STAR Programs Climate Tracking Network

David Fawcett and Trevin Cooper

CONCEPT OF OPERATIONS

REVISION – 2
4 December 2017

CONCEPT OF OPERATIONS
FOR
STAR Programs Climate Tracking Network

TEAM STAR PROGRAMS

APPROVED BY:

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1	9/15/2017	Trevin Cooper		Draft Release
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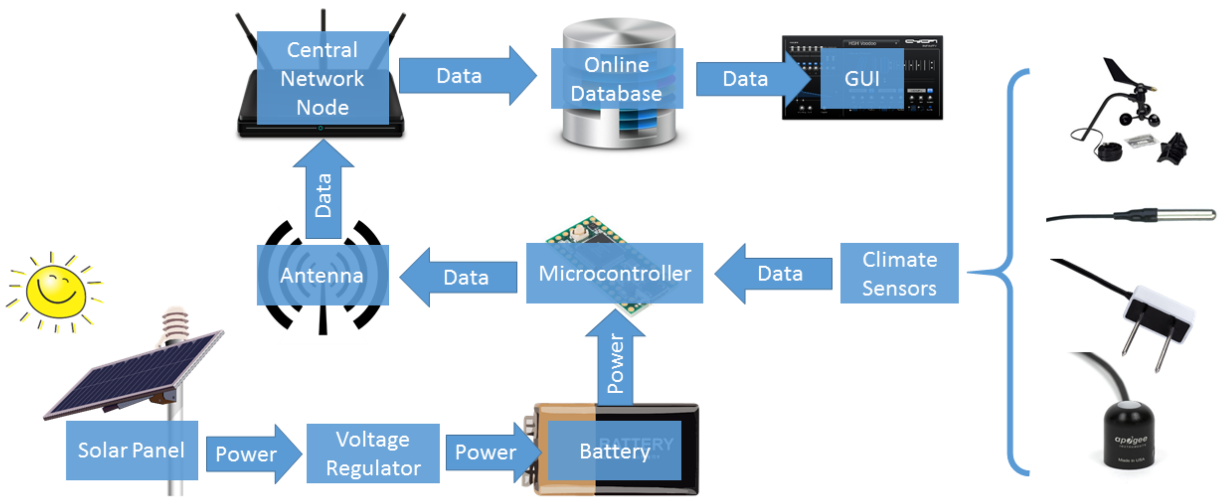
1. Executive Summary

The purpose of this project is to address the need for regional climate and environmental data to improve agricultural performance. The solution specified is to develop a network of climate sensor stations distributed across a cultivatable area and the surrounding region to monitor relevant climate factors over time. Specifically, the climate factors that will be recorded are rainfall, solar irradiance, air temperature, soil temperature, soil moisture content, wind speed, and water levels. Each sensor station will operate on solar power and take measurements hourly. The stations will then transmit the information to a base station. The central network station will upload all of the data to the internet twice a day where the data will be presented in a user interface that is accessible to the agricultural end user through the web. The scope of this project is a proof of concept for a prototype climate sensor station, prototype stock pond depth sensor station, and central node which will be networked to gather and to upload the information so that it is accessible through a website on the internet.

Figure 1: Functional System Diagram of Climate Tracking Network



2. Introduction

The purpose of this document is to present the Climate Tracking Network, a distributed network of agricultural sensors that monitor relevant climate parameters in order to assist farmers with crop selection and management techniques. This project has the potential of improving agricultural performance and enabling agricultural in areas where it has not yet been tried by providing additional and necessary information.

2.1. Background

There is an increasing worldwide demand for food that requires new farming techniques and paradigms [1]. STAR (South Texas Advancement Resource) Programs believes Southwest Texas could be a new region where agriculture needs can be met. Southwest Texas is a harsh environment where farming has not been developed, and ranching is the predominate means of food production. In order to develop a system of agriculture which is profitable in Southwest Texas, additional local climate and micro-environmental data will be needed. The Climate Tracking Network will help support the initiative by providing data to aid in the crop selection and management programs STAR Programs is pursuing.

The Climate Tracking Network has an additional goal of providing data to supplement already developed agricultural systems. The profit margins in agriculture are usually very narrow, which leaves very little room for uncertainty [2]. Success is often dependent on the accuracy of information about specific variables, many of which are related to the climate of the region. Although public weather information is commonly available across the country, this information is tailored to specific sensors across a wide region, and it is possible that none are located anywhere near the agricultural property in question. It also does not typically include parameters that are useful for a particular farmer. Therefore, it is frequently inaccurate or not useful for agricultural purposes, especially when crop yield is trying to be optimized.

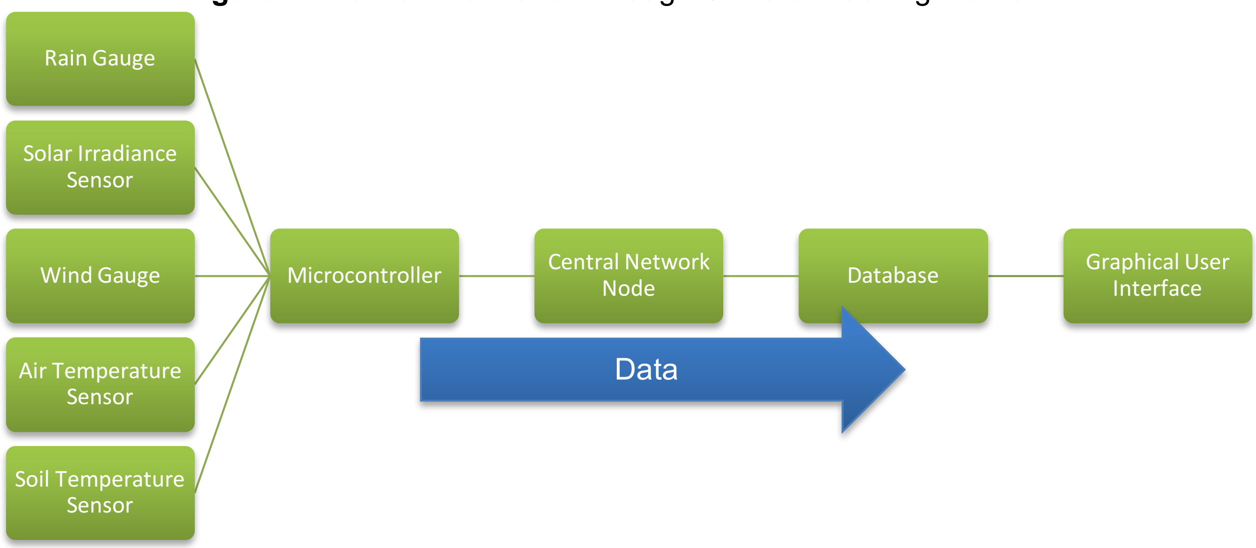
There are systems available on the market that can be implemented to aggregate climate data for a specific area of land. These systems import data from sensors into units that store the information and transmit it back to a centralized location. However, these systems tend to be very expensive and offer little flexibility for expanding the functionality of the system or for using it in conjunction with sensors produced by other manufacturers. When the profit margins are already very narrow in agriculture, an affordable solution is necessary if widespread use of these networks is to become common practice in agriculture. Therefore, the Climate Tracking Network will leverage technology that is widely available and comparatively cheap to that used by the tailor-made equipment in other systems.

The system will also be environmentally friendly since it will be powered entirely from solar energy and will enable farmers to conserve resources when the system indicates there is no need for them. It has been shown that agriculture consumes about 75% of all human water use, and the ability to conserve water without endangering the crops will increase water usage efficiency [4]. Such an increase in water efficiency will be accompanied by optimized fuel and chemical usage, serving to help the environment and improve sustainability in agriculture.

2.2. Overview

The network will consist of several sensor stations that are comprised of sensors interfaced into a microcontroller. Each station will continuously record measurements and send them to a central location, which will upload all of the information through the internet to a database. A web application will show recent and historical data pulled from the database. Over the course of several years in order to show the historical averages and general trends will build up within the database. This will allow farmers to select crops that are known to do well in that environment and use techniques to compensate for those parameters that are limiting the yield of their crops. The schematic in Figure 1 below shows the flow of information and feedback control that the system will leverage.

Figure 2: Flow of information through Climate Tracking Network



Additional functionality, which may be added to the design as stretch goals for the scope of this project, is described in further detail later in this document.

2.3. Referenced Documents and Standards

[1] “Global agriculture towards 2050”. *Food and Agriculture Organization of the United Nations*, October 2009 Accessed at http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf

[2] Hoppe, R. “Profit Margin Increases With Farm Size”. *United States Department of Agriculture*. Accessed at https://www.ers.usda.gov/amber-waves/2015/januaryfebruary/profit-margin-increases-with-farm-size/

[3] “Climate Education for Agriculture – Instruments”. *North Caroline State University*. Accessed at http://climate.ncsu.edu/edu/ag/instruments

[4] Wallace, J. “Increasing agricultural water use efficiency to meet future food production”. *Elsevier,* Vol 82, Iss. 1-3. December 2000. Accessed at http://www.sciencedirect.com/science/article/pii/S0167880900002206

3. Operating Concept

3.1. Scope

For the scope of this project, a proof of concept system is being designed that will be able to confirm all of the relevant operating parameters that the full Climate Tracking Network would need to be employ. The exact deliverables for the scope of this project are as follows:

- Standard Climate Sensor Station
- Depth Sensor Station
- Central Network Node
- Database with GUI

Documentation for the design, construction, and programming of the units will be provided for all parts of the project.

3.2. Operational Description and Constraints

The Climate Tracking Network is intended for use in the agricultural industry in areas with sufficient sunlight for the solar panels to power the units. It is also intended for open areas with direct lines of sight to the places where the climate sensor stations will be placed. The environments in which it is to be used must meet all of the following criteria:

- A year-round temperature range of -20 - 140° Fahrenheit
- Sufficient solar exposure to power the units
- Direct lines of sight between the central network node and all sensor stations
- Small enough radio interference for units to communicate effectively

Furthermore, the system is not designed or intended to operate in and/or survive extreme natural events, such as earthquakes, tornadoes, hurricanes, lightning, etc.

More specific details on the operational description and constraints are recorded in the FSR, which takes precedence in the case of a conflict between with any operational description or constraints detailed here.

3.3. System Description

The Climate Tracking Network will consist of multiple climate sensor stations, a centralized network node, a database, and a graphical user interface. This can be broken down into five different subsystems, described in detail below:

Sensor Subsystem: The five parameters that are most important for developing systems of agriculture are gathered by the sensors connected to the microcontroller to obtain the needed information. Additional sensors and subsystems that support the acquisition and storage of the data are detailed below.

Pyranometer: A pyranometer measures solar irradiance. The values measured by the pyranometer will vary throughout the day and can be affected by shadows produced by nearby plants or sensors. The pyranometer will be placed well above the ground and in such a manner that no shadows will be cast on it. These sensors typically output a small voltage associated with the wattage per square meter incident upon it.

Figure 3: Pyranometer

Rain gauge: The rain gauge will measure precipitation. Rain gauges typically operate with a tipping bucket design. A tipping bucket collects water and tips when a certain amount of water as fallen. This tipping triggers a pulse which can be recorded and used to determine the total amount of rainfall in a given amount of time.


Figure 4: Rain Gauge

Anemometer: An anemometer measures wind speed and direction. A common anemometer design is a cup anemometer. The cups capture the wind and begin to spin. The faster the cups spin, the higher the voltage provided by the data output. This voltage can be used to determine the wind speed.


Figure 5: Anemometer

Thermometer: Two different types of thermometers will be implemented. One thermometer will measure air temperature at each climate sensor station, and another type of thermometer will measure soil temperature at each climate sensor station. These thermometers modify the resistance seen from the microcontroller, which can be measured by a simple voltage divider circuit.


Figure 6: Thermometer

Soil Moisture Sensor: A soil moisture sensor measures the volumetric content of water in the soil. It measures the dielectric permittivity of the soil by acting like a capacitor. By measuring the performance of the capacitor, the dielectric permittivity of the soil can be found, which is directly proportional to the water content in the soil.

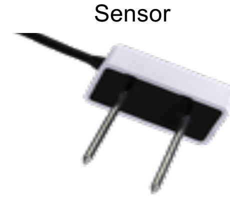


Figure 7: Soil Moisture Sensor

Pressure Transducer Depth Sensor: A pressure transducer depth sensor calculates the pressure it is under by its changing resistance as the pressure changes. The transducer can also be vented to help calibrate for changes in barometric pressure.


