Medical centers will find this system relatively cheap while being extremely reliable in updating the status on important fridges and freezers</td>
<td>This system will be used to monitor the medical samples, vaccines, and other items temperature and power use</td>
</tr>
</tbody>
</table>
Table II: Market Competitors

<table>
<thead>
<tr>
<th>Market Leader</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AcuRite</td>
<td>is an American company mainly known for manufacturing and selling precise weather measurement instruments since 1943. They have however gotten into the home/appliance temperature measurement industry coming out with mainly digital systems.[11]</td>
</tr>
<tr>
<td>Mocreo</td>
<td>is an American company based in San Francisco. They have a variety of different at home devices, dealing mostly with high precision sensing and the ability to interpret and display data using applications. [12]</td>
</tr>
<tr>
<td>Govee</td>
<td>was founded in 2017 based in Hong Kong. They provide a variety of products including smart bulbs, LED strips, home security devices, and thermometers. They also have a wireless interface using applications. [13]</td>
</tr>
<tr>
<td>YoLink</td>
<td>is an American company based in Irvine, CA founded in 2009. They have a very wide range of products including sensor systems, lighting systems, home security systems, and many other home systems based on ease of use and convenience. [14]</td>
</tr>
</tbody>
</table>

There is a wide range of temperature sensor competition on the market however the sensor system proposed here caters to a different more scientific and research based market rather than consumers who need these devices for home use.

E: Market Description

This section describes how this product would go to market and the challenges that may come with introducing this product to the market.

The temperature/power sensor is a system that monitors power and temperature levels of the fridge or freezer that it is attached to. Using and interpreting this data the system sends alerts to the customer through text messages or emails. The system uses a thermocouple sensor to send data to a microcontroller for interpretation and if a problem arises then the microcontroller uses wifi to send alerts to the customer. The whole system is dual powered meaning it can either use batteries or regular outlet power. The combination ensures that even if a power outage occurs then the device is still powered but at the same time doesn’t go through the battery’s power too fast when using outlet power. There are a few limitations of current solutions seen in the market. The first is most temperature sensors have most of the system inside the fridge. This works fine for consumer fridges and freezers however when it comes to scientific fridges and freezers space becomes limited and needs to be saved. Another limitation is the way that power gets to the systems. Most products in the market either use batteries or a charging mechanism. This works even when the power is off however this requires the monitoring of the device to make sure it is charged or the batteries are not dead. If a system runs out of power there’s no way to tell if the fridge/freezer is working properly unless you are physically there. Because of these limitations the more scientific market including hospitals, laboratories, and universities, are not as well served. These markets use as much space as possible in their fridge and freezer units so having larger sensors inside the fridge does not work particularly well. The solutions of these limitations in this system are that the system is mostly outside the fridge/freezer except for the thermocouple which is very small. The second solution is the dual power system which can switch between outlet power and battery power depending on if there is a power outage or not. Some potential problems for this system however is the user interface. A few of the competitors in the market use real time data sent to an application. There could be a lack of information at certain points and possible miscommunication.
between the device and the user. In terms of entering the market the effort to enter would not be the most difficult. There would be challenges in having to take the time to research and develop the product which could take time. Also, with competitors already having decent solutions it might take time for customers to come around to adopting a new system. To be successful in this industry it would be most beneficial to partner with either scientific bodies like Universities, Medical Centers, and research institutes or to partner with fridge/freezer appliance companies and possibly integrate the sensor system into the fridge and freezer system. A very good lead customer could be the Cal Poly Biomedical department. Based on their problems of losing products this solution fits perfectly for their needs. These main two strategy plans have their pros and cons but a mixture of hitting both could prove beneficial. The potential partners could also be potential customers. The same market of academic and medical centers could be a very profitable one if competitive prices are offered and the system can get its reliability and communication consistent.

F: Marketing Requirements
This section describes the necessary attributes of the system to be successful in the market for temperature sensors for fridges/freezers.

In the U.S alone there are 21,191 Diagnostic and Medical Laboratories as of 2022[15], 6090 hospitals[16], and 3982 Universities[17]. Every one of these facilities needs scientific grade fridges and freezers. These fridges and freezers hold everything from biological embryos to student research projects, things crucial to medical, professional, and academic success. The assurance of the safety of these things is one of the most crucial aspects of these industries and establishments. As the U.S Energy Information Administration explains, “Since EIA began collecting reliability data in 2013, U.S. electricity customers have consistently experienced average total power interruptions of about two hours (106 minutes to 118 minutes) per year when major events are excluded.” [18] This temperature and power sensor is aimed at these markets. Though many similar products exist this product caters to the market extremely concerned about reliability over other factors.

As the website Markets and Markets reports, “The temperature sensor market is projected to grow from USD 5.9 billion in 2021 to USD 8.0 billion by 2028, at a CAGR of 4.5% from 2021 to 2028.” [19] The need and want for temperature sensors, especially high reliability ones, is increasing rapidly. Reliable power supply and a design to use little necessary space inside fridges and freezers makes this design a very good fit for the temperature sensor market. There are a few requirements that this temperature and power sensor needs to hit for it to be a successful one in the market. These are mostly aspects that are similar to those products in the market currently including compact size, ease of use, inexpensive, and most important reliability. The table below compares and contrasts the different requirements using the pairwise method. This method weights all the top marketing requirements based on the comparison of each individual requirement to each other individual requirement. This weight is then normalized to a sum of 1.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Easy to Use</th>
<th>Reliable</th>
<th>Compact Size</th>
<th>Inexpensive</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to Use</td>
<td>1</td>
<td>1/3</td>
<td>1/3</td>
<td>2</td>
<td>.207</td>
</tr>
<tr>
<td>Reliable</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>.260</td>
</tr>
<tr>
<td>Compact Size</td>
<td>3</td>
<td>1/2</td>
<td>1</td>
<td>1</td>
<td>.230</td>
</tr>
<tr>
<td>Inexpensive</td>
<td>1/2</td>
<td>1/3</td>
<td>1</td>
<td>1</td>
<td>.195</td>
</tr>
</tbody>
</table>
G: Engineering Requirements

