Senior Design Proposal: Smart Hive

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***Abstract* — Apiculture is on the edge of implementing the newest technologies provided by the fourth industrial revolution referred to as the "Internet of Things." A new directive for the mason green fund has been to streamline the process of beekeeping with the assistance of sensors, databases, and smart frames. This proposal can provide a new approach at George Mason University for monitoring the overall health of the hive.**

I. INTRODUCTION

The honeybee population is critical for the population of wild plants and most importantly for the fruit and vegetables we consume. It is estimated that one-third of the food we eat in America is pollinated by honeybees. However, honey bees are dying at unprecedented rates due to invasive species, pesticides, and air pollution. They require our intervention to prevent extinction. Our Senior Design team has chosen to contribute to the Smart Hive Project at George Mason University - an effort aimed to remotely monitor bee hives to measure hive health and prevent bee swarms. This will be accomplished through the deployment of an array of sensors (Carbon Dioxide, temperature, humidity, and audio level sensors) to collect data, store the data on a database, and display the data on a web dashboard. The stored data can be used to analyze trends and can be made available to beekeepers to keep the bee population healthy and separate colonies when they grow too large.

II. BACKGROUND

Smart Hives are a system of bee care designed to precisely monitor and manage the conditions present in bee hives. Historically, beekeepers visit beehives on a weekly or monthly basis to check on the condition of the bees [23]. In contrast with this system, a Smart Hive monitors the conditions of bee colonies 24/7 and can keep beekeepers alert to the need for intervention with the hive as soon as a problem situation occurs. With the introduction of the Internet of things within the last few years, an application can be found for our system. With an estimated 50 billion devices connected as IOT solutions in 2020, it is a notable consideration into the design [11]. Cloud designs have been implemented into data models for everything from medical devices to traffic intersections in order to automatize the world [11].

Our system would eliminate the situation where a beekeeper is unaware of problems or threats regarding the beehive and reacting to such phenomena late. Additionally, an application of our smart hive that would appeal to the market is having a significant impact on the bottom line of farmers, orchardists, and commercial beekeepers. In the United States, beekeepers lose almost half of their bee colonies each year [23]. Our smart hive would allow for more precise monitoring and treatment, which would significantly improve colony survival rates.

III .CUSTOMER NEEDS

Infrastructure as code in addition to the fourth industrial revolution referred to as the "Internet of things" has created new ways for us to solve problems. Our group was prompted with monitoring the CO2, temperature, and humidity of beehives within George Mason University. Previous methods of doing this stated by the customer is manually with a CO2 monitor as well as thermometer. One of the larger challenges of this method is not only the constant scope creep of which sensors will be needed in the final implementation of the project but actually future proofing what needs to be accomplished in this design. A common standard within the website application community is referred to as the MERN stack.

A. *Measured Requirements*

The following list was gathered from the customer of note in a direct interview and cited within a previous project conducted on the exact grounds.

1. The power source provided on premises is an array of 4 nickel batteries (3.3 V Power supply required for Raspberry Pi)
2. The general maintenance of the apiary is short intermittent visits 4 times each week
3. Hives during acclimate temperatures, are opened to inspect the hive's health
4. A range of 1 to four sensors per frame was found to be accurate enough for the information required of the customer.
5. Light is found to be a key disturbance for the hives and must be kept to a minimum if not completely nullified
6. 0.375 of an inch was found to be the minimum gap

which

7. The expected temperature within the hive is 90-93 degrees Fahrenheit provided by the client, while expected humidity within the hive to support healthy colonies is 40%-60% [22]
8. The distance from the main power supply to the hives is less than 15 feet
9. System should be functional for 1 month, specified by client

IV. MARKET OVERVIEW

A. Current Commercial Solution

Current smart hive solutions available on the market include Smart Hive 2.0 which was deployed in 2020 at George Mason University [19]. The smart hive uses six MCP9808 sensors to measure temperature in bee hives, and includes Raspberry-Pi boards that transmit data over wifi [20]. The smart hive logs data every six hours in ASCII-formatted files. Frank Linton tracks companies such as Arnia, Solution Bee, and Broodminder which are also developing smart hives that measure hive weight, temperature, and humidity [21]. These companies' products give beekeepers technology for monitoring bee colonies and reduce the need for disruptive manual inspections [21]. Often, these companies use expensive sensors and parts to build their design, and the user-facing architecture is not as expandable for future developments in the field of smart hives [21].