Figure 8: Pressure Transducer

Microcontroller Subsystem: The microcontroller will interface with and manage each of the components in the climate and depth sensor substations, including the power subsystem, sensor subsystem, and communication subsystem. In the central network node, it will manage the communication subsystem and ensure all of the data is routed to the proper place.

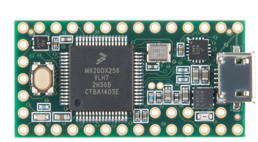


Figure 9: Microcontroller

Power Subsystem: The power subsystem will consist of a solar panel, a voltage regulator, and a battery at each of the climate/depth sensor stations and central network node. It will be the sole source of power for the physical components of the system.

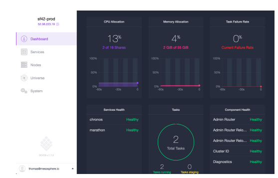
Figure 10: *Solar Panel*

Communication Subsystem: The communication subsystem is comprised of the antennas and modulation chips that are connected to the microcontrollers of each system for the purposes of communicating between the stations and the central network node, as well as uploading the data from the central network node to the online database.

Figure 11: Antenna

Information Storage and Presentation Subsystem: The online database, with the associated GUI for the user to view the data from the system, is the Information Storage and Presentation Subsystem. This will be the means by which the user is able to consume the data and make decisions to optimize agricultural performance.

Figure 12: Display Panel



3.4. Modes of Operations

The Climate Tracking Network shall use a primary mode of operation in which the data from the sensors is collected, transmitted to the central network node, uploaded to the online database, and presented to the user for viewing.

The system will also have error notification mechanisms in place to alert the user in the event of any noticeable problems in the operation of the system, such as the voltage to the battery dropping too low. In events that could threaten the long-term survival of the system, a secondary mode of operation will be used in which the system stops transmitting data to preserve the lifespan of the components.

3.5. Users

The Climate Tracking Network is intended for use by farmers and others who have experience in the agriculture industry for the purposes of enhancing crop yield, but will be designed so that the average person familiar with the climate parameters will be able to interpret the data presented to the user. In order to perform maintenance on the system, the user will need at least a basic understanding of the components of the system, including solar panels, batteries, microcontrollers, sensors, and antennas.

3.6. Support

User manuals will be provided with details on how the Climate Tracking Network works and interfaces together. The user manual will help provide documentation for each subsystem to help troubleshoot any difficultly that occurs after the project is completed.

4. Scenarios

4.1. Gathering Baseline Weather Data

The Climate Tracking Network will provide point source data about a given local environment. The point source data can be synthesized with a general model to provide a better understanding of the region's environment. This model can be used to establish trends and precedents and to predict future micro-weather patterns.

4.2. Aiding in Crop Selection

The Climate Tracking Network is focused on gathering data which applies to agricultural management and crop selection. Knowing the key parameters of solar irradiance, precipitation levels, and wind speeds will help teams of agricultural engineers select a viable and commercially successful crop for the region. The importance of the network is made more obvious by the lack of historical local data for agricultural engineers in the Southwest Texas region. Providing this data for the historically unfarmed region of Southwest Texas is the central goal of the Climate Tracking Network and directly supports other projects led by STAR Programs.

4.3. Optimizing Crop Performance

Even after a crop has been selected, the use of resources to care for the plants can be optimized by the Climate Tracking Network. Knowledge about the health of soil and crops in different plots of land will allow farmers to conserve resources when utilizing them will not result in greater yield or to expend them when necessary. This reduces cost and increases revenue for farmers leading to an overall rise in profitability.

5. Analysis

5.1. Summary of Proposed Improvements

- The Climate Tracking Network will support STAR Programs efforts for developing an economically successful method of growing a cash crop in Southwest Texas. The data will be used to provide additional source of information for the crop selection and management.
- Success in the development of a cash crop will introduce a new supply of produce into the world market. This will impact not only Texas, but other areas with similar environmental conditions. These new markets will change the face of food production, improve local economies, and help meet the growing need for food around the globe.
- Farmers around the world will be able to improve their use of resources, management of crops, and yields through the Climate Tracking Network. The Climate Tracking Network will provide previously unknown but important and basic climate data for STAR Programs' land in Southwest Texas. The technology developed here can also be used by farmers as a cheap and effective way to introduce data into agriculture a key to better resource management. The Climate Tracking Network should be cheaper than many distributed sensor networks available for agriculture allowing more farmers to take advantage of precision farming.

5.2. Disadvantages and Limitations

The largest barrier and limitation to the climate tracking network is that it will be several years before trends and precedents can be determined based upon the data. The usefulness of the data that is being gathered will be proportional to the amount of data gathered. Therefore, it may be some time before the STAR Programs or others will see a return on investment for the Climate Tracking Network. However, the data that is being gather is valuable, and the time required is reasonable for the long-term goals of STAR Programs.

Since the system is being built at a very low level, it may be difficult for people to implement themselves. The use of these microcontrollers and sensors may be foreign to some users who would benefit from the Climate Tracking Network. Some of this can be overcome with manuals detailing how to construct the system, prefabricated systems, and ready to software that allows for easy installation in the field.

Adding functionality to the system will be very difficult. The system will not be designed to be plug-and-play with other types or kinds of sensors. Thus, those desiring different measurements will be faced with a difficult task of implementing it themselves. In order to avoid the disadvantage of this limitation, the Climate Tracking Network is focusing on the most beneficial data sources for crop selection and agriculture management.

5.3. Alternatives

There are several alternatives to implementing the Climate Tracking Network. The first would be to gather the data manually without a permanent network. This would involve a portable sensor that could be used at each of the various points of interest. The main difficultly with this solution would be the additional labor and clerical work needed during the acquisition process. The Climate Tracking Network would require less time for the user to gather and compile the data by automatically and regularly gathering it. Another alternative would be to contract a company to implement the system. There are companies that specialize in precision agriculture and could implement the system. The primary barrier to this alternative is that the cost to implement a custom solution will be very high. Additionally, nothing will be learned by STAR programs on how other farmers could implement this technology themselves, which is a key goal of the sponsor. Finally, there are companies, such as Meter and Davis Instruments, which sell plug-and-play sensors and dataloggers for agricultural purposes. These systems are very expensive and often do not offer the parameters requested at a reasonable price.

STAR Programs Climate Tracking Network

David Fawcett and Trevin Cooper

INTERFACE CONTROL DOCUMENT

REVISION – 1
4 October 2017

INTERFACE CONTROL DOCUMENT
FOR
STAR Programs Climate Tracking Network

TEAM STAR PROGRAMS

APPROVED BY:

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David Fawcett Date

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Prof. S. Kalafatis Date

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Bahareh Anvari Date

Change Record

Rev.	Date	Originator	Approvals	Description
1	9/15/17	Trevin Cooper		Draft Release
2	12/4/17	Trevin Cooper		MySQL and microcontroller interface descriptions added

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1. Overview

The Interface Control Document (ICD) for the entire Climate Tracking Network will provide more detail on how the subsystems in the Concept of Operations and the Functional System Requests will be produced. The ICD will include physical descriptions of the various elements and the electrical interface, power, and placement of each sensors. The document will also explain how the subsystems will interface together to achieve the goals and requirements mentioned in the FSR and ConOps documents.

2. References and Definitions

2.1. References

IEEE Standard 802.15.4-2015
Standard for Low-Rate Wireless Personal Wireless networks
2015 revision

IEEE Standard 802.11
Standard for Wi-Fi Networks

IEEE Standard 802.16
Standard for Metropolitan Area Networks

2.2. Definitions

GUI	Graphical User Interface
MHz	Megahertz (1,000,000 Hz)
m	Meter
mV	Millivolt
RF	Radio frequency
V	Volt
Ah	Amp-hour
W	Watt

3. Physical Interface

3.1. Weight

3.1.1. Weight of climate sensor stations

The climate sensor stations will weigh less than fifty pounds. This allows for an average person to lift and move the entire station into place and the station will be more secure with added weight near its base. This will become even easier if the design becomes modular.

Table 1: Weather Station Weight Specifications

Component	Weight
Thermometer	4.5 oz.
Radiation Shield	Estimate: 1 lbs.
Pyranometer	3.17466 oz.
Davis Rain Gauge	2 lbs. 3 oz.
Anemometer	2 lbs. 15 oz.
Soil Temp & Moisture	Estimate: 0.5 lbs.
Teensy	0.035274 oz.
Xbee	0.17637 oz.
Solar Panel	3.3 lbs.
Battery	4.5 lbs.
Buck Converter	0.035274 oz.
Tripod	Est. 15 lbs
Housings	Est. 3 lbs
Antenna	Est. 2 lbs
Total	34.63 lbs

3.1.2. Weight of depth sensor stations

The depth sensor stations will also weigh less than fifty pounds. The only difference in the depth sensor and the climate sensor station is the addition of a pressure transducer. The additional weight of the pressure sensors is less than two pounds. The reasoning is identical to the one previously in that it allows someone to easily move the station into place and allows the station to be more stable with added weight near its base.

3.1.3. Weight of central network node

The central network node will weigh less than fifty pounds. The only addition to the central network node is a cellular 3G modem which weighs the same as the XBee mentioned above. The reasoning for the weight of fifty pounds is identical to the ones above in that it allows someone to easily move the station into place and allows the station to be more stable with added weight near its base.

3.2. Dimensions

3.2.1. Dimension of climate sensor stations

The climate sensor stations will fit inside a rectangular prism which is 1m in length and width and 3m tall. Table 2 below shows the dimensions of each of the technical components of the climate sensor substations.

Table 2: Weather Station Dimension Specifications

Component	Diameter	Length	Width	Height
Thermometer	0.312"	2.5"	N/A	N/A
Radiation Shield	N/A	Est. 5"	Est. 5"	Est. 8"
Pyranometer	0.01"	N/A	N/A	0.01"
Davis Rain Gauge	8.75"	N/A	N/A	9.5"
Anemometer	N/A	18.5"	7.5"	4.75"
Soil Temp & Moisture	N/A	3.93"	1.2"	Est. 1"
Teensy	N/A	1.4"	0.7"	Est. 0.1"
Xbee	N/A	1.297"	0.962"	0.215"
Solar Panel	N/A	10"	16"	.7"
Battery	N/A	7.1"	6.6"	3"
Buck Converter	N/A	12"	0.5"	N/A

3.2.2. Dimension of depth sensor stations

The depth sensor stations will fit inside a rectangular prism which is 1m in length and width and 3m tall, not including the depth sensor itself which will extend to the bottom of the stock pond.

3.3. Mounting Locations

3.3.1. Placement of Station

The station will need to be placed on a flat square meter section of land. The station will also need to be fixed into the ground with stakes if windy conditions will be present. This will require a mallet and soil with the appropriate conditions for securing the station to the ground.

3.3.2. Mounting of Sensors

The sensors will be placed in the ground or mounted on tripods to provide the optimum environment for the sensor to gather the data. For example, the pyranometer will be mounted such that no shadows are ever cast upon it and the anemometer will be mounted so that nothing is blocking wind around it. There are several options for purchasing mounting equip for each of the sensors mentioned in this document.

3.3.3. Mounting of Solar Panel, Controller, and Battery

The battery solar panel will be mounted such that it receives an optimum amount of sun every day throughout the year. The controller will be underneath the solar panel along with the battery inside a waterproof housing.

3.3.4. Mounting of Microcontroller and Power Converter

The microcontroller and power converter will be placed in a waterproof housing underneath the solar panel. The cabling for the sensors will run into the housing and be processed by the microcontroller. There will also be an opening for an RPSMA wire to run to the antenna.

3.3.5. Mounting of Antenna

The antenna will be mounted so that it points towards the central network node. An RPSMA cable will run to the XBee communication chip attached to the microcontroller.

3.3.6. Mounting Locations for Central Network Node

The central network node will have an option for mounting it onto a pole to help establish line of sight with the sensor stations and/or improve antenna and communication performance between the central network node and sensor stations.

4. Thermal Interface

4.1. Thermal Shielding for Air Temperature Sensor

The air temperature sensor on the climate sensor stations will have a radiation shield on it to improve accuracy of the sensor with respect to detecting the exact air temperature without influence from incident radiation from the sun.