Table IV: Engineering Requirements

<table>
<thead>
<tr>
<th>Customer Requirements</th>
<th>Engineering Specifications</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Product should not exceed 6&quot; by 6&quot; by 4&quot;</td>
<td>Reduce price of production and to make it easily installable and fit on appliance comfortably</td>
</tr>
<tr>
<td>4</td>
<td>Cost should not exceed $100</td>
<td>Similar for other competitors, cost around $50-$150</td>
</tr>
<tr>
<td>5,6</td>
<td>System should use outlet power but be able to store power</td>
<td>No need to replace batteries but also in case of outages needs to store power</td>
</tr>
<tr>
<td>2,3,5</td>
<td>Wifi for wireless communication between MCU and phone</td>
<td>For very fast and easy communication of data/status</td>
</tr>
<tr>
<td>7</td>
<td>System should be programmable for temperature, time temperature can be not ideal</td>
<td>Depending on a customers materials in the fridge the temperature/time could be different</td>
</tr>
<tr>
<td>5,7</td>
<td>Controller should have status updates on sensor data</td>
<td>Make sure the sensor system is working accurately and has not failed/broken</td>
</tr>
<tr>
<td>5,7</td>
<td>LED status indicator on the Microcontroller</td>
<td>Make sure that the microcontroller in the system is working properly</td>
</tr>
<tr>
<td>4,5,6</td>
<td>Power used by system below x watts</td>
<td>Low power for more reliable, more efficient, longer span if power goes off</td>
</tr>
<tr>
<td>2,3,6,7</td>
<td>Text message/email sent from interface of controller with external software</td>
<td>Software to send customers alerts/information about their fridge/freezer and sensor systems</td>
</tr>
</tbody>
</table>

Marketing Requirements:
1. Compact
2. Ability to wirelessly communicate
3. Quick Response Time
4. Affordable
5. Reliable
6. Easy to Power
7. Easy to use/interpret data

Above are the engineering specifications of this system. These specifications are based on the marketing requirements required for the product. These are also listed below. It finally gives some justification in terms of research or logic for each specification.

H: Scheduling

The current GANNT chart is seen in Appendix D Figure 31. This GANTT was utilized to the best of its predictions but was not a living document for the duration of the quarter.

I: Bill of Materials

The current bill of materials listed in Appendix D Figure 32, are the current prices as of December 2022 of the materials required to build this system. The total funding required by Cal Poly is under $200 and the system requires a far smaller sum of money.

IV: System Design

This temperature/power alert system was a combination of a few hardware modules and some software. This section describes what the modules are and how they interfaced with each other and the software.

A) Functional Decomposition (Level 0):
This is the highest design level that includes the inputs and outputs to the entire system as a black box. The system has three primary inputs and one primary output. The inputs to the system are the power, which is from US power outlets at 120V with 60Hz for the frequency. The second is a 9V battery DC signal. The third input is the temperature of whatever system’s temperature is being measured, also the ambient temperature is measured. The final input is the user defined max or min temperature. This temperature is the threshold for if the system will send an email to the user or not. The primary output of the system is an email alert. This alert is triggered by either the power going out or the temperature being past the user defined level for a certain amount of time.

Figure 7: Functional Decomposition Level 0
B) Functional Decomposition (Level 1):
This functional Decomposition includes all the major modules that go into the overall design. This includes how the module is powered, how the temperature is read and the data is processed, and how the wireless alert system works.

Figure 8: Functional Decomposition Level 1

Table V: Power Supply

<table>
<thead>
<tr>
<th>Module</th>
<th>AC to DC Wall Outlet Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td>120 Vac 60 Hz Standard US Outlet Power</td>
</tr>
<tr>
<td>Outputs</td>
<td>9V DC Signal</td>
</tr>
<tr>
<td>Functionality</td>
<td>This module converts AC outlet power to a usable 9V signal for other modules power supply</td>
</tr>
</tbody>
</table>

Table VI: Power Switching System

<table>
<thead>
<tr>
<th>Module</th>
<th>Power Switching System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td>Power Supply 9V DC, 9V Battery</td>
</tr>
<tr>
<td>Outputs</td>
<td>9V DC Power Signal</td>
</tr>
<tr>
<td>Functionality</td>
<td>This system is able to switch from outlet power to battery power if there is a power outage.</td>
</tr>
</tbody>
</table>

Table VII: Power Sensor System

<table>
<thead>
<tr>
<th>Module</th>
<th>Outlet Power Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td>DC 9V from Power Supply</td>
</tr>
<tr>
<td>Outputs</td>
<td>Voltage Reading</td>
</tr>
<tr>
<td>Functionality</td>
<td>This system sends a voltage reading of the power supply to the microcontroller</td>
</tr>
</tbody>
</table>

Table VIII: Temperature Sensor System

<table>
<thead>
<tr>
<th>Module</th>
<th>Temperature Sensor System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td>Ambient Temperature, Fridge/Freezer Temperature, 3.3V, SPI</td>
</tr>
<tr>
<td>Outputs</td>
<td>SPI</td>
</tr>
<tr>
<td>Functionality</td>
<td>This system processes the temperature from the fridge/freezer and sends the celsius reading to the microcontroller</td>
</tr>
</tbody>
</table>