B. Critique and improvements to current commercial solution

While this plan is fairly encompassing for what our current user requirements are, the general architecture doesn't allow for as much expandability as may be needed in the future. Many of the systems stated work non-congruently with technologies such as SMS, RFID, Wi-Fi, and do not contain a central or locally hosted database in which to rely on [18]. The Smart Hive 2.0 which was implemented lacked an easier ability to expand as well as the accessibility which the customer required [19]. In order to improve upon these designs, a website which was custom-written has been included within the approach of this paper. This website will allow for data to be viewed continuously and for it to be visualized clearly in plots. Additionally, less sensors will be used to lower the cost of our design in comparison. We use a combination of temperature, humidity, and CO_2 sensors to add more useful data pertaining to the bee's health for the user as well, rather than just temperature measurements. Our design will also include shorter intervals for sending measurements to the website, giving the user better knowledge of variations in measurements over time.

V. APPROACH

A. Justification of Systems Architecture

There are several reasons why Node-Red is our highest candidate. The primary justification being Node-Red allows one to implement an internet of things approach to networks with minimal troubleshooting. The flow has nodes, and each node we can program to achieve the desired outcome. The second reason for using Node-Red is the ability to have a live feed dashboard as shown in the architecture. The third reason is to establish a connection to a database which then sends the data to the website. MongoDB is the database chosen because it is well suited to Node-red. They both use JavaScript which is the very clean mapping needed.

The following system architecture describes the structure and behavior of our smart hive design:

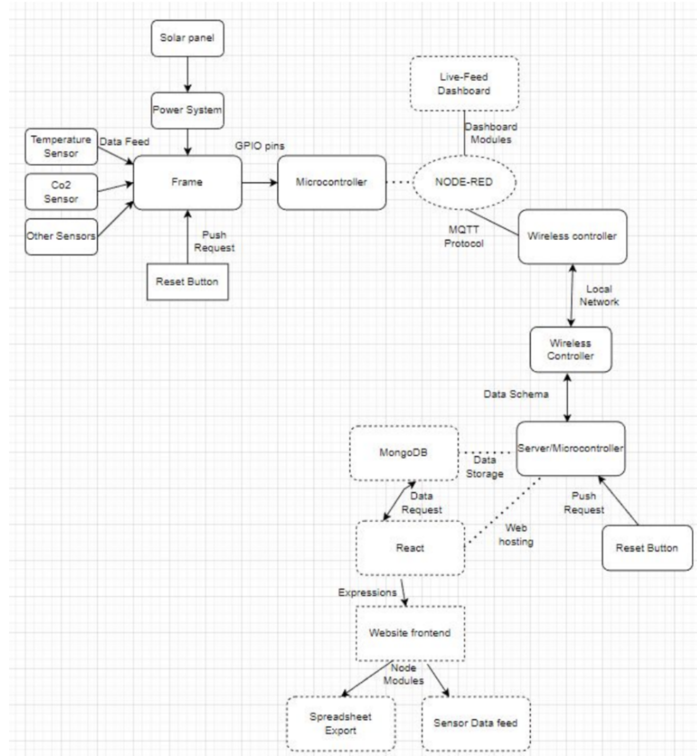


Figure 1: Website approach

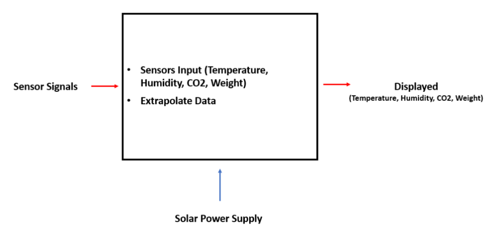


Figure 2: Level 0 Function Design

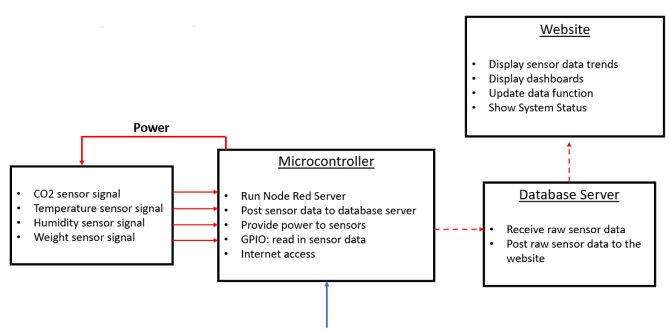


Figure 3: Level 1 Function Design

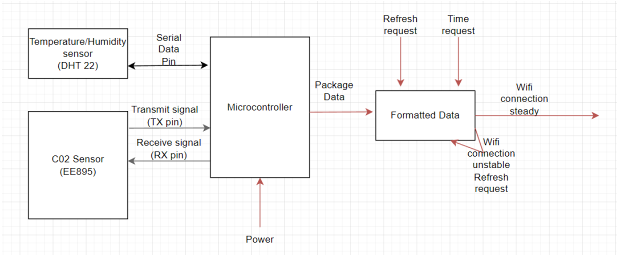


Figure 4: Level 2 Function Design

B. Hardware

The DHT22 as well as the DHT-11 have nearly identical footprints and have been implemented in a “Smartframe lite” like design as seen below. Due to our smart frame utilizing several different designs to cut cost and redundancy, we have decided to make two different frames. The smaller design is seen below in symbolic form:

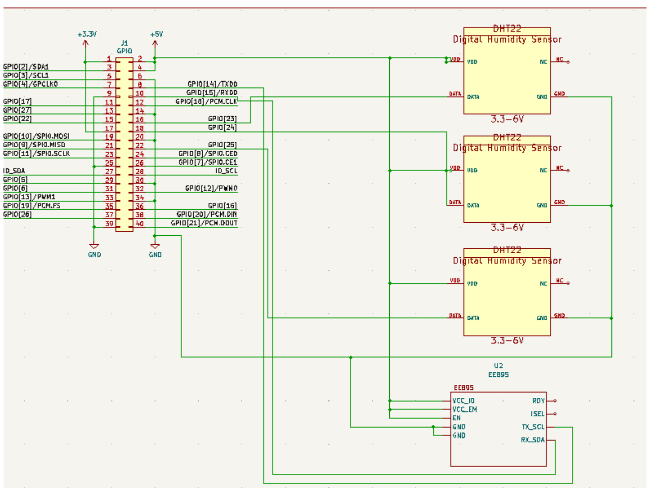


Figure 5: Frame Schematic

The section below is how our design is derived from the symbolic reference and is a non-routed design for the DHT sensor to the raspberry pi. Although the DHT sensor is required to measure temperature, the importance in the choice of this sensor is not high as the data schema formed for this design can implement any sensor of choice or additional sensors as long as they are formatted correctly.

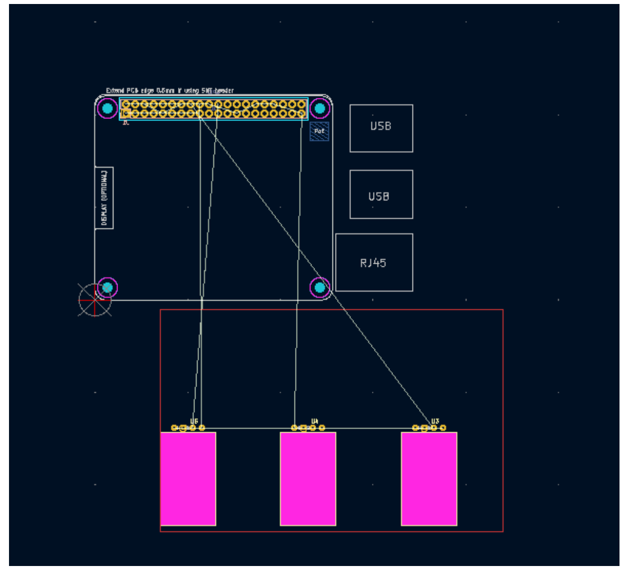


Figure 6: DHT Sensor

One of the larger problems we had with our sensor selection was the lack of a footprint for our CO2 sensors. Therefore, we have implemented a custom breakout board in our design in order to account for it missing.