4.2. Cooling of Battery

The battery will be air cooled under the solar panel. The heat generated by the battery should be able to dissipate on its own.

5. Electrical Interface

5.1. Primary Input Power

5.1.1. Primary Power for Climate Sensor Stations

All power for the climate sensor station will be supplied by the 10W solar panel, which will be used to charge the 12V battery. The battery will then be used to supply power to the computing, sensing, and communication subsystems. The voltage will be regulated and buck converters will be used to supply acceptable voltage levels to components which cannot use 12V inputs.

5.2. Signal Interfaces

5.2.1. Digital Climate Sensors

The digital climate sensors will communicate to the computing subsystem in their native language. The native language for each type of sensor is shown in table 1 below.

Table 3: Native Languages for Digital Sensors

Sensor	Sensor Type	Native Language
Decagon 5TM	Soil moisture & temperature	SDI-12

5.2.2. Analog Climate Sensors

The analog climate sensors will communicate to the computing subsystem by outputting a voltage in the range specified below in table 4. The specification sheets for each sensors will be used to program the computing subsystem to interpret the output values of the subsystem.

Table 4: Output Ranges for Analog Sensors

Sensor	Sensor Type	Output Range
Davis 6465	Rainfall	Pulse
Apogee SP-110	Solar irradiance	0 to 2.5V
Davis 6475	Air temperature	~0Ω to ~300kΩ
Davis 7911	Wind speed	Pulse
APG PT-510	Depth	4mA to 20mA

5.3. Voltage and Current Levels

The current being drawn by the majority of the sensors can be regulated and they will not draw a significant amount of current. However, the XBee communication chip and the PT-510 depth sensor will both draw a significant amount of current when in use. The XBee will consume 250 mA during transmission, and the PT-510 will consume no more 10mA on average. The 7 Ah battery and 10-watt solar panel will be more than enough to compensate for the current drain of these two activities.

5.4. User Control Interface

The only interface with the user that the climate tracking network will have is the web-based GUI which will allow the user to view the data being collected by the sensor. No other user interface is required or has been requested by the sponsor.

5.5. Microcontroller Pin Interface

It is important to have a standardized interface for which pins on the microcontroller correspond to each use, in order to facilitate the testing of code that was developed separately. Table 5 shows which pins have been reserved for their corresponding uses, while the remaining pins can be used as needed until otherwise specified during the development of the project.

Table 5: Pin Interface for Teensy 3.2 Microcontroller

Teensy 3.2 Pin	Use
0	Ground
1	UART Rx to Xbee
2	UART Tx to Xbee
9	Anemometer pullup
11	Rain collector pullup
16	Water depth, analog input
18	Pyranometer, analog input
20	Air temperature probe, analog input
22	Soil moisture/temperature, digital input
24	+3.3V power
25	Ground
26	+5V power, input from buck converter

6. Communications / Device Interface Protocols

6.1. Xbee Communications Protocol

All communications between the climate/depth sensor stations and the central network node will be handled using the Xbee communication protocol on the Xbee RF modules at a range centered at or near 900MHz. This protocol operates in specification of IEEE standard 802.15.4-2015.

6.2. Microcontroller Input and Output

The microcontroller has a variety of digital and analog input and output pins. The pins can read and transmit signals from 0V-5V. This meets the requirements of all of the data protocols used by the sensors mentioned above.

6.3. 3G Communication

The microcontroller will also use an Xbee that uses the 3G communication protocol described in the IEEE 802.16 standard. This will be used to connect the central network node to the 3G communications network.

6.4. MySQL Protocol

The packets to initiate and complete the handshake with the MySQL database, along with the packets to complete queries with the database, will be created at the central network node and passed to the socket connection in the modem that interfaces with the 3G cellular network.

STAR Programs Climate Tracking Network

Trevin Cooper and David Fawcett

FUNCTIONAL SYSTEM REQUIREMENTS

REVISION – 2
4 December 2017

FUNCTIONAL SYSTEM REQUIREMENTS
FOR
STAR Programs Climate Tracking Network

TEAM STAR PROGRAMS

APPROVED BY:

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David Fawcett Date

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Prof. S. Kalafatis Date

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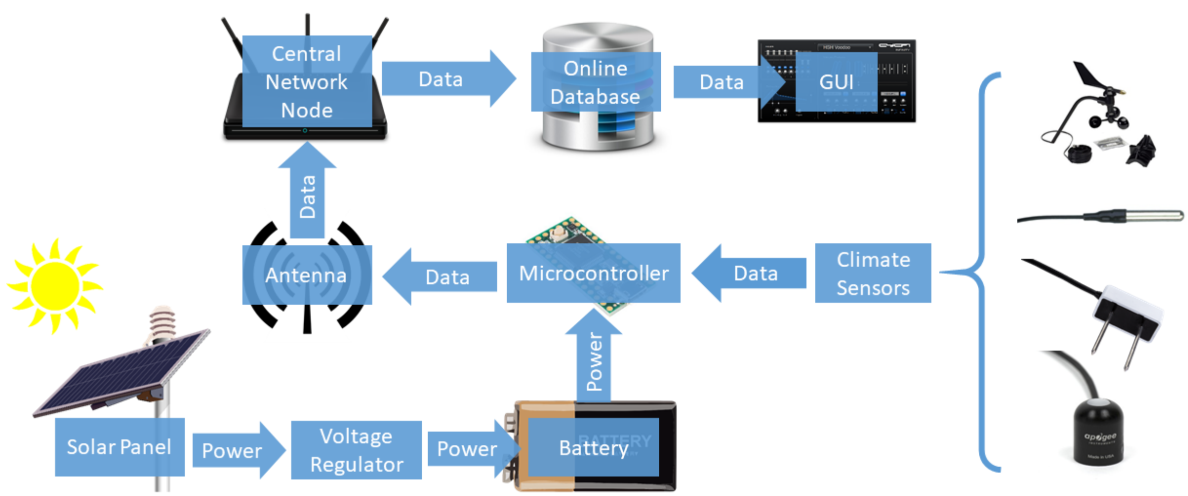
1. Introduction

1.1. Purpose and Scope

The climate tracking network is an efficient way to monitor the precise conditions of a microclimate, which is particularly useful for agricultural areas where there is little to no historical data available. It is designed to be implemented by the average person who has an agricultural background, and has the ability to enhance crop efficiency and profit by allowing farmers to fine tune their crop selection and techniques for crop growth to the parameters that their land provides. Figure 1 shows a representative integration of the project in the proposed CONOPS.

Figure 1: Functional System Diagram of Climate Tracking Network



The system will be powered entirely by solar power, and each sensor station shall record information about the air temperature, solar irradiance, rainfall, wind speed, soil temperature, and soil moisture specific to the area in which the sensor stations are deployed. A separate kind of sensor shall record the level of water in stock ponds in the area. All of this information shall be transmitted to a central network node, which shall upload it to an online database. The system shall aggregate all the climate data over a period of several years and present it to the user in a convenient, easily understood format.

The system may do analytics on the information collected, such as prediction algorithms, which could forecast general future weather conditions based on historical trends and present conditions. The system may compliment the data gathered by it with information from public weather services.

1.2. Responsibility and Change Authority

The team leader, David Fawcett, is charged with ensuring all specifications of the system are met. Any changes to the specifications or deliverables of the project must be approved by the team leader, David Fawcett, and the sponsor's official representative, Bill Raney.

2. Applicable and Reference Documents

2.1. Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Table 1: Application Standard Documents

Document Number	Revision/Release Date	Document Title
IEEE 802.11	2012	IEEE Standard for Information technology—Telecommunications and information exchange between systems Local and metropolitan area networks—Specific Requirements
IEEE 307	1969	IEEE Standard Definitions of Terms for Solar Cells
C2-2017	2017	National Electrical Safety Code(R)

2.2. Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification, and are not controlled by their reference herein.

Table 2: Reference Documents

Document Number	Revision/Release Date	Document Title
Version 1.4	May 2017	SDI-12 A Serial-Digital Interface Standard For Microprocessor-Based Sensors

2.3. Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable document are considered to be for guidance and information only, with the exception of ICDs that have their applicable documents considered to be incorporated as cited.

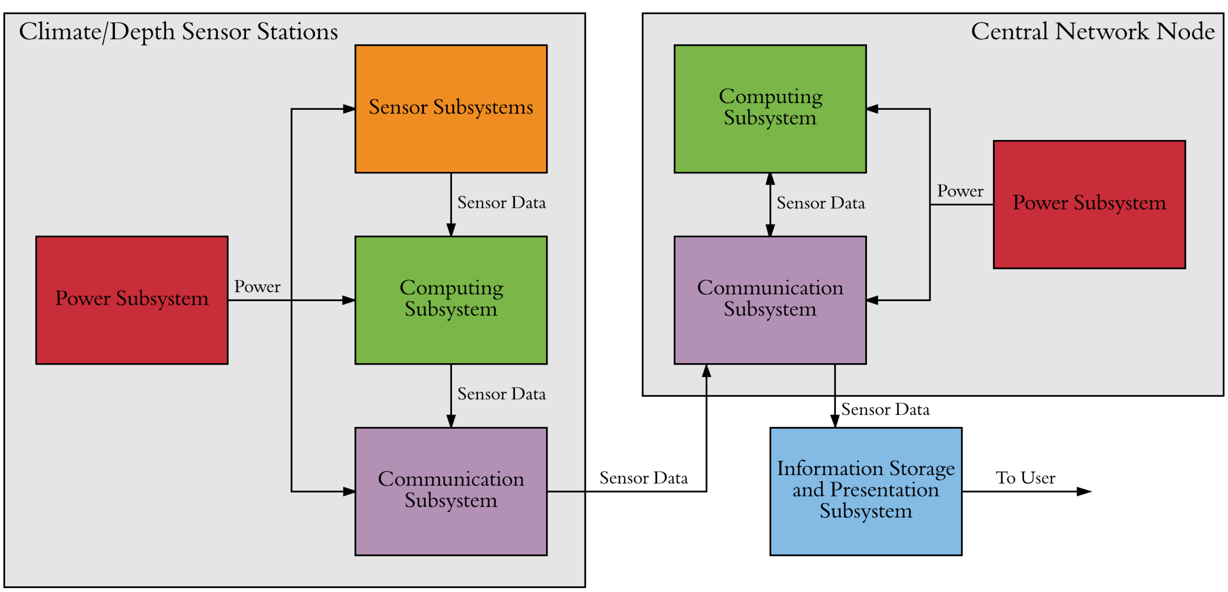
3. Requirements

In the following section, “climate tracking network” will exclusively refer to the entire system for which the proof of concept is being developed in the scope of this project. This includes all the climate and depth sensor stations, central network node that can interface with the internet, the online database where the information is stored, and the graphical user interface with which the user can view the data being collected. The term “climate sensor station” will exclusively refer to the physical units which record climate data and transmit it to the central network node. The term “central network node” exclusively refers to the device which receives the data from the sensor stations and uploads it to the online database. The term “online database” refers to the web-based storage system where all of the data collected is continuously aggregated. The term “graphical user interface” exclusively refers to the software program which allows the user to view and interpret the data which has been collected.

3.1. System Definition

The Climate Tracking Network will be comprised of 5 subsystems, which are shown in Figure 2. The sensor subsystem is unique to the climate sensor station and depth sensor stations, but the power, communication, and computing subsystems have parts in both the climate/depth sensor stations and central network node. The information is loaded from the central network node to the information storage and presentation subsystem, where it is accumulated over the course of years and presented to the user for viewing.

Figure 2: Block Diagram of Climate Tracking Network



In each case, the power subsystem shall consist of a solar panel that harvests energy from the sun, a voltage regulator to provide a constant voltage to charge the battery, and the battery to power the units when the solar panel does not produce enough energy.

The sensor subsystem shall gather the information about the environment and transmit it to the computing subsystem. The climate parameters gathered by the sensor subsystem for the climate sensor stations are air temperature, rainfall, solar irradiance, wind speed, soil temperature, and soil moisture. For the depth sensor stations, the sensor subsystem collects all of the information a climate sensor station does along with information on the depth of the stock pond. This information is then sent to the computing subsystem.

For the climate and depth sensor stations, the computing subsystem shall take in the data from the sensor subsystem, store it temporarily, and prepare it to be transmitted wirelessly. The computing subsystem for the central network node shall take in data from the communication subsystem that was sent from the climate/depth sensor stations and store it temporarily until it can be uploaded to the internet, through another part of the communication subsystem for that unit.