Table IX: Microcontroller Data Processing System

<table>
<thead>
<tr>
<th>Module</th>
<th>Arduino NANO 33 IOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td>Power Sensor system voltage reading 9V DC, SPI from Temperature sensor, User Defined Temperature Threshold</td>
</tr>
<tr>
<td>Outputs</td>
<td>3.3V, SPI to Temperature Sensor System, Server Request</td>
</tr>
<tr>
<td>Functionality</td>
<td>This module processes the temperature data and power supply data to determine whether or not to send an email request to the webhooks server.</td>
</tr>
</tbody>
</table>
### Table X: Webhooks Server

<table>
<thead>
<tr>
<th>Module</th>
<th>Webhooks Server</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td>User Defined Message, Microcontroller Server Request</td>
</tr>
<tr>
<td><strong>Outputs</strong></td>
<td>Email to User</td>
</tr>
<tr>
<td><strong>Functionality</strong></td>
<td>This Server receives a request from the microcontroller and is able to send a message to the user’s email.</td>
</tr>
</tbody>
</table>

#### C) Functional Decomposition Level 2:

**a) Temperature Sensor System**

This Level 2 functional Decomposition delves into the physical and electrical makeup of the temperature sensor system. This is from table VII from functional decomposition Level 1. The temperature sensor is made up of 2 modules. This includes a K-Type thermocouple that goes into the fridge or freezer and the MAX31865 IC which acts as the cold compensation for the K-Type thermocouple. The output of the thermocouple is a voltage difference which is interpreted and converted to a degree measurement in celsius. This measurement is sent as a binary code using SPI communication to the microcontroller which converts the binary to a decimal number.

**b) Power Sensor**

The power Sensor and Power switching modules are simple modules using few components to help make the functionality of the system. The power sensor system consists of a voltage divider that has 2 resistors a 10 kohms and 5.6 kohms, these resistor values bring the 9V input voltage to 3.3V. This is because the max voltage the arduino microcontroller can use for its input pins is 3.6V. They also provide a high resistance to lower current usage and therefore power usage.

**c) Power Switching System**

The power switching system uses a common cathode design. This design allows only one of the sources to conduct either the battery or the AC-DC power supply. The common cathode switches from the outlet power to battery power quickly if the power supply’s voltage goes to 0V in the case of a power outage. The 10uF capacitor also helps to make sure the output voltage stays at a voltage that can still power the microcontroller while the power switch occurs. This system helps to ensure the arduino has enough time and power to send the user a message that there has been a power outage.
d) Wireless Communication System
The wireless communication system uses the Arduino NANO 33 IOT device that also collects and interprets the power and temperature data. The microcontroller constantly checks the temperature and power readings. If the power is off or the temperature is out of the user defined range then the microcontroller, which has WIFI capability, sends a request to a Webhooks server. Webhooks is a free to use website that allows users to send emails and then change the content of those emails. Once the server has received the request it sends an email to the user specified email.

![Webhooks Website and Email Title](image1)

Figure 12: Webhooks Website and Email Title

![Webhooks Flow Control](image2)

Figure 13: Webhooks Flow Control

![Example of Email Sent to User](image3)

Figure 14: Example of Email Sent to User

e) Arduino Interface and User input
This section addresses and explains how a user would change the defined temperature threshold and input the correct WIFI for the Arduino NANO 33 IOT microcontroller.

Currently in the system there is not a true user interface other than directly editing the source code. A user could ask the manufacturer to input desired WIFI information and temperature threshold or can use a micro usb to plug into the Arduino NANO 33 IOT and change the code themselves.

![Arduino Temperature Threshold and WIFI User Inputs](image4)

Figure 15: Arduino Temperature Threshold and WIFI User Inputs

In figure 15 it shows the microcontroller used in the system. On the far left of the image is the port that a micro usb can be plugged into. The code can also be reset/rerun if the white button on the microcontroller is pressed.

![Arduino NANO 33 IOT Microcontroller](image5)

Figure 16: Arduino NANO 33 IOT Microcontroller

f) Logic Flow of the Arduino Software
Below in figure 17 is the logic flow of the system. The first thing the software does is search for the WIFI network that is input by the user using the information in section 6 of system design. The second step is the microcontroller trying to connect to the Webhooks Server. This server is able to take requests from the microcontroller and is able to send emails. Once the WIFI is on and the server is connected to, the software starts checking the power and temperature readings. It starts by taking the power
reading, if it is at 0V a request is sent to the webhooks server to send the user an email. The software then does a polling loop until the power is back on.

If the power is on then the temperature is checked next. If the temperature is below the user defined input threshold then the software loops back to checking the power. If it is above the user threshold then the software stops for 10 minutes then the temperature is checked again. If the temperature is back under the threshold then the software loops back to checking the power. If the temperature is still above the defined threshold then webhooks sends a request to email the user that the temperature has been out of range for too long. The software then does a polling loop until the temperature is back in range and then the software loops back to checking the power.

g) **SPI communication**
The Arduino NANO 33 IOT uses SPI communication to interface with the MAX31865 cold compensation IC. There are 4 main wires that connect the arduino to the cold compensation IC. The MOSI, which allows the microcontroller to write to the cold compensation IC, this means changing register presets and telling the IC what data to output. The MISO allows the arduino to receive the output data from the cold compensation IC which is a binary number that corresponds to a celsius degree reading. The SCLK which is the clock that the arduino and the cold compensation IC use. This clock is at 25 MHz. The final main signal is the CS. This CS helps to tell the cold compensation IC when it should be reading and writing data.

![Figure 18: MAX31865 SPI Communication](image18)

**h) External Red LED**
Also on the current breadboard system there is a red LED that can signal different things. While the microcontroller is searching for the WIFI network the LED will blink. When the microcontroller has connected to the webhooks server the LED will signal this by turning on. Finally the last function is if the outlet power goes out the LED will blink until the power returns. The LED is pictured with the microcontroller below in figure 19 with a Red box surrounding it.