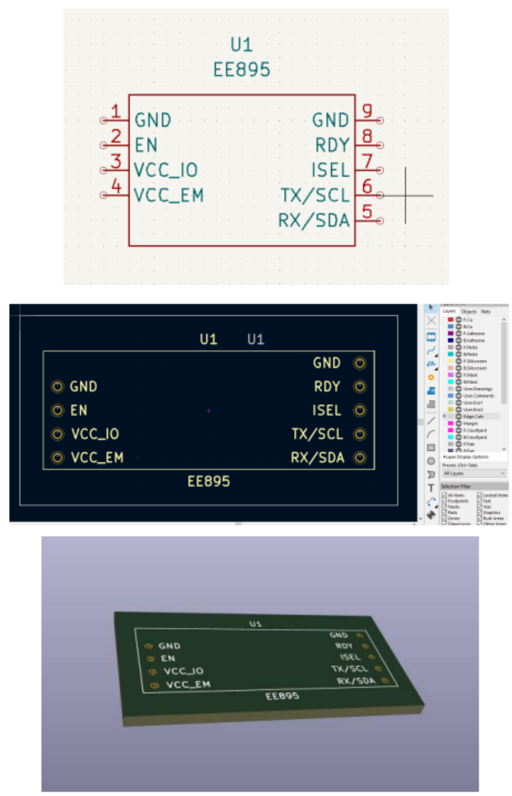


Figure 7: EE895 KiCad Integration

C. Identification of Needs

1. Multi-sensor device to measure significant data for analyzing the health of beehives or other apiculture related environments
   a. Examples of such sensors would include CO2/air quality detectors, weight scales for supers/comb frames, temperature (where appropriate), illumination of interior of hive

b. Secondary objective would be to have the ability to have a modular approach to the sensor apparatus
2. The device must be wirelessly connected to Mason's Wi-Fi or be able to access data remotely
   a. The customer's data must automatically be archived and have the ability to be extrapolated over time for further analysis of long-term health of the apiculture subject
3. The measurements of the product must be automated or require minimal tampering for the end user
4. The final product must not exceed power consumption than the surroundings of the environment is able to provide
5. The solution/product must not exceed or greatly adjust the dimensions of a colony
6. The User must be able to still complete daily care of the bees after installation of the Product
   a. such actions include but are not limited to: feeding, removing components, removing super frames, the smoking of bees, and the splitting of colonies
7. The product must in no way shape, or form harm, disable, or interfere with colony structure or development.
8. The product must be "accessible to a 13 year old" and have "less than half a page of instruction for use"
9. Developed solution must be reasonable for the end user to afford given the utility of the product (competitive market price is approximately $150-200 maximum for extraneous tools for apiculture)
   a. This price is for the final development of the product
10. Final product must be capable of withstanding weather conditions inside of the hive if embedded within the hive
11. Final product must not interfere with the location or convenience of the colony
12. The end user has also included further bonus objectives which will be listed below
   a. Sensing the population of varroa mites within a hive would greatly innovate the apiculture industry
   b. determining/predicting the event of a "swarm" or overpopulation of a hive before it occurs would be "a big hit"
   c. Being able to track a queen would be beneficial for beekeepers within our target Demographic

D. Decision Matrix of Components with Justification

We derived a short list for our sensors, needing to measure temperature, humidity, and Co2 levels. Weight and illumination were specified as bonuses, but not required for our client. We included decision matrices for them as well. We used five factors to determine the suitability of each sensor for our implementation (cost, durability, size, digital/analog, and accuracy). We assigned different weights for each of them according to how important each factor was for each sensor in our design, higher scores pertaining to more importance. Higher scores in each category reflect more preference for use in our design.

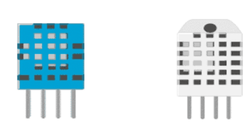
- Cost- Preferably lower cost corresponding to a higher rating
- Durability- Important for interaction with bees/material in hive, higher score indicates more durable due to material/sensor layout/hardware
- Size- Not as important, but preferably smaller size to fit on smart frame in hive
- Digital/Analog- Both can be implemented, but preferably digital for Raspberry PI (Digital GPIO Pins)
- Accuracy- Very important, including measurements taken per second to send data to server/website. Datasheets observed.

1. Temperature Sensor:

Our best candidate is the DHT22 because of its relatively cheap cost compared to the other sensors. It also appears more durable than the other sensors including the DS18B20 which contained a long, thin wire [5]. The sensor must be durable to withstand the bees and different materials/chemicals in the hive. The DHT22 was also more accurate compared to the DHT11 and had a lower sampling rate, and was digital as compared to analog for the LM35. The datasheets for all four parts that include dimensions and accuracy are listed in the references section [3][5][7][8].