The communication subsystem shall be the mechanism by which data is transmitted from the climate and depth sensor stations to the central network node, received by the central network node, and uploaded by the central network node to the online database for the user to view.

The information storage and presentation subsystem shall consist of the online database where the data is continuously aggregated and the GUI that the user is able to view. It may also consist of programs that process the data or complement it with public weather service data.

3.2. Characteristics

3.2.1. Functional / Performance Requirements

3.2.1.1. Frequency of Measurements

Each sensor in the Climate Tracking Network will take a measurement every 30 minutes. The only exception will be the rain gauge which will take samples continuously, reporting the total rain fallen every 30 minutes.

> *Rationale: This frequency is expected to detect subtle weather events such as light rain showers, but will not provide an excessive amount of data that could become difficult to manage.*

3.2.1.2. Accuracy of Measurements

The Climate Tracking Network will provide climate information using sensors that are rated as being accurate to within the following specification for each type of sensor.

Table 3: Required rated accuracy of sensors

Sensor	Accuracy
Rainfall	+/- 5%
Solar Irradiance	+/- 5%
Air Temperature	+/- 1°F
Soil Temperature	+/- 1°F
Soil Moisture	+/- 3%
Wind Speed	+/- 2mph
Water Depth	+/- 0.25 feet

Rationale: These are standard values that most sensors of decent quality are able to achieve. Further resolution than these values is also not considered to add significant value to the system, and is not within the scope of the Climate Tracking Network.

3.2.1.3. Lifespan and Maintenance

The Climate Tracking Network will be designed with a target life of 5 years. It should operate independently for up to 6 months without needing any maintenance or inspection from the user.

Rationale: Most of the components of the physical side of the system are typically designed to last for about 5 years, which limits the lifespan of the overall system to that time. It is inconvenient to check each climate sensor station more frequently than 6 months, but natural effects could gradually cause damage to the system, which can be prevented if it is inspected occasionally.

3.2.1.4. Communications Requirements

The Climate Tracking Network will require line of sight for all paths of transmissions. Climate and depth sensor stations will be designed to transmit (or relay) information across an 11 mile span.

Rationale: Line of sight helps ensure reliable communications over the lifespan of the system, and 11 miles is needed to support the particular area of interest to the sponsor. Allowing the system to relay information, if needed to reach the 11 mile requirement, will increase the flexibility of the system and enable it to cover a wider area.

3.2.2. Physical Characteristics

3.2.2.1. Structural

The climate and depth sensor stations will use metal tripods for structural support. The technical components of the system will be bracketed on to the tripod or reach down into the soil or stock pond, depending on the need of the component. The central network node will not use a tripod, but will contain an option for being bracketed onto another structure.

Rationale: The tripod will keep sensitive components off the ground to reduce damage caused by natural effects, and provide the necessary place for the anemometer, air temperature, and humidity sensors to detect the respective parameters from the air.

3.2.3. Electrical Characteristics

3.2.3.1. Inputs

The only inputs the Climate Tracking Network is designed to handle is power from the solar panels and environmental data gathered by the sensors. The input data from the sensors will consist of basic digital and analog values governed by the data sheet provided by the given sensor. The sensor may also communicate with the microprocessor via a standard protocol such as SDI-12, a common communication protocol for agricultural sensors. The design will not allow user to modify or change any of the inputs.

> *Rationale: There are no parameters of the electrical inputs to the system that would be particularly useful to the user to modify since it is only intended to collect climate information.*

3.2.3.2. Power Consumption

The peak power for the physical units in the system shall not exceed the power available from the solar panels. The solar panel will therefore be able to full recharge the battery within a single day in sunny conditions. The units themselves should draw less than half of the battery per day. This will allow the units to run for 2 days without power and the solar panel will be able to restore lost power in about 8 hours of sunlight. All of the sensors utilize negligible current except for the radios which will only operate for small periods twice a day.

> *Rationale: The power from the battery should be sufficient to power each unit for at least two days, the solar panel should be able to replace lost charge quickly, and a need for another source of power would lower the utility of the system.*

3.2.3.3. Input Voltage Level

The input voltage level for each component will be either +12V or +5V.

> *Rationale: The battery will be a +12V battery, but the microcontroller will need +5V, and considerations for design simplicity make it impractical to allow for any other input.*

3.2.3.4. Sensor Station Output

The only means by which data is required to be output from the climate and depth sensor stations is by wireless transmission to the central network node, but the sensor stations may allow for a computer connection to the microcontroller in the sensor stations.

> *Rationale: The system is intended for automated collection of climate data via continuous transmission of the data wirelessly to the central network node. It is impractical to perform manual collection of the system, but the option to connect a computer to the station to view the data would be helpful for troubleshooting purposes.*

3.2.3.5. System Data Output

All data of interest to the user from the system will be output to the user through the GUI. The data will be stored in a database online if more direct access is necessary.

> *Rationale: The presentation of the data will be most useful and easily digestible via a graphical user interface.*

3.2.4. Environmental Requirements

3.2.4.1. Pressure (Altitude)

The Climate Tracking Network shall be designed to withstand and operate in air pressures of altitudes from sea level (0ft) to 4000ft. The only sensor required to sustain additional pressure is the depth sensors in the stock pond. If placed at the bottom of the stock pond it will experience additional pressure.

> *Rationale: This range includes the altitude at which the customer is interested in implementing the Climate Tracking Network, and is typical of many agricultural environments.*

3.2.4.2. Thermal

The Climate Tracking Network shall be designed to withstand and operate in temperatures of -20°F to 140°F.

> *Rationale: This range includes the temperature of the region in which the customer is interested in implementing the Climate Tracking Network, and is typical of many agricultural environments.*

3.2.4.3. External Contamination

The Climate Tracking Network shall be designed to withstand and operate in ordinary natural contamination such as dust, pollen, and occasional insects, but is not intended to guarantee survival from insects or animals who frequently tamper with it or use it in part or whole for the place where they live, or from natural events which may cause excessive contamination in a short period of time such as dust storms, tornadoes, etc.

> *Rationale: Since the system is designed for agricultural purposes, it must be able to withstand ordinary natural contamination, but it is outside of the scope of the project to make it impervious to all possible forces of nature.*

3.2.4.4. Rain

The Climate Tracking Network shall be designed to withstand and operate in rain which does not exceed more than 2” per hour and which is not accompanied by flooding or weakening of the soil in which the sensor stations and central network node are located.

> *Rationale: This is a limit to the level of rain in the region in which the customer is interested in implementing the Climate Tracking Network, and is typical of many agricultural environments.*

3.2.4.5. Humidity

The Climate Tracking Network shall be designed to withstand and operate in a relative humidity range of 5% to 95%.

> *Rationale: This range includes the average humidity of the region in which the customer is interested in implementing the Climate Tracking Network, and is typical of many agricultural environments. Designing the system beyond these ranges would complicate the design and provide little additional utility for the system.*

3.2.4.6. Absence of Solar Exposure

The climate and depth sensor substations shall not be designed to withstand or operate in a period of time without sun exposure that exceeds 2 full days. This includes both natural events and physical obstacles blocking the sun exposure of the solar panels.

> *Rationale: Any further operation would require powering the sensor stations from a source besides solar power.*

3.2.4.7. Natural Disasters

The Climate Tracking Network shall not be designed to withstand or operate in any natural disasters, such as tornadoes, dust storms, hurricanes, earthquakes, floods, lightning storms, acid rain, hail, blizzards, etc.

> *Rationale: It is outside the scope of this project to create a system which is impervious to all forces of nature.*

3.2.5. Failure Propagation

3.2.5.1. Wireless Transmission Errors

The Climate Tracking Network will utilize failure checking algorithms to identify incorrect bits and request retransmission of data if information is detected in error. Every transmission received by the central network node will meet reliability specifications as outlined in IEEE 802.11.

> *Rationale: This will help preserve the integrity of the data being collected.*

3.2.5.2. Diagnostic Errors

The Climate Tracking Network will monitor the voltage levels for the power subsystem, whether sensors are reporting or not, and other relevant parameters of the units, and send alerts to the user if any errors are identified.

> *Rationale: This will allow the user to make any necessary changes to keep the system running if there is a problem.*

4. Support Requirements

4.1.1. Computer Terminal with Internet Access

In order to view the data and use the system as designed, the user must use a computer terminal with access to the internet and a web browser to view the application.

> *Rationale: Other forms of accessing the information from the system are outside the scope of this project.*

4.1.2. 3G Reception

The user must have reliable 3G cell service reception in the area where the central network node will be located.

> *Rationale: This will be the means by which the system uploads information to the database for the user to use.*

4.1.3. Maintenance

The user must maintain the stations by visiting them at least once every six months to ensure no equipment has been damaged or tampered with.

> *Rationale: The system is designed with the premise that the user will be able to access the stations and will be able to address any physical issues at the site that arise.*

Appendix A Acronyms and Abbreviations

GUI	Graphical User Interface
MHz	Megahertz (1,000,000 Hz)
V	Volt

Appendix B Definition of Terms

Central Network Node	Network element to which climate sensor stations report information and from which information is uploaded to the online database.
Climate Tracking System	Complete system being designed, including climate and depth sensor stations, central network node, online database, and GUI
Climate Sensor Station	Unit designed to collect climate data from sensors and report it to the central network node
Depth Sensor Station	A Climate Tracking Station with an additional sensor to acquire the depth of a nearby stock pond
Graphical User Interface	Software program designed to display data stored in the online database for the user
Online Database	Software storage system for climate data

Appendix C Interface Control Documents

Interface Control Document is attached as a separate document.