![Figure 19: Microcontroller and Red LED](image19)
V. Testing

This section outlines how the functionality and attributes of the system align with the engineering requirements outlined in Table IV in section G of Product Planning and Research. The first requirement, the system being compact, is almost in the required 6”x6”x4”. The current system is 6.5”x 4”x 1”, this requirement is constrained by the available breadboard which makes up the size of the system. This would be easily fixed by going to a PCB or finding a smaller breadboard.

The second requirement, ability to wirelessly communicate, is outlined well by the example email from figure 14 and the data from table XIV.

The third requirement, quick response time, has been met based on the time it takes for the thermocouple to respond to temperature change, shown in Figure 21 and 22 and in the software by the time it takes to send an email shown in table XIV.

The fourth requirement, cost of the system, defined in Appendix D Figure 32 Bill of Materials, is well below the allotted max cost that Cal Poly allows of $200 USD.

The fifth requirement, reliability is also shown to be met based on the data of the rapid response time of the software to send an email and in hardware based on the data collected from the temperature measurements and also the longevity of the battery backup for its specific purpose.

The sixth requirement, Easy to Power, has been met. The power of the system uses common US outlet power which is 120Vac at 60Hz. This is readily available in almost all buildings in the US. The second part of the power system involves a 9V battery. This is also in line with the engineering requirement because 9V batteries are cheap and readily available.

Finally the seventh requirement, easy to use/interpret data, is met based on the simplicity of the emails content. Also because of the thermocouple data shown in figures 22 and 23.

A) Verification Method for the Hardware

For verifying the hardware there were a couple key pieces of data that can determine the reliability or validity of this system. The first was determining how fast the system could react to a temperature change, and secondly how long could the system stay powered and do its job reliably when it needed to use battery power. Below are a few parameters that need to be stated to give a good idea of how the hardware was set up. As seen in figure 20 the small brown wire is the thermocouple that tucks into the freezer door.

![Figure 20: System on top of Freezer](image)

<table>
<thead>
<tr>
<th>Table XI: Parameters for Hardware Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>Thermocouple Type</td>
</tr>
<tr>
<td>Length of Thermocouple (cm)</td>
</tr>
<tr>
<td>Fridge depth(cm)</td>
</tr>
<tr>
<td>Thermocouple Depth into Fridge (cm)</td>
</tr>
<tr>
<td>Ambient Temperature(℃)</td>
</tr>
<tr>
<td>Lowest Freezer Temperature(℃)</td>
</tr>
</tbody>
</table>

For the verification of the temperature sensor, the thermocouple was placed inside the fridge at 35cm from the front of the fridge through the door, as seen in Figure 20. First the thermocouple was left inside the fridge until it recorded its lowest temperature which came to be -14 degrees. The fridge was then opened and the temperature change and time of the changes were recorded, as shown in figure 21. The temperature was recorded by the MAX31865 cold junction compensation IC and interpreted by the Arduino NANO 33 IOT microcontroller. The time was recorded by the Arduino’s internal timer which is called by using the function millis(). The temperature...
was allowed to increase around 10-15 degrees which is the maximum temperature difference, this was decided before the project to be the maximum temperature difference the freezer should have. This value can however be changed through the software.

Figure 21: Temperature Graph Going from Freezer Temperature to Out of Range

This was done in 3 runs. Each at a different starting temperature to simulate the different temperatures the freezer can be at based on how long it is open. The temperature went from the lowest measurement to 15 degrees away. These measurements are taken in °C/s to determine how long the delay before an email should be sent. These measurements give a good idea of how long it takes the thermocouple to stabilize at certain temperatures. If the delay is too short the emails would be sent too fast and the email would be sent even though the freezer has been closed properly.

Table XII: From Low to 15 Degrees Away Temperature Rate of Change

<table>
<thead>
<tr>
<th>Data Points</th>
<th>Rate of Change of Temperature (°C/s)</th>
<th>Exponential Time Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>1.0707</td>
<td>.83</td>
</tr>
<tr>
<td>Yellow</td>
<td>1.1102</td>
<td>.978</td>
</tr>
<tr>
<td>Red</td>
<td>1.1657</td>
<td>.979</td>
</tr>
<tr>
<td>Nominal (From Datasheet)</td>
<td>N/A</td>
<td>1.2</td>
</tr>
</tbody>
</table>

The second part of the hardware verification was taking the thermocouple/freezer to a temperature close to ambient by leaving it open for 5 minutes and then closing the thermocouple in the freezer and measuring the temperature change. Below in figure 22 3 different runs were made. The yellow and blue runs were similar but had a different start point at 13 degrees for yellow and 14 for blue. The difference between the red and the other two runs was when the data was taken. The red data was taken after the thermocouple had been in the freezer overnight while the blue and yellow were taken after the freezer had been opened and closed a few times.

Figure 22: Temperature Graph Going from Out of Range to Freezer Temperature

Table XIII: From Temperature When Freezer was open back into the allowed range

<table>
<thead>
<tr>
<th>Data Points</th>
<th>Rate of Change of Temperature (°C/s)</th>
<th>Exponential Time Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>0.048943</td>
<td>.975</td>
</tr>
<tr>
<td>Yellow</td>
<td>0.049234</td>
<td>.98</td>
</tr>
<tr>
<td>Red</td>
<td>0.082265</td>
<td>.986</td>
</tr>
<tr>
<td>Nominal (From Datasheet)</td>
<td>N/A</td>
<td>1.2</td>
</tr>
</tbody>
</table>

When going from a high temperature to a low temperature the rate of change of the temperature was significantly less than going from a low temperature to a high temperature. The thermocouple used has a nominal time constant of 1.2s, which means the time it takes for the thermocouple to get to 66.67% from the last temperature to a new temperature. This however is, as called in the thermocouple data sheet, “in fast moving air”. This explains why going from
high to low takes a lot longer to measure. The lower temperature leads to slower moving air so the thermocouple cannot react as fast as when it goes from freezing temperature to ambient temperature.