	Weight ->	9	10	5	2	10	
Part Number:		Cost	Durability	Size	Digital/Analog	Accuracy	Final Rank
DHT22		9	6	9	10	9	43
DS18B20		10	3	7	10	8	38
DHT11		9	6	9	10	7	41
LM35		6	4	9	5	10	34

Table 1: Temperature Sensor Decision Matrix



	DHT11	DHT22
Operating Voltage	3 to 5V	3 to 5V
Max Operating Current	2.5mA max	2.5mA max
Temperature Range	0-50°C / ± 2°C	-40 to 80°C / ± 0.5°C
Humidity Range	20-80% / 5%	0-100% / 2-5%
Sampling Rate	1 Hz (reading every second)	0.5 Hz (reading every 2 seconds)
Advantage	low cost	More Accurate

Figure 8: Temperature Sensors Comparison

2. Humidity Sensor:

We chose the DHT22 sensor to measure humidity in our design. The cost savings were a main reason as we are using this sensor to measure temperature as well. Additionally, accuracy was the most important factor for us and the DHT22 fulfilled this criteria the best. The datasheets for all four parts that include dimensions and accuracy are listed in the references section [7][8][9][16].

	Weight ->	9	10	5	2	10	
Part Number:		Cost	Durability	Size	Digital/Analog	Accuracy	Final Rank
BME280		5	6	9	10	7	37
SHT40		6	7	10	10	8	41
DHT22		9	6	9	10	9	43
DHT11		9	6	9	10	8	42

Table 2: Humidity Sensor Decision Matrix

3. Weight Sensor (Additional)):

We chose the HX711 weight sensor for our design due to the relatively low cost, its ability to connect multiple of the same HX711 sensors together to measure weight, and its improved accuracy over the other sensors. The datasheets for all three parts that include dimensions and accuracy are listed in the references section [1][4][12].

	Weight ->	9	10	5	2	10	
Part Number:		Cost	Durability	Size	Digital/Analog	Accuracy	Final Rank
HX711		7	7	9	5	10	38
H26R0		7	5	10	5	8	35
MF02A-N-221-A01		8	3	8	0	8	27

Table 3: Weight Sensor Decision Matrix

4. CO2 Sensor:

We chose the EE895 sensor for our design because of its improved accuracy over the other sensors, and increased durability as the sensor contains a covering. The trade-off was the cost as this sensor is more expensive than the others. The datasheets for all four parts that include dimensions and accuracy are listed in the references section [2][6][10][13].

	Weight ->	9	10	5	2	10	
Part Number:		Cost	Durability	Size	Digital/Analog	Accuracy	Final Rank
K30		4	5	7	10	8	34
SCD30		6	5	7	10	8	36
EE895		5	6	8	10	9	38
CCS811		7	4	8	5	7	31

Table 4: C02 Sensor Decision Matrix

5. Illumination Sensor (Additional):

We chose the LM393 light sensor because of its cheaper cost compared to the UUGEAR LSM sensor. The sensor can also run for longer than the others and is small, being able to fit in a smart frame inside the hive well. The datasheets/websites for all three parts that include dimensions and accuracy are listed in the references section [14][17].

	Weight ->	9	10	5	2	10	
Part Number:		Cost	Durability	Size	Digital/Analog	Accuracy	Final Rank
LM393		10	6	8	10	8	42
UUGEAR LSM		9	6	8	10	8	41
KY-018		9	3	9	10	8	39

Table 5: Illumination Sensor Decision Matrix

6. Website Implementation:

MongoDB is our most capable candidate for its flexibility and ability to create an API as needed. The database implementation unlike other designs has the capability of creating a custom data schema which can adjust as needed. For our design it looks as such:

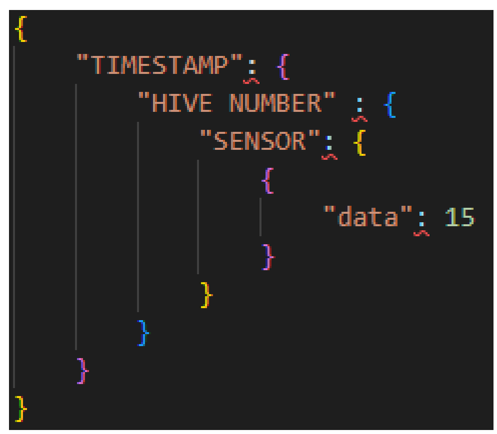


Figure 9: Website Implementation

This implementation allows for any number of hives, any number of frames, any number of sensors on each frame, and whatever data is needed across any amount of time. This approach has allowed us to implement newer sensors if need be into the design. For example, if an illumination sensor is required later, it can be added into the node red sensor and therefore added to the components list. Our Node Red code will be open source and available on Github for future students to use and update. Users will be able to select which sensor's data they want to create plots for, and download data for different time ranges to save for future use.