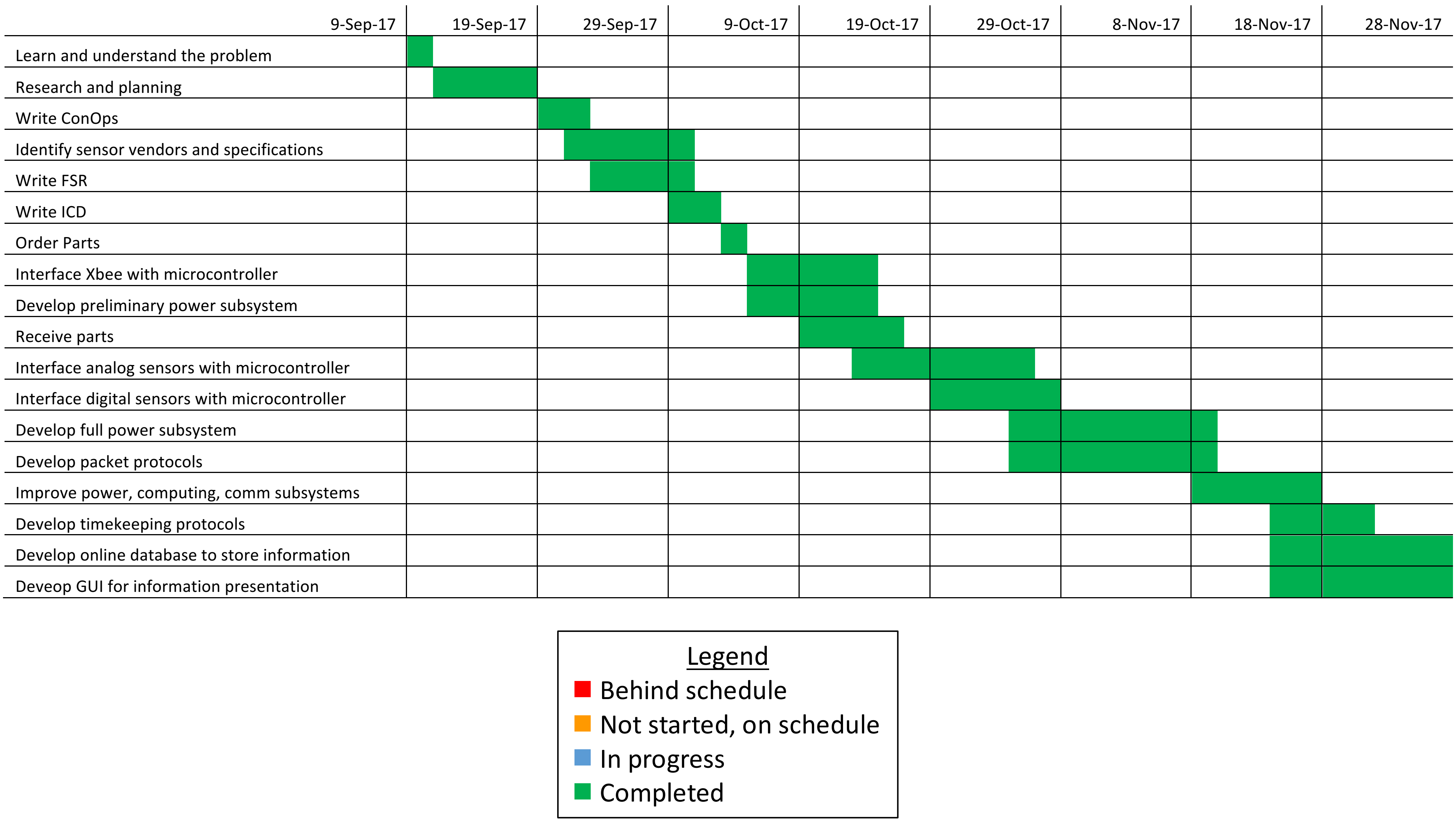
STAR Programs Climate Tracking Network

David Fawcett and Trevin Cooper

SCHEDULE

REVISION – 1
6 December 2017

Execution Plan for STAR Programs Climate Tracking Network



STAR Programs Climate Tracking Network

David Fawcett and Trevin Cooper

VALIDATION

REVISION – 1
6 December 2017

Validation Plan for STAR Programs Climate Tracking Network

Status Indicators	
Completed	■
On Schedule/In Progress	■
Behind Schedule	■

Task	Deadline	Current Status	
Sensor subsystem		Completed	■
Register contact shorting to ground on anemometer	10/20/17	Completed	■
Calibrate anemometer reading to wind tunnel reading	11/30/17	Completed	■
Receive biased voltage input from air temperature probe	10/25/17	Completed	■
Calibrate air temperature probe to independent thermometers	11/30/17	Completed	■
Register rain gauge contact shorting to ground	10/30/17	Completed	■
Calibrate amount of rainfall to the number of closures observed	11/30/17	Completed	■
Receive analog voltage input to the pyranometer	11/05/17	Completed	■
Monitor operation of pyranometer with full day test	11/30/17	Completed	■
Send measurement commands to soil sensor and register response	11/10/17	Completed	■
Compare soil temperature readings with independent thermometer	11/30/17	Completed	■

Compare soil moisture readings with known increases in VWC	11/30/17	Completed	
Register depth sensor voltage from current-biased resistor	11/20/17	Completed	
Calibrate voltage readings with known water depths	11/30/17	Completed	
Power Subsystem		Completed	
Generate power from sun	11/03/17	Completed	
Store power in battery	11/06/17	Completed	
Characterize buck converter voltage levels	11/07/17	Completed	
Communication Subsystem		Completed	
Test XBee transparent mode operation over UART	10/20/17	Completed	
Model antenna design for directivity	11/20/17	Completed	
Confirm VSWR of antenna is in operating range	11/25/17	Completed	
Upload MySQL queries to online database	11/27/17	Completed	
Test antenna transmission rate and range	12/2/17	Completed	
Send packetized information between XBees with data and timestamps	12/2/17	Completed	
Computing Subsystem		Completed	
Run individual sensor collection programs	11/22/17	Completed	
Compile MySQL libraries for communication with server	11/27/17	Completed	

Designate pins for use with specific components	11/30/17	Completed	■
Run full sensor collection algorithm	12/3/17	Completed	■
Information Storage and Presentation Subsystem		Completed	■
Store dummy information in database	11/25/17	Completed	■
Query database to view information	11/25/17	Completed	■
Display information on website	11/25/17	Completed	■
Test to see if new additions to database are pulled	11/25/17	Completed	■

Performance on Execution Plan

The execution plan was executed completely. Although some tasks were actually performed somewhat out of order to accommodate the schedules of both teammates and the people operating the equipment used for the validation of the sensors, each task that was set forth in the execution plan was completed on time. The project was completed in full, with all of the objectives that were outlined at the beginning of the project demonstrated as required by the initial proposed solution.

Performance on Validation Plan

The validation plan was completed thoroughly, with each aspect of the individual subsystems being rigorously checked. Data was collected on each of the different subsystems and their performance, in order to ensure that they will properly fulfill their individual function when integrated with the full system next semester. Although some difficulties were encountered, most notably with the MySQL interface from the XBee 3G modem, the different parts of the systems were tested to be reliable in the end, and the data acquired confirms this.

STAR Programs Climate Tracking Network

David Fawcett and Trevin Cooper

SUBSYSTEM REPORTS

REVISION – Original
4 December 2017

STAR Programs Climate Tracking Network

David Fawcett and Trevin Cooper

SUBSYSTEM REPORTS

REVISION – Original
4 December 2017

SUBSYSTEMS REPORT
FOR
Climate Tracking Network

TEAM STAR PROGRAMS

APPROVED BY:

David Fawcett 11/30/17
Project Leader Date

Prof. S. Kalafatis Date

T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
1	11/30/2017	Trevin Cooper	David Fawcett	Original Release

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1. Introduction

The climate tracking network will autonomously aggregate climate data that pertains to agriculture. The system gathers data at each sensor substation and pushes all of the data to a single point in the network, where it is uploaded to an online database and accessible through a web interface. The system is broken down into the sensor, power, computing, communication, and information storage and presentation subsystems, each of which was designed and rigorously tested. Since each subsystem was validated to be working correctly and fulfilling all requirements, there is a clear path to integration for these subsystems into the full system specified in the Conops, FSR, and ICD.

2. Power Subsystem Report

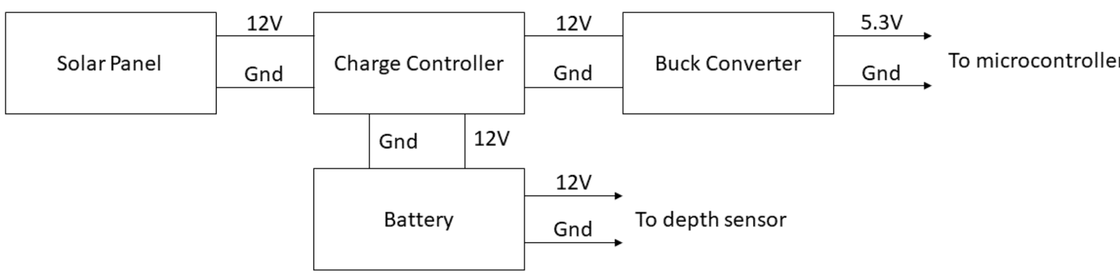
2.1. Subsystem Introduction

The power subsystem is designed to supply regular power to all the components of the system that will be placed in the field. The subsystem is powered exclusively by solar power, which is stored in a battery for operation during the night or when there is little solar energy available. The power subsystem was tested to confirm its stability, capacity, and consistency. Each test helped verify that the power subsystem will support the components of the system that will be powered by it.

2.2. Subsystem Details

A block diagram of the subsystem is shown below.

Figure 1: Functional block diagram of the power subsystem.



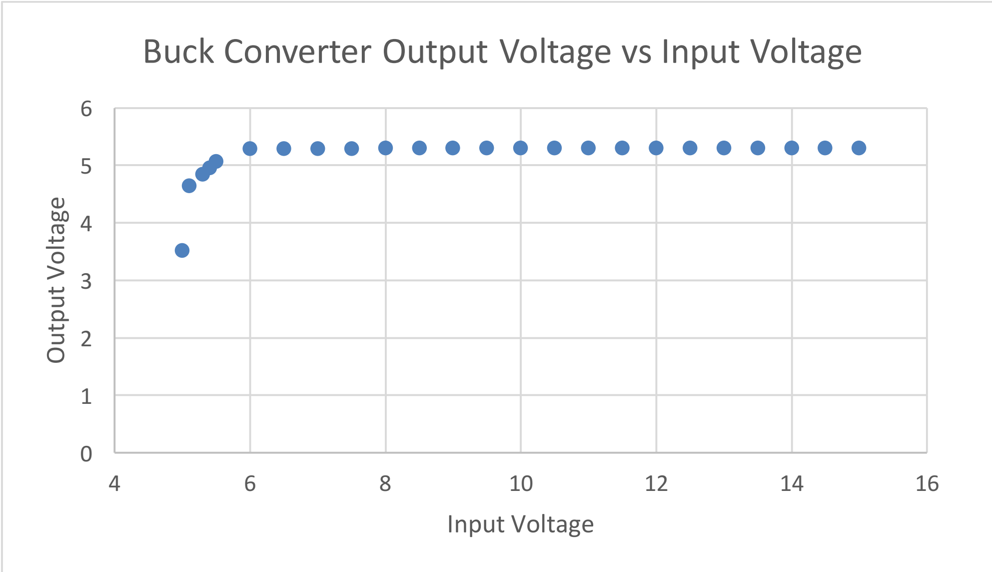
The primary challenge with the power subsystem was ensuring that it would be able to generate and store enough energy to supply power to the devices for the times when the solar panel is not generating power, and that the solar panel generates enough power to recharge the battery fully when 8 hours of sunlight are observed.

This check was done before purchasing the solar panel since a solar panel that could not generate enough power would not be useful for the project. Since most of the design to this subsystem was done at the manufacturer's level, it did not require significant design or alteration.

2.3. Subsystem Validation

The buck converter was first tested for stability. This was done by supplying a variety of input voltages and measuring the output with a voltmeter. A buck converter that works correctly should supply a constant voltage for a wide range of inputs, in order to sure that the device at the output—in this case, the Teensy 3.2 Microcontroller—can operate with the expectation of a reliable power voltage, regardless of any small changes in the DC voltage input into it.

Figure 2: Buck converter output response based on input supply voltage



The ability to power the microcontroller from the battery, by using the charge controller and buck converter, was confirmed. This confirmed the ability of the power subsystem to supply power to the microcontroller (and therefore the sensor subsystem) during times when there is little to no solar power available. In conjunction with the characterization of the buck converter above, these tests confirm that as long as the battery voltage remains close to its nominal voltage, the system should be able to maintain the power it needs for operation when it is all connected together, thereby validating its performance.

The table below shows the current draw of each of the different components of the sensor stations. Most of these components will be operating at 3.3V since that is the Teensy's operational voltage.

Table 1: Current Draw of Sensor Substation Components

Component	Current Draw
Teensy 3.2 Microcontroller	10mA (usually less)
XBee 900 MHz Radio	30mA (idle),80mA(Tx), <1mA (sleep)
Water Depth Sensor	8mA (average)
Air Temperature Probe	0.165mA (average)
Soil Sensor	0.3mA (average)
Anemometer	<1mA
Rain Gauge	<1mA
Pyranometer	0mA (self powered)

Since the battery used is a 7Ah battery at 12V, there is 84Wh of energy, which enough to power each of the devices for over 4 days on a fully charged battery, though it is only specified to last 2 days before needing to recharge. This extra buffer was needed to ensure the specification would be met.

2.4. Subsystem Conclusion

Each part of the subsystem was shown to work correctly. The power subsystem effectively generates and stores the needed power for each of the components of the sensor stations. When interfaced with the other subsystems, it will enable the system to continuously and autonomously aggregate data and transmit it to the database through the network.

3. Sensor Subsystem Report

3.1. Subsystem Introduction

Since the purpose of the climate tracking network is to aggregate data on the environment, it is critical to confirm that the sensor subsystem is operating correctly. For this reason, after interfacing each of the sensors to the microcontroller to read their values, each sensor was tested to validate that it performed as the manufacturer described.