The last data taken for hardware verification was the usage of the battery backup. The battery backup is designed to work when the main outlet power is cut off or unplugged. To collect this data the outlet power was unplugged and the 9V battery was measured every 2.5 mins. This was done up until 30 minutes because every 30 minutes the system sends another email about the power being off. In this data collection the battery was used for the full 30 minutes and two emails were sent in that span.

Figure 23: Battery Voltage Change
As seen from the data the battery goes from 9.46V to 8.69V over a 30 minute window. The minimum voltage that the microcontroller can use to operate is around 3.3V. With checking the power, sending emails, and blinking the Red LED the battery lost voltage at a rate of 0.02566666667 V/min. With this rate for an exact 9V battery it would take around 222 minutes or around 3.7 hours until it couldn’t power the microcontroller anymore. This again however is only the rate when the outlet power is off.

B) Verification Method for the Software
The main verification for the software is how fast it can interpret the data and send an email to the user if there is an issue. To measure this, the time between when the power was turned off and when the user received the email was measured. From the IFFT website the email should be sent in around 10 seconds from the request being received. Below in Table XIV are the amount of time it took for the user to receive the email.

<table>
<thead>
<tr>
<th>Email Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.1</td>
</tr>
<tr>
<td>11.7</td>
</tr>
<tr>
<td>10.63</td>
</tr>
<tr>
<td>11.03</td>
</tr>
<tr>
<td>11.12</td>
</tr>
<tr>
<td>11.79</td>
</tr>
<tr>
<td>11.71</td>
</tr>
<tr>
<td>10.83</td>
</tr>
<tr>
<td>10.58</td>
</tr>
<tr>
<td>10.8</td>
</tr>
</tbody>
</table>

Average Response Time = 11.129s
The average response time was 11.129s with the worst being 11.79s. The average response time was over 10s however because of the way the software is organized. The software acts almost as a polling loop first checking the power level and then the temperature rating. The software could be at any point in this loop which is why there are differences in the receiving times. The way these were timed was using an electronic timer from when the plug was pulled to when the user received the email. The microcontroller was on the Cal Poly IOT WIFI network and the user was on the Cal Poly eduroam WIFI. Use of different wifi or the use of cellular data instead of WIFI could change these numbers.

C) Analysis
a) Analysis of the Hardware Verification
The hardware data had good results in terms of rate of change of the temperature and length of battery life. There was however some inconsistency of the thermocouple/cold junction temperature measurements. Whether the temperature was increasing or decreasing the rates were different from one measurement to the next, so the consistency or reliability of the system could come into question at points. The purpose of the system is to realize and inform the user about a significant change in temperature and power, which the system was pretty consistent at doing. However for the temperature measurements they were not always consistent. As seen in figure 22 and 23 the rates of the temperature change as seen by the thermocouple and cold junction...
compensation IC were different from run to run. Not large enough to bring huge concern for a system like this however there were factors that influenced this. Things like how many times the freezer was opened and closed in a certain amount of time or how long the freezer was opened affected how quickly the thermocouple reacted. Comparing the temperature output readings of the IC to that of a traditional thermometer, the change was slower and less accurate. A more accurate thermocouple or more stable conditions could have improved the data and therefore overall consistency of the system. Secondly for the backup battery data, the system was not excellent but is good for the system’s purpose. The rate of change of voltage lends it to survive for 3-4 hours when the system is solely powered on a battery. This is fine because it is only meant to be a backup for the outlet power but for a future design of the product things like putting the microcontroller into sleep mode for periods of time would improve the power performance. Also if the power performance got efficient enough the system could possibly be run solely on battery power instead of outlet power.

b) Analysis of the Software Verification

The software had good data when it came to how long it took to respond to a power outage. The average time was around 11 seconds, seen in table XIV. This time is heavily dependent on the latency of sending and receiving emails over the webhooks server however. The software possibly could have shaved off a second or so if something like interrupts were used instead of a polling loop but having to send a request to a server to send the email makes up a bulk of the email received time in table XIV. Though this time is around 10-11 seconds to get the email for the purpose of this system it is more than good enough. Most likely when these emails are sent a person may not be in the room and the difference of a few seconds of someone getting the email will not make a large enough difference for changes to be made.

c) Improvements that Could be Made to the System

In analyzing this system for design requirements the system did meet the minimums on most requirements however with the data taken, some of the requirements could have been improved upon. The overall system does its job of wirelessly communicating with a simple email to the user when the temperature is out of a certain range or the power goes out, however there are things like power usage, software efficiency, size, and temperature accuracy that could have been improved. First is the size and make of the system. The size is almost in range of the requirements however the system uses a breadboard and through hole components. This gets the job done however makes the system look and feel bulky and unfinished. The next step would be using a PCB. Another physical thing that would be changed would be the mount and thermocouple placement. Currently the thermocouple doesn’t have a solid holder so it moves around which in turn has made measurements slightly inconsistent. The next step would be developing a system to hold the thermocouple in place.