Javascript React is a relatively newer web app architecture which has the flexibility of custom

HTML5 based components as well as JSX compatibility. This allows us to render charts dynamically based on API calls of the sensors without having to worry about previous data or sensors which have been added long after the initial implementation was created.

The raspberry pi was chosen as our board due to its small form factor, low energy requirements, and flexibility across our network to act as our database and general infrastructure microcontroller. The low cost allowed us to utilize this component in addition to its high amount of documentation to ensure further future proofing. Which exact model isn't necessarily important as most tasks to be accomplished this project are low in resource and computation power.

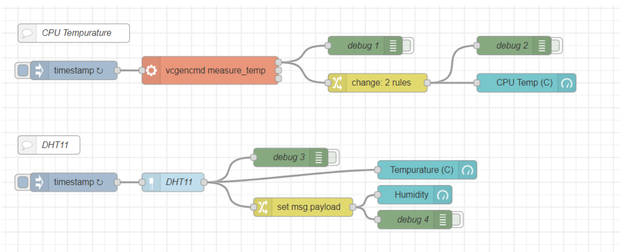


Figure 10: Node Red Design

VI. ALTERNATIVE COMPONENTS

Due to the multiple components, we will write an alternative component for each section of the project.

I. Server

From a hardware perspective, if we cannot use a central computer in the area, we could always use a cloud-based solution or have the microcontrollers transmit to a Kubernetes server. If a MERN stack cannot be used, we could use a quick HTTP server via a python script. In addition, doing the website in python would allow us to process the information in any way that the javascript would allow in spreadsheet form however, it would not be as quickly accessible.

II. Beebox

Several components have been considered for the microcontroller such as an ESP32, or beagle bone black. As long as the microcontroller can transmit the data schema and read the information from the sensors, it would work as a reasonable replacement.

III. SmartFrame

The Smart frame does not have a reasonable replacement in terms of exact design at the moment, but many alternative sensors exist that we could use instead of the ones we are planning to use. If GPIO is a contingency, we could always place a microcontroller on the frame instead of the use of a Beebox which would make the frames more expensive, but definitely would make the Beebox redundant.

V. Alternative sensors

A weight sensor was also requested by the customer and would be possible to implement if the Beebox was an external feature to the frame. However, this has been found to add to the cost of a fairly low-cost solution. A much cheaper alternative would be to weigh the hives as needed with a standard analog weight as it does not need to be measured as much as the temperature and CO2 do. The significance of which sensor is used does not directly harm our data schema nor is directly dependent on other components within our project.

A. Approach 2: Direct python HTTP server

This data as seen in Figure 2 can be also utilized into a python script which uses a fairly small resource HTTP server. This server would be similar to the previous implementation without charts in order to access said data. This is not preferable as it does not implement efficient means of storing data compared to the MongoDB server. Not reallocation is needed for this design. This design is independent of the data schema as well as sensor use and whether we use NODE-RED or not. It is fast to implement as it simply places a directory on the records used

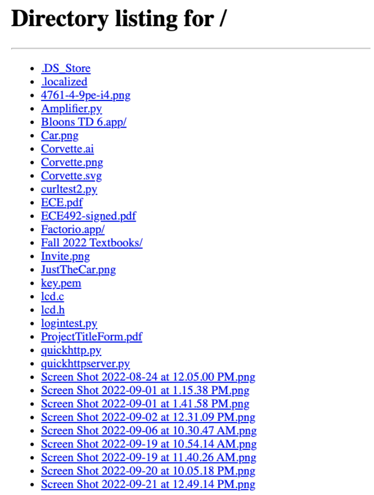


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Figure 11: Directory listing

B. Deliverables

- 15 Smart Fram (3 per hive)
- 5 "Bee boxes" (1 per hive)
- 1 server capable of concurrently running a javascript react-based website and MongoDB server
- User manual
- Technical manual
- Source code detailed in GitHub
- Website capable of …
- Live dashboard feed of sensor readout data per hive

VII. PRELIMINARY EXPERIMENTAL PLAN

A. Requirements for Experimental Validation

The experimentations will involve several minimum viable products. For the BeeBox, we will need to create a custom "NODE-RED" schema which will take advantage of the software in order to send sensor data quickly with little to no code to troubleshoot. Additionally, we will need to see what the total power input is and if that wattage changes over time.