3.2. Water Depth Sensor

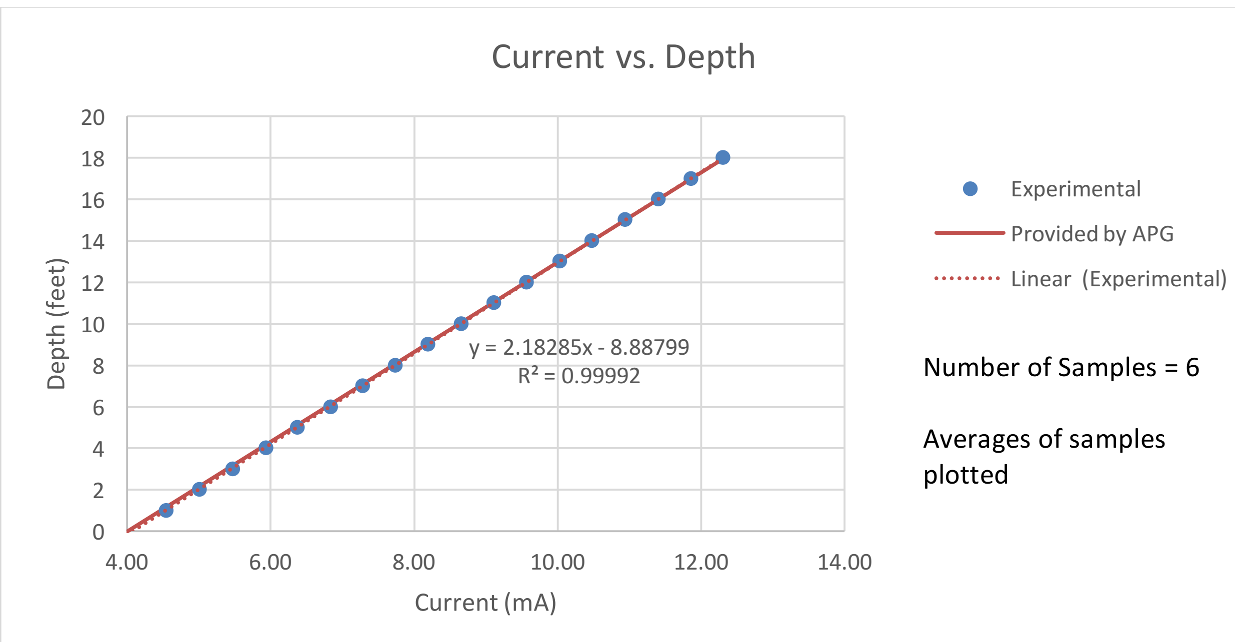
3.2.1. Operation

For the water depth sensor, an APG PT-510-C15 sensor was used. This sensor consists of a pressure transducer which varies the mount of current flowing through the device based on the pressure of the water around it. Since depth is directly related to pressure, measuring the current flowing through the device

3.2.2. Validation

It was validated by lowering the depth sensor to a known depth in a deep pool and recording the current output from the sensor. It was validated to a depth of 18 feet, since that was the maximum available

Figure 3: Validation of the Water Depth Sensor



The recorded performance, which is shown above, is almost exactly linear, an d nearly identical to the relationship that was provided by APG.

3.3. Anemometer

3.3.1. Operation

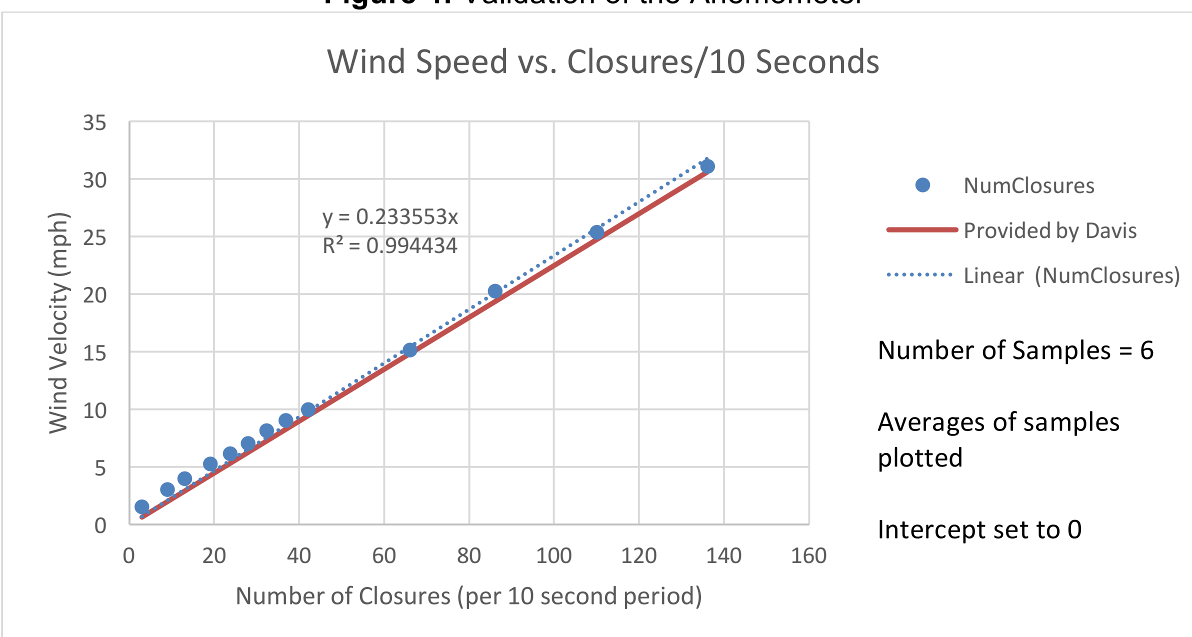
A Davis Anemometer was used for the wind speed sensor. By correspondence with experts in crop growth, wind speed was determined to be one of the most important climate parameters for success in agriculture since the transpiration of the crops will be directly affected by the speed of wind in the area.

The anemometer works by shorting the two inputs together once on each revolution of the sensor. The wind speed can be found by sampling the number of closures in a given time period and using an equation to convert into wind speed in miles per hour. For the purposes of sensor validation, we used a time interval of 10 seconds, though this could be increased to better capture the average wind speed in an environment where it is not held constant.

3.3.2. Validation

The accuracy of this sensor was validated by using a wind tunnel in the aerospace department of Texas A&M. By setting the tunnel airflow speed to a known velocity and measuring the number of closures in a 10 second period, a regression could be drawn.

Figure 4: Validation of the Anemometer



The data agreed well with the equation provided by Davis, with only small discrepancies that could be attributed to the instability of the instruments used to fix the anemometer in the wind tunnel. The intercept was set to 0 because any regression which describes the wind speed as a function of the number of closures observed must have a wind speed of 0 when no closures have been observed.

3.4. Rain Gauge

3.4.1. Operation

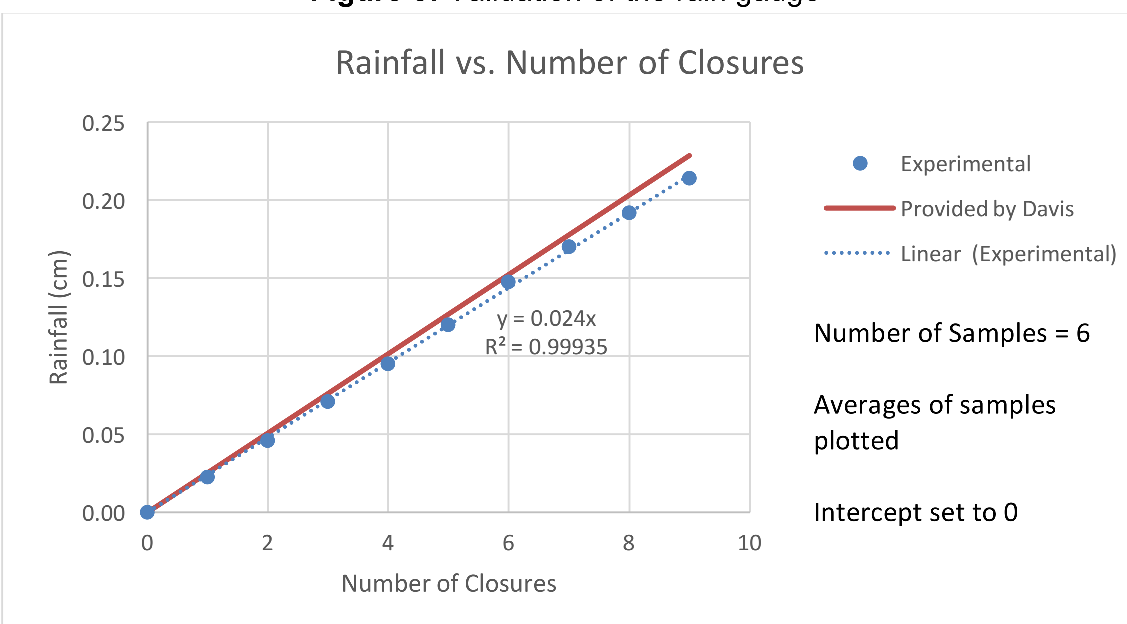
To measure rainfall, the Davis aerocone rain collector was used. This sensor funnels water over a given area into a bucket, which will tip when enough water has flowed into it, and short a contact to ground. By measuring the number of contacts that have been shorted to ground, equations can be used to convert this into total rainfall in the area.

Since it is unknown when the rain gauge will short the contact to ground, an interrupt function must be used to increment the total number of closures whenever the rain gauge tips. The running total amount of rain will also have to be reset periodically

3.4.2. Validation

The rain gauge was validated by using a buret in a laboratory to pour a known amount of water into the rain gauge, taking note of all the points at which the contact was closed to ground. These data points were compared with the values provided by Davis, and the trends aligned well, as shown below. However, it should be noted that the results indicate that the rainfall for a given number of closures is slightly lower than the manufacturer specified. This could be due to a subtle difference in the shape or volume of the particular cup that was installed into the rain gauge used.

Figure 5: Validation of the rain gauge



The trendline for rainfall regression was set to intercept the y-axis at 0 since any regression to describe the amount of rain fallen must indicate no rain has fallen when there have been no detected closures of the contact in the sensor.

3.5. Air Thermometer

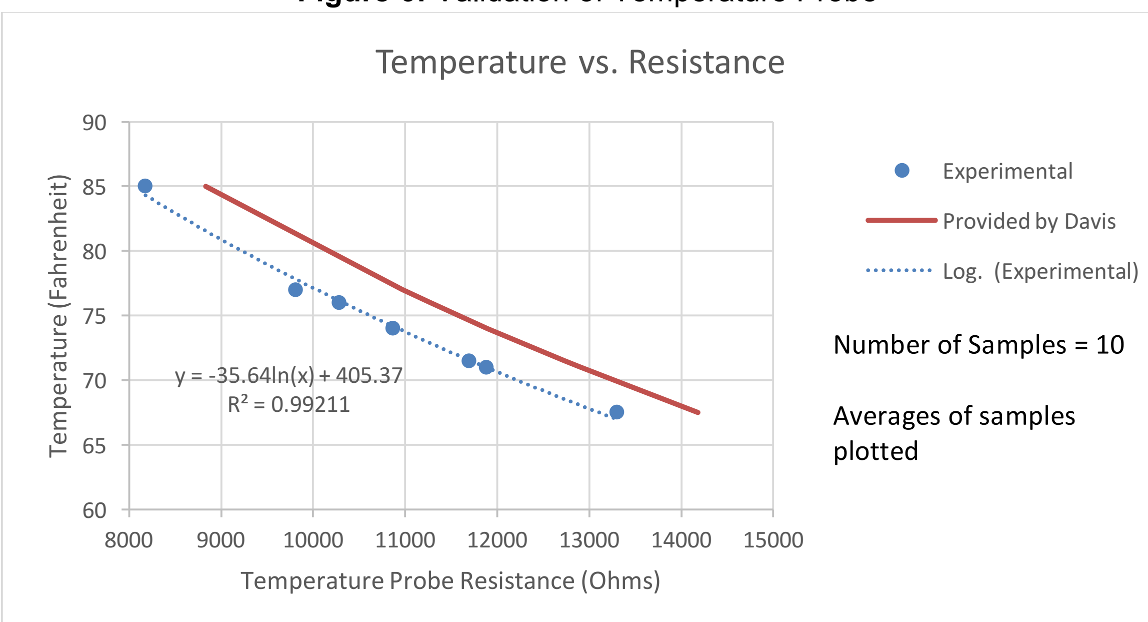
3.5.1. Operation

To measure air temperature, a thermistor probe was used. By setting up a voltage division circuit, a known, constant resistance can be used to measure the voltage bias between the resistors, which can then be used to calculate the resistance in the thermistor. Another equation can convert the resistance in the thermistor to the ambient air temperature. Since the voltage read at the pin will depend partly on the value of the resistance used to bias the probe, it is better to convert from voltage to resistance, and then to temperature so that a single value (the exact value of the resistor used to bias the pin), can be entered for each unit created in order to improve the accuracy of the measurements at each station.