A second improvement that could be made, which was mentioned in section a would be improving the software. This would involve using external interrupts to trigger power and temperature emails. Currently the system uses a large polling loop which wastes time and resources continuously checking the temperature and power every second or so. A third improvement could be the use of a DC-DC converter instead of a resistor voltage divider for the power sensor. The resistor network is less efficient than something like a DC-DC buck converter. If price/space efficiency is the highest priority then the resistor voltage divider is a better and more simple method.
VI. Conclusion

With issues of things like power outages becoming more and more common systems like these have to become more viable and readily available. This system although could have some improvements does the job it is intended to do well especially as the first rendition of this system. The power sensor and microcontroller are accurate in reading correct power levels and responding correspondingly with an email to the user. The temperature sensor, although not 100% consistent and accurate, detects significant enough changes in the temperature to send the user accurate emails about when the system detects problems. Looking at the software, different methods i.e. using interrupts instead of polling loops, could have been used to increase performance, but the current performance of the software is more than enough to get the user important messages quickly. The readability of the code could have also been increased by using more functions for things like reading the thermocouple data, reading the power data, and sending requests to the webhooks server.

Going off of the improvements section in Section V: Testing, the long term goal for this project would be adding a mount for the fridge and thermocouple, reducing power usage through software and hardware improvements, and going to a PCB instead of a breadboard. These things would increase testing accuracy and reduce power consumption. A final goal of this system could be converting completely to battery power once the system is consistent and efficient enough.

Appendix A

Impact Analysis of Senior Project

Project Title: Fridge/Freezer Temperature and Power Wireless Alert System

Student Name: Peter Nelson

Advisor’s Name: Ben Hawkins

A. Summary of Functional Requirements
The first requirement is the system should be able to read and interpret changes in temperature from a fridge or freezer. The system should also be able to tell if there is a power outage or that the outlet that is powering the system is out. After the interpretation of this data the system should be able to wirelessly communicate with a user through email to let them know that the temperature is out of range or the power has gone out.

B. Primary Constraints
The first primary constraint is that the system should not be too large, less than 6” x 6” x 4” and there should be minimal equipment inside the fridge/freezer. The system should also not cost more than $100. The system should also be able to quickly send emails to the user when the data is out of a certain range, within a few minutes.

C. Manufacturing
With around 200 million refrigerators sold per year[20], if this product were to be manufactured on a commercial basis the total number of devices to be sold would be around 1% of the 200 million. The manufacturing cost based on the BOM above is around $85 this however will be reduced significantly once more research is done on the product. The estimated purchase price will be reduced to around $50 once the BOM is fine tuned. With a $50 and a hopeful manufacturing cost of $30, the estimated profit would be around $400,000 per year. The estimated cost for the user to use this device would be less than $10 per year. Based on the longevity of the components around 5 and the estimated price of around $50 this comes out to $10 a year.

D. Environmental
This product is not the most environmentally impacting system when not manufactured in large quantities. It will be mostly used inside for fridge and freezer systems. The main environmental challenge for this system is the power supply. Though the system uses wall power it also uses batteries which if not recycled correctly are harmful to the environment. If this was to get into a large stage operation, the environmental impact would increase significantly. When projects are upscaled to large manufacturing every aspect of the project affects the project's environmental impact. From making each individual IC to the large amount of batteries used
E. Sustainability
The main issues/challenges with sustaining this product are the power consumption. Because the system is constantly running to monitor the temperature this could run down components faster and lead to failure. Also, because the system uses batteries for a backup if the wall power goes out, these have limited lifespans and need to be changed even with the system having a charging element for the batteries. Some upgrades could be more sustainable batteries like lithium ion ones. These last longer and are also better for the environment than traditional batteries.

F. Social and Political
This product mostly impacts only the users of the product if at a small scale. The main stakeholders are the designer and the consumer. If the product gets upscaled to manufacturing a large number the product becomes more socially and politically prominent. This would include the pollution from manufacturing, shipping, and the waste of batteries being used. This would bring more stakeholders like the government for policy regulation of manufacturing, and the people who build the products. If this product were to fail all the stakeholders are affected as the waste of the product is large and many units would be thrown away.

G. Health/safety
The overall system is not the most dangerous, however there are still some concerns. The main concern of the safety of the system is the use of batteries and wall power. Batteries have the chance to burst or fail if misused or the lifetime runs out which as the wrong time could harm the user when changing or using the system. Also because the system uses 120V wall power if the power converter were to fail the system could be overloaded and cause harm.

H. Ethics
The main ethical concerns of this project are privacy, environmental, and responsibility. On the topic of privacy this product uses wireless communication and takes a phone number or email from the user. This could possibly be a concern because misuse of personal information is a large problem in this super connected world. The alerts sent to the user should be strictly about the status on their fridge/freezer system. On the topic of the environment, the main problem with this design is the use of batteries. Batteries overall are not the most efficient power source. This mixed with the fact that if not properly recycled they will not break down and will be more toxic for the environment. On the topic of responsibility, this product is used as a safety and peace of mind system. The user wants to be able to leave their system alone and not check on it constantly. If the system were to give the wrong reading or fail to send a message this responsibility would be on the engineer. This ethical concern is put on the engineer because of the claims of the system.

I. Development
The main new tool I learned for the development and analysis of this system was temperature measurement through a thermocouple and cold junction compensation method. This was learned from source 4 in the references at the bottom of this paper. A thermocouple junction goes in a fridge and is made of two different metals soldered together. At the same temperature the two metals carry a different voltage so there is a voltage drop between them. On the other side of the thermocouple wires it is connected to some sort of cold junction compensation. This cold junction compensation acts as a reference temperature. An IC or other measurement device can interpret this voltage difference as a temperature using the reference temperature.
Appendix B: Schematics