The Smart frame will require some experimentation to see which temperature sensors work best for our purposes. Such as: are the sensors compatible with the final microcontroller we would be using? How precise are these controllers compared to others in the market? How reliable in more extreme weather conditions, as these are not planned to be placed indoors at any point.

The database will need to be able to retrieve and transmit data as well as figure out which type of computer we would use for the hosting. This could vary widely however, there are many alternatives to Raspberry Pi if the transfer rate is not sufficient.

1	Project Selection	READY	9/26/22	
2	Project Manager Selection	READY	9/2/22	
3	Project Title Form Delivery	READY	9/9/22	
4	Project Proposal Preparation	READY	9/16/22	
5	Draft Proposal Delivery	READY	9/23/22	
6	Proposal Delivery	READY	9/30/22	
7	Oral Proposal Presentation to FS and AF	READY	10/14/22 3:00 pm	
8	Draft Design Document delivery	READY	Yesterday	
9	Proposal Presentation 2 with Dr. Carley Fisher-Maltese	IN PROGRESS	Tuesday	
10	Proposal Presentation 2 with Dr. Tolga Soyata	IN PROGRESS	Tuesday	
11	SmartHive Website Development (onmason)	IN PROGRESS	11/19/22	
12	Design Review Presentations	IN PROGRESS		
13	Design Document delivery	TO DO	12/2/22	

Figure 12: Timeline

Project Management Template Update

Phase 1 - Strategy + NEW TASK ✓ SHOW CLOSED

TO DO 7 TASKS	ASSIGNEE	DUE DATE	PRIORITY
Draft Proposal Delivery		Fri	
Oral Presentation to FS and AF		Sep 30	
Proposal Delivery		Sep 30	
Oral Design Review Presentation to Faculty Supervisor		Nov 4	
Presentation slides delivery.		Nov 4	
Draft Design Document delivery		Oct 11	
Design Document delivery		Dec 2	

+ New task

Project Management Template Update ✓ SHOW CLOSED

Figure 13: Timeline

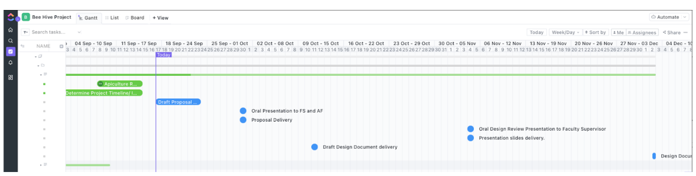

Figure 14: Gantt Chart Timeline

B. Experiments to be conducted next semester - Spring 2023

a) Testing if sensors work with our microcontroller – Raspberry Pi –, are accurate compared to readings we receive with measuring tools within a certain percentage.

b) Testing if our database receives and transmits data to our online tool reliably over many trials and circumstances – introducing hazards.

c) Testing the wax on a microcontroller over a period of time

d) Testing the functionality of unit tests over the web API developed in the current website architecture

VIII. ALLOCATION OF RESPONSIBILITIES

Nicholas: All testing and development of the website and data schema

Ahmed: Development of the NODE-RED components and connectivity between the smart frame and BeeBox

Sidney: Development and testing of the database as well as power allocation of the microcontrollers

Ismael and Ergi: Development of Smart Frame

Neil: Development of materials list and sensor choice for the smart frame

IX. POTENTIAL PROBLEMS

A key area of our smart hive design project that could lead to potential problems is learning the skills required to use the different technologies that we plan to implement in our design. One of these is Node-RED, and along with it Node.js. We will use Node-RED, a programming tool for wiring together hardware devices, APIs, and online services to connect our smart hive's hardware with our server and online tool. Javascript will also have to be learned to implement our runtime applications. We will also have to better our knowledge of printed circuit board (PCB) design to implement our smart frames for the bee hives and connect the different electronic components of our design together. A potential problem regarding the design of our project itself is poor internet in the beehive environment. We must ensure that our database has a stable connection and the server is able to send/receive information reliably. We also have to make sure our online tool displays the most recent data accurately and without gaps in the data. Additionally, we need to weatherproof our hardware in case rain short-circuits our electronic components in the hive. Power outages that lead to data corruption must also be accounted for.

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