3.5.2. Validation

The air temperature must be recorded in an environment free from incident solar radiation, which would affect the measurement. For that reason, the measurements used to validate the performance of the sensor were taken in the shade, which will be provided by a heat shield when the sensors are deployed in the field. For a known temperature (measured with independent thermometers), the measured resistance was compared with the value provided by Davis, and the plots generally agreed well.

Figure 6: Validation of Temperature Probe



A logarithmic regression was used for the temperature probe since that was the relationship provided by Davis in the datasheets for the thermistor. Even though the exact values are slightly off, the type of regression agrees with the data observed, and when the experimental regression was used, it provided a high degree of corroboration with independent thermometers, which validated the operation of the sensor.

3.6. Soil Sensor

3.6.1. Soil Temperature

3.6.1.1. Operation

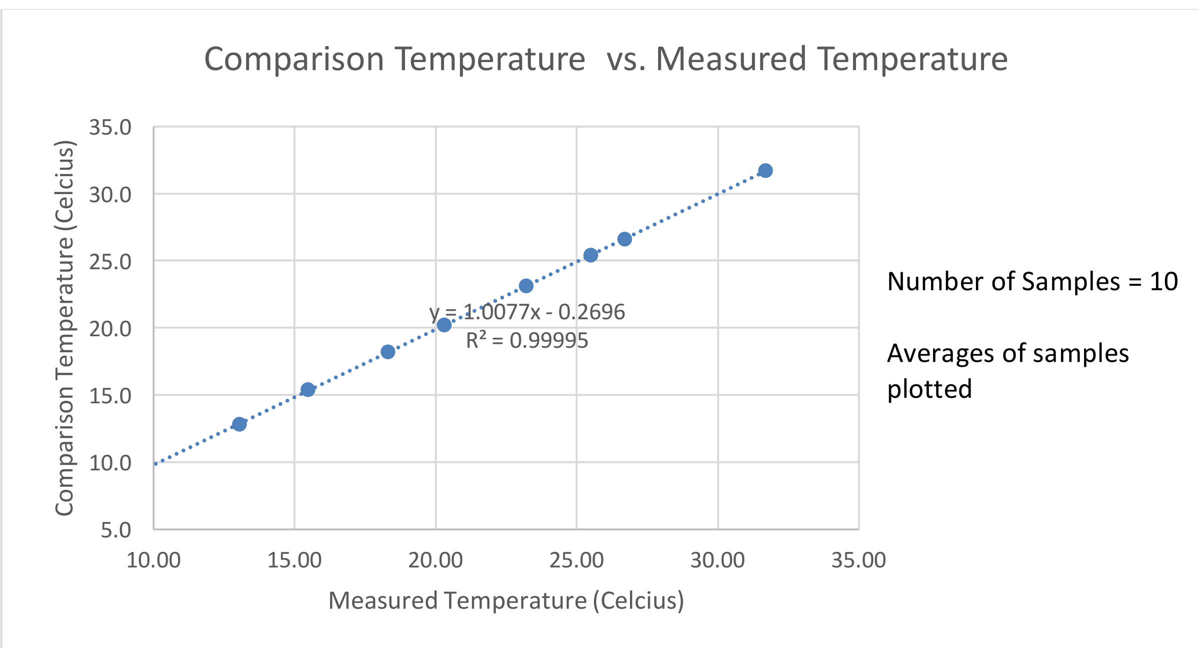
For soil temperature measurements, the Decagon 5TM sensor was used. This was the only digital sensor used, and it has a distinct advantage of also being a soil moisture sensor. Both of these parameters are useful for agricultural purposes, and it was both more cost effective and conservative with respect to the ports used on the teensy microcontroller.

This sensor uses an SDI-12 interface, which allows the microcontroller to take measurements and obtain data from it by sending commands in the SDI-12 language. Although SDI-12 was designed to allow several devices to operate on a single bus, and there will only be one of each of these devices associated with each of the sensor stations, using this sensor will increase the flexibility of the design by allowing anyone modifying the final system to use SDI-12 sensors with relative ease.

3.6.1.2. Validation

The soil temperature accuracy was validated by changing the temperature of the medium it was in and comparing it to the value read from an independent thermometer. The two values agreed very well over all as shown below.

Figure 7: Validation of Soil Temperature Probe



The regression should ideally have a slope of 1 with an intercept of 0 if both sensors are correctly reading the exact value of the sample. Since the slope of the regression is almost exactly 1 and the R^2 coefficient is very close to 1, the sensor was successfully validated as reporting the correct temperature of the soil.

3.6.2. Soil Moisture

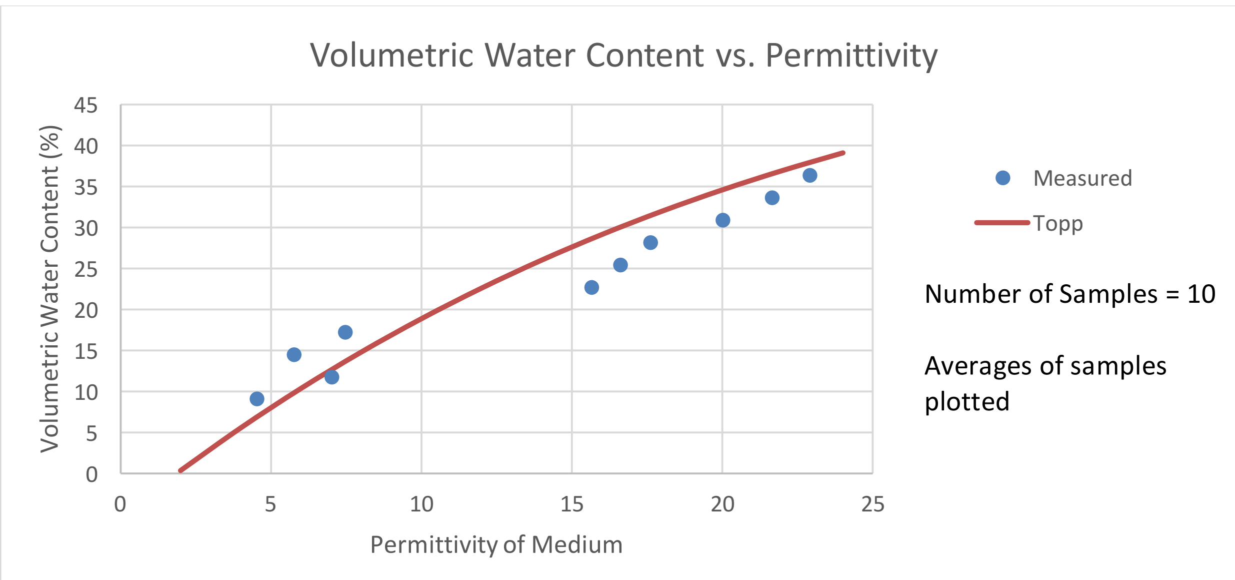
3.6.2.1. Operation

Soil moisture is critical to success in agriculture because water is an essential resource for all crops, and the water content in the soil could severely inhibit or expand upon the possibilities of which crops can be grown and the techniques used to optimize crop yield. The metric of volumetric water content is typically used, which is a ratio of the total volume of water in a given amount of soil volume to the volume sampled. This ratio can be calculated from the permittivity of the medium, which bears a strong correlation to the amount of water in a sample of soil.

3.6.2.2. Validation

Of all the parameters measured, soil moisture was the most challenging to validate. The process used was to measure a known amount of water and add it to a sample of soil, mixing the sample thoroughly to provide the most accurate measurement. The results from the test are shown below.

Figure 8: Validation of the Soil Moisture Sensor



Although there is not the clear-cut trend that would be desirable, the general trend of what was experimentally observed is explained by the curve of the Topp equation, which is the standard way to convert permittivity into volumetric water content. The error in the data can be attributed to inhomogeneous distribution of water in the sample, since the measurement of permittivity of the sample will be offset by any moisture or lack thereof in the immediate vicinity of the probe.

In spite of the anomalies in the soil mixture, the trend given by the Topp equation agreed well with what was observed experimentally, which validated the performance of the sensor.

3.7. Pyranometer

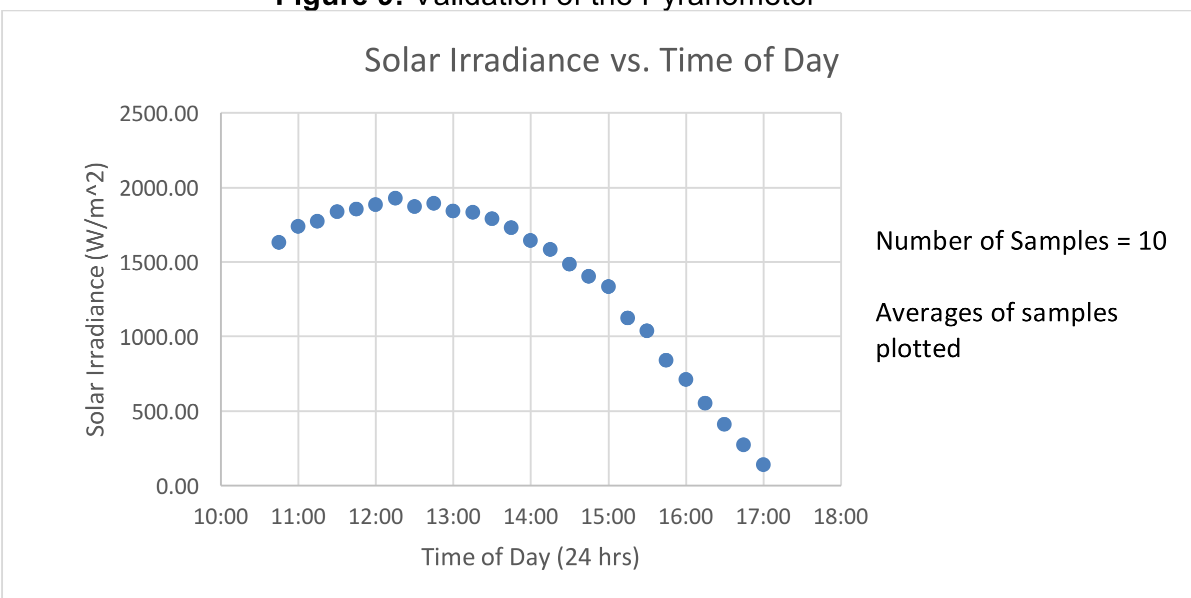
3.7.1. Operation

A pyranometer record the amount of incident solar irradiance on it, which is important for agriculture because each type of crop has a unique response to an increase or decrease of solar irradiance. The pyranometer works by generating a voltage based on the incident solar irradiance, and providing the voltage as a dc output to the microcontroller.

3.7.2. Validation

The test to validate the pyranometer was to run a test throughout the course of a day and to observe the output from the device. This data was then compared to local weather data to confirm it responded correctly.

Figure 9: Validation of the Pyranometer



As shown in the figure, the solar irradiance peaked at about 1950W/m^2, which is a value typical of college station weather in the winter. The trend of the solar radiation throughout the day also has the correct shape since the solar irradiance will diminish throughout the day. The sensor was therefore validated to be operating correctly.

3.8. Subsystem Conclusion

Each of the sensors was shown to operate as designed. Despite some small discrepancies between the manufacturer's specifications with what was observed on some of the sensors, the sensors generally worked as specified and all of them showed the correct trends. These sensors are a critical part of the overall system, and their ability to work with the microcontroller ensures that they will be able to continuously collect data autonomously.

4. Computing Subsystem Report

4.1. Subsystem Introduction

The hardware of the computing system supports interfacing between the sensor subsystem and communication subsystem. While the Climate Tracking Network requires little computational resources, they are nevertheless an essential part of the data aggregation system and run continuously to support the network.

4.2. Subsystem Details

A Teensy 3.2 microcontroller is currently the only portion of the computing subsystem. The Teensy 3.2 has a sufficient number of analog and digital pins and supply voltages to meet the needs of the Climate Tracking Network.

The Teensy 3.2 has 21 Analog Input Pins and 34 Digital I/O pins. This is more than enough pins to accommodate the seven sensors being used. The analog input is able to have thirteen useable bits of resolution, which is suitable for the analog pyranometer, pressure transducer, and air temperature sensor. The teensy can be powered with an input from 3.6 to 6.0 volts which encompasses the voltage the buck converter with supply. The microcontroller is also able to provide a 3.3 V output to power the communication subsystem.