Figure 24: Full System With Battery

Figure 25: System Setup On Freezer
Figure 26: Thermocouple into Fridge

Figure 27: Full Schematic
Appendix C: Full Code

```c
#include <WiFi.h>
#include <SPI.h>

#include "Secret.h"

// please enter your sensitive data in the Secret tab
char ssid[] = "SECRETSSID";
char pass[] = "SECRET_PASS";
int status = WL_IDLE_STATUS;

int MaxTemp = 18;
int Power_stat = 1;
int ledState = HIGH;
//DEBUG LED
int ledPin = 5;
// Pin to check outlet Power
int power_pin = 6;
//SPI chip select pin
int CS_pin = 10;

WiFiClient client;

char HOST_NAME[] = "maker.ifttt.com";
String PATH_NAME = "/trigger/temperature_out_of_range/with/key/dVXYu3I3lpuB_SFCBoUccveQ4e4R6T7KXBSAct_fL5e"; // change your EVENT-NAME and YOUR-KEY
String queryString = "\nValue=58\nValue2=25"; // Maybe change
String PATH_NAME_PD = "/trigger/Power_Diag/with/key/dVXYu3I3lpuB_SFCBoUccveQ4e4R6T7KXBSAct_fL5e";

void setup(){
  // initialize WiFi connection
  // initialize LED Pins
  pinMode(LED_BUILTIN, OUTPUT);
  pinMode(ledPin, OUTPUT);
  pinMode(CS_pin, OUTPUT);

  while (status != WL_CONNECTED) {
    Serial.print("\nAttempting to connect to network: ");
    Serial.println(ssid);
    // Connect to WiFi/VPN network:
    Serial.println(pass);
    status = WiFi.begin(ssid, pass);
    // wait 10 seconds for connection:
    delay(10000);
    digitalWrite(LED_BUILTIN, HIGH);
    delay(500);
    digitalWrite(LED_BUILTIN, LOW);
    delay(300);
  }

  // connect to web server on port 80:
  if (client.connect(HOST_NAME, 80)) {
    // Flash LED to show connected to Webhooks
    digitalWrite(LED_BUILTIN, HIGH);
    delay(3000);
  } else {// if not connected:
    Serial.println("Connection failed");
  }

  SPI.begin();
  SPI.beginTransaction(SPISettings(5000000, MSBFIRST, SPI_MODE3));
  //SPI.endTransaction();
  //\loop();

  //Initialize cold comp IC
  // Change Low fault threshold
  SPI.transfer(0x3); //Send register location
  SPI.transfer(0); //Send value to record into register
  //thermocouple cold comp sends read data on falling edge of the clock
}
```
```c
void looop() {
    // Serial.println("START LOOP");
    // Unlinearlized TC Temperature register addresses
    int reg = 0;
    int read_reg1 = 14; // Small, first byte
    int read_reg2 = 13; // Medium, middle byte
    int read_reg3 = 12; // Large, last byte also includes sign bit

    digitalWrite(I2CPin, HIGH);
    digitalWrite(CS_pin, HIGH);

    while(1) {
        // Grab data from wall power input
        Power_stat = digitalRead(power_pin);

        if (Power_stat == 0){
            client.println("GET " + PATH_NAME + query = " HTTP/1.1");
            client.println("Host: " + String(HOST_NAME)");
            client.println(); // end HTTP header
            delay(1000);
            while (Power_stat == 0){
                // Blink LED to signify Power is Out
                digitalWrite(I2CPin, LOW);
                delay(1000);
                digitalWrite(I2CPin, HIGH);
                delay(1000);
                Power_stat = digitalRead(power_pin);
            }
        }

        digitalWrite(CS_pin, LOW);
        // take the chip select high to de-select:
        digitalWrite(CS_pin, HIGH);
        delay(100);

        // Part of code that checks temperature
        // Serial.println("CHECK TEMP");
        int current_data = 0;
        // Send register address that needs to be read and outputs data
        // data collection
        digitalWrite(CS_pin, LOW);
        SPI.transfer(read_reg1);
        // send a value of 0 to read the first byte returned:
        int received_data1 = SPI.transfer(0x00);
        digitalWrite(CS_pin, HIGH);
        current_data = received_data1>>12; // Shift to get decimal nums
        digitalWrite(CS_pin, LOW);
        SPI.transfer(read_reg2);
        // send a value of 0 to read the second byte returned:
        int received_data2 = SPI.transfer(0x00);
        digitalWrite(CS_pin, HIGH);
        received_data2 = received_data2>>4; //current_data = received_data2 current_data;

        digitalWrite(CS_pin, LOW);
        SPI.transfer(read_reg3);
        // send a value of 0 to read the third byte returned:
        int received_data3 = SPI.transfer(0x00);
        digitalWrite(CS_pin, HIGH);
        delay(3000);

        // mask
        int sign = received_data3 & 256;       // First bit is sign bit
        received_data3 = received_data3 & 127; // Mask out sign bit
        received_data3 = received_data3<<4;  //current_data = received_data3 current_data;

        if (sign == 256) {
            sign = -1;
        } else {
            sign = 1;
        }
        current_data = current_data*sign;
    }
```
if (current_data >= MaxTemp) {
    // Delay then check again
    delay(100000); // for 15 minutes
    delay(10000);

    int current_data = 0;
    // Send register address that needs to be read and outputs data
    // data collection
    digitalWrite(CS_pin, LOW);

    SPI.transfer(read_reg1);
    // send a value of 0 to read the first byte returned:
    int received_data1 = SPI.transfer(0x00);
    digitalWrite(CS_pin, HIGH);
    current_data = received_data1>>12; // Shift to get decimal nums

    digitalWrite(CS_pin, LOW);
    SPI.transfer(read_reg2);
    // send a value of 0 to read the second byte returned:
    int received_data2 = SPI.transfer(0x00);
    digitalWrite(CS_pin, HIGH);

    received_data2 = received_data2>>4;
    current_data = received_data2-current_data;

    digitalWrite(CS_pin, LOW);
    // int received_data3 = SPI.transfer(read_reg3);
    SPI.transfer(read_reg3);
    // send a value of 0 to read the third byte returned:
    int received_data3 = SPI.transfer(0x00);
    digitalWrite(CS_pin, HIGH);
    delay(3000);