A key feature of the computing subsystem is its ability to monitor sensors and take readings continuously. Each sensor requires a different method to acquire data from it. For example, the air temperature can be measured directly from the analog voltage level at the pin, but the anemometer requires a block of time in which it counts the number of contact closures to ground. The computing subsystem was programmed to handle each of these.

The computing subsystem also has to maintain all of the logic behind the communication with other stations and with the internet at the central network node. Code for all of these operations was written and successfully tested as part of the other subsystems.

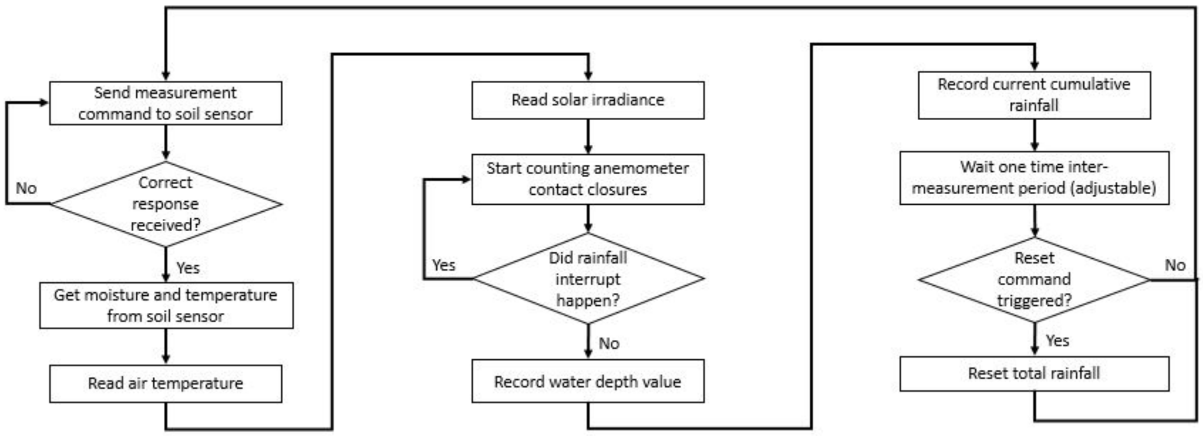
A PCB will later be added to replace the breadboard prototyping and provide more secure connections between all of the subsystems. The PCB will have to coordinate the operations of each of the different subsystems.

4.3. Subsystem Validation

The computing subsystem was validated to meet all the criteria needed. Since its primary function is to support the logical and processing needs of each of the other subsystems, it was validated by the support it provided to the other subsystems, though each of which was done independently. Integration will involve putting different parts of the code written for this subsystem into a single program that will operate the system.

The flowchart in figure 10 shows the logical operation of the sensor program, which was the primary use of the computing subsystem. Each sensor used a different way to gather data, and these methods are shown in the diagram.

Figure 10: Flow Diagram of Sensor Collection Program



Not explicitly shown in the flowchart is the fact that the rainfall is recorded by interrupts, so that it can be incremented at any point in the process. This will ensure that all rainfall will be collected by the sensor, regardless of when the sensor is triggered by a sufficient amount of rainfall.

This algorithm was successfully executed on the teensy with all the correct results validating the subsystem.

In the interest of providing cross functionality between different programs that are written, a pin interface was designed, and added to the ICD, to indicate which pins are reserved for certain functions. Barring any needed modifications, this table will facilitate full integration of the subsystems. It is shown below in table 2.

Table 2: Designated Pins for Computing Subsystem

Teensy 3.2 Pin	Use
0	Ground
1	UART Rx to Xbee
2	UART Tx to Xbee
9	Anemometer pullup
11	Rain collector pullup
16	Water depth, analog input
18	Pyranometer, analog input
20	Air temperature probe, analog input
22	Soil moisture/temperature, digital input
24	+3.3V power
25	Ground
26	+5V power, input from buck converter

4.4. Subsystem Conclusion

The subsystem works correctly as expected and provides all the necessary support to the other subsystems. There are also enough pins with the needed functionality for all of the operations that are required, which ensures that the teensy will support the full needs of the sensor substations and central network node. The computing subsystem will be essential in integrating the different parts of the project together in the future.

5. Communication Subsystem Report

5.1. Subsystem Introduction

The communication subsystem provides the means by which data is moved from the microcontroller to the central base station and from the base station to the internet over a cellular network.

5.2. Local Communication

The movement of data from sensor stations to the central network node is referred to as local communication. The local communication is facilitated by XBee 900MHz Pro communication chips.

5.2.1. Hardware

5.2.1.1. XBee Arduino Interface

The Teensy can interface with the XBee 900Mhz Pro over the UART serial pins. The XBee requires breakout board to be used in breadboard development. Internal buffers in the XBee module store the transmitted bytes as they are queued for transmission. Incoming bytes are buffered by the Teensy's UART serial pins.

5.2.1.2. Current Requirements

The XBee 900MHz communication radios were tested to have a current draw of 29mA when idle. The transmitting current is rated by the manufacturer at over 200mA, but when tested, only 80mA of current were observed to be drawn. This is likely due to the fact that the current draw for transmission comes in very brief spurts that do not register on DC ammeters.

5.2.1.3. Antenna

Two types of antennas were used for the local communication of the XBee radios. An omni-directional monopole antenna was used for the central network node, since this must receive transmission from any direction around it.

A high gain antenna was needed for the sensor substations, so a Yagi was designed and constructed. Although it would be impractical to manually build a Yagi for each individual sensor station when the system is fully implemented, as a proof of concept project it was desirable to show that a Yagi could fulfill the requirements of the communications subsystem.

5.2.2. Software

5.2.2.1. XBee Pro API

Although the XBee can operate in "transparent mode" where all bytes are sent once a given delimiter to specifies the end of the packet, utilizing its API gives an added layer of error checking and functionality.

The XBee's escaped character API offers multiple forms of error checking. First, the packet structure incorporates a packet length which allows the XBee to know when the data portion of the frame should end. At the end of the data stream there a checksum which will detect bit errors in the packet. The XBee will respond that the packet was malformed. Second, the start delimiter of the API is escaped throughout the frame. If the start delimiter appears in the middle of the frame all of the data prior to the start delimiter is silently discarded. The fields of the API are shown in the table below.

Table 3: XBee API Format

Field Name	Byte	Description
Start Delimiter	1	0x7e
Length	2-3	Big Endian
Frame data	4-n	API-Specific Structure
Checksum	n+1	1 Byte

The API-Specific structure used in the frame data field is the same for all transmission messages. The ZigBee protocol for a transmission frame is shown below.

Table 4: XBee API Transmit Frame

Frame Name	Offset	Description
Frame Type	3	0x10
Frame ID	4	Used to correlate subsequent ACK
64-bit destination	5-12	MSB first LSB last
Reserved	13-14	Set to 0xFFFE
Broadcast radius	15	Set maximum number of hops for broadcast
Transmit options	16	See transmit options table
RF data	17-n	Up to NP bytes per packet

Table 5: Transmit Options

Bit	Meaning	Description
0	Disable ACK	Disable acknowledgements on unicasts
1	Disable RD	Disable Route Discovery on DigiMesh unicast
2	NACK	Enable NACK for DigiMesh API
3	Trace route	Enable Trace Route on DigiMesh API
4	Reserved	Set bit to zero
5	Reserved	Set bit to zero
6,7	Delivery Method	b’00 = <invalid option> b’01 - Point-multipoint (0x40) b’10 = Repeater mode (directed broadcast) b’11 = DigiMesh (0xC0)

This protocol allows the network to behave in many different ways. The network topology chosen for the Climate Tracking Network is a point-to-point network topology. This topology could be altered to the DigiMesh should a more distributed network be necessary.

Figure 11: Point to Multipoint Network Topology

5.2.2.2. Local Communication API

The RF data in the transmit protocol mentioned above will utilize the following protocol to send the data it gathers.

Table 6: CTN Join Request Packet Structure

Field Name	Data Type	Description
Data type	1 Byte	See Data Type
Data	1 Bytes	Join Request 0x01

Table 7: CTN Packet Structure

Field Name	Data Type	Description
Data Type	1 Byte	Listed in following table
Packet Num	1 Bytes	Used for Validation
Data	4 Bytes	Data from the sensor or handshake
Datetime	7 Bytes	[1-2] YYYY, [3] MM, [4] DD, [5] HH, [6] MM, [7] SS
Sensor Id	4 Bytes	Unique Id of the sensor

Table 8: CTN Data Types

Data Type	Hex Code
Handshake	0x01
NACK	0x02
ACK	0x03
Soil Moisture	0x10
Soil Temperature	0x11
Air Temperature	0x12
Wind Speed	0x13
Rain Fall	0x14
Solar Irradiance	0x15
Water Depth	0x16

Table 9: Handshake Data Codes

Data Type	Hex Code
Join Accepted	0x01
Associated	0x02
Join Failed	0x03

5.3. Cellular Communication

Once the data is delivered to the central network node, it can be processed and delivered to the MySQL database.

5.3.1. Hardware

5.3.1.1. XBee Arduino Interface

As mentioned previously the XBee-Arduino interface is over UART serial pins. The Xbee Cellular Modem, like the XBee 900Mhz Pro, required a breakout board to be used for breadboard development. The breakout board allowed the Teensy to power the XBee and interface over UART.

5.3.1.2. Antenna

A simple GSM strip antenna was used for the cellular modem's antenna. The antenna is omni-directional, but is sufficient given local cell coverage.

5.3.1.3. SIM Card

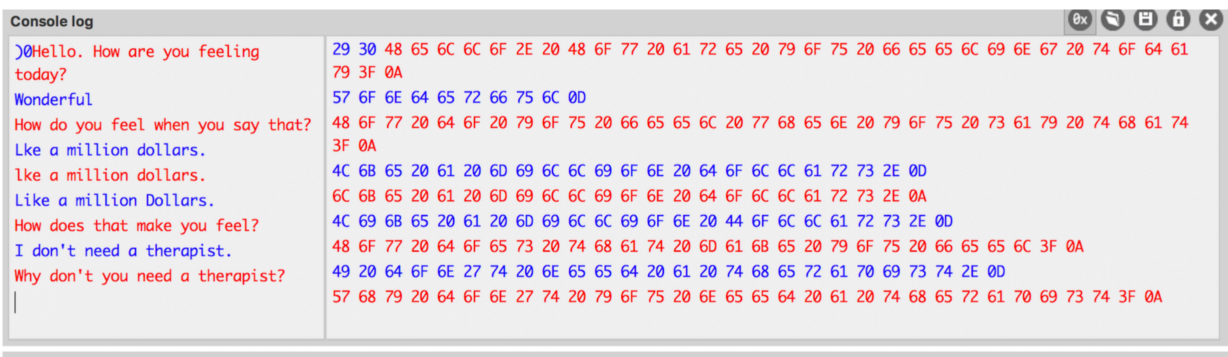
Setting up the XBee Cellular Modem required a SIM Card and the APN (Access Point Name) used by the carrier. A data only SIM card was purchased from AT&T. A dedicated data plan must be purchased as data over the General Packet Radio Service was not reliable despite AT&T marketing very competitive data rates. AT&T uses a variety of Access Point Names for different application types. Since the Climate Tracking Network will only be using the internet, the *broadband* APN was used.

5.3.2. Software

5.3.2.1. XBee Cellular Modem API

The Cellular Modem can operate in transparent or API mode. The modem was first tested in transparent mode and then later in API mode. Digi, the manufacturer of the XBee modem, hosts a chat server that can be used to test their modems. The IP address and port number of the server were used along with the XCTU console, software designed for the XBee, to test the XBee's data connection. Below is the output from the console.

Figure 12: Console Output from Connection with Eliza Server



Like the XBee 900MHz pro, the XBee cellular modem was used in the escaped character API mode. The cellular modem uses an IPV4 frame to communicate over the internet. The fields of the frame are displayed in the table below. The IPV4 frame is placed within the API frame show in table three above.

Table 10: XBee API IPV4 Frame Format

Field Name	Field Value	Data Type	Description
Frame type	0x20	Byte	
Frame ID		Byte	Used to match status response
Destination Address		32-bit big endian	
Destination Port		16-bit big endian	
Source Port		16-bit big endian	All 0000 finds existing socket or opens new opens a new socket
Protocol		Byte	
Transmit Option		Byte (bit field)	Bits 2-8 are reserved 1-Terminates TCP socket 0-Leave socket open
Payload		Variable	Up to 1500 bytes