    // Mask
    int sign = received_data3 & 256;  // First bit is sign bit
    received_data3 = received_data3 & 127; // Mask out sign bit
    received_data3 = received_data3<<4;
    current_data = received_data3-current_data;

    if (current_data >= MaxTemp) {
        // make a HTTP request:
        // send HTTP header
        client.println("GET " + PATH_NAME + queryStringEncoding + " HTTP/1.1\n); client.println("Host: " + String(HOST_NAME));
        //client.println("Connection: close");
        client.println(); // end HTTP header
        delay(10000);
    }
}

Figure 28: Complete Arduino Code
Appendix D
Additional Documents
A. Business Model Graphic

Figure 29: Business Model Graphic
B. Marketing Data Graphic

Figure 30: Marketing Data Graphic
### C. GANTT Chart

#### Design Data Acquisition
- Title: 1 day, Tue 1/22/22 - Mon 1/30/22, 1
- Functional Decomposition Level II: 4 days, Wed 1/25/22 - Mon 2/6/22, 1
- Functional Decomposition Level I: 4 days, Mon 2/6/22 - Mon 2/13/22, 1
- Temperature: 6 days, Wed 2/15/22 - Tue 2/28/22, 1
- Power Supply Design: 6 days, Tue 2/28/22 - Mon 3/13/22, 1
- Dual-Power Supply Design: 6 days, Mon 3/13/22 - Mon 3/20/22, 1
- Design Data Acquisition Circuit: 6 days, Mon 3/20/22 - Tue 3/28/22, 1
- Software Design: 7 days, Wed 3/29/22 - Thu 4/6/22, 1
- Total System Design: 6 days, Fri 4/7/22 - Fri 4/14/22, 1
- Ensuring Design: 6 days, Fri 4/14/22 - Mon 4/17/22, 1

#### Build Data Acquisition
- Temperature Filter Build: 7 days, Tue 4/5/22 - Wed 4/12/22, 2
- Power Sensor Build: 7 days, Wed 4/12/22 - Wed 4/27/22, 2
- Dual-Power Supply Build: 7 days, Wed 4/27/22 - Wed 5/12/22, 2
- Build Data Acquisition Circuit: 7 days, Wed 5/12/22 - Tue 5/18/22, 2
- Incorporate System Together: 7 days, Tue 5/18/22 - Mon 5/24/22, 2
- Ensuring Build: 7 days, Mon 5/24/22 - Thu 5/28/22, 2

#### Validate Data Acquisition
- Temperature Sensor Validation: 3 days, Thu 5/29/22 - Sat 5/31/22, 2
- Power Sensor Validation: 3 days, Fri 6/2/22 - Sat 6/3/22, 2
- Data-Acquisition Circuit Validation: 3 days, Sat 6/3/22 - Mon 6/5/22, 2
- Full Data-Acquisition Circuit Validation: 3 days, Mon 6/5/22 - Wed 6/7/22, 2
- Validate Ensuring with Full Circuit: 3 days, Wed 6/7/22 - Fri 6/9/22, 2

#### Design Wireless Communication
- Design Wireless Communication: 10 days, Wed 6/14/22 - Thu 6/29/22, 3
- Design Wireless Communication Hardware: 10 days, Thu 6/29/22 - Thu 7/8/22, 3
- Design Software For Sending Messages: 7 days, Tue 7/8/22 - Fri 7/14/22, 3
- Design Message Being Sent for Use: 1 day, Thu 7/14/22 - Thu 7/14/22, 3

#### Build Wireless Communication
- Build Wireless Communication: 14 days, Fri 7/15/22 - Thu 7/28/22, 4
- Build Wireless Communication System: 14 days, Thu 7/28/22 - Thu 8/11/22, 4

#### Validate Wireless Communication
- Validate Wireless Communication: 14 days, Thu 8/11/22 - Thu 8/24/22, 4
- Message Sent: 14 days, Thu 8/24/22 - Thu 9/6/22, 4

#### Release
- Research on Other Products/Innovations: 5 days, Wed 8/17/22 - Tue 8/23/22, 40
- Design Presentation/Post Board for Senior Project Show: 10 days, Wed 8/23/22 - Tue 8/30/22, 40
- Show at Senior Project: 1 day, Wed 8/30/22 - Wed 8/30/22, 40

---

**Figure 31: GANTT Chart**
## D. Bill of Materials

**Senior:** Fridge Freezer Alert System  
**TEAM:** Peter Nelson  
**DATE/REV:** March 6, 2022 Ver 1.

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**Material Total** 62.5700  0.0000

Figure 32: Bill of Materials
Figure 33: Software Flow Control
References


10. Amazon, Thermocouple Temperature Sensors Wire K-Type MB Thread 30mm / 1.2in Probe Length Temperature Range 0~400 (1M) [Online] Available: https://www.amazon.com/Thermocouple-Temperature-Sensors-K-Type-Thread/dp/B07PQR1V63 [Accessed: 29-Jan-2022] Source for Figure 6


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    (Thermocouples, RTDS, Thermistors, Temperature
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    mperature-sensor-market-522.html#:~:text=%2720Pages%20Report%27%20The%20temperature,4.5%2
    5%20from%202021%20to%202028.&text=However%2
    C%20high%20initial%20cost%20involved,expected%2
    0%20to%20restraint%20market%20growth.
   [Accessed: 30-Jan-2022]
   Provides data about the temperature sensor market.

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    reezers/#topicHeader_wrapper

GitHub Repository:

Link:
https://github.com/pmnelson1/CP_T-P_Sensor.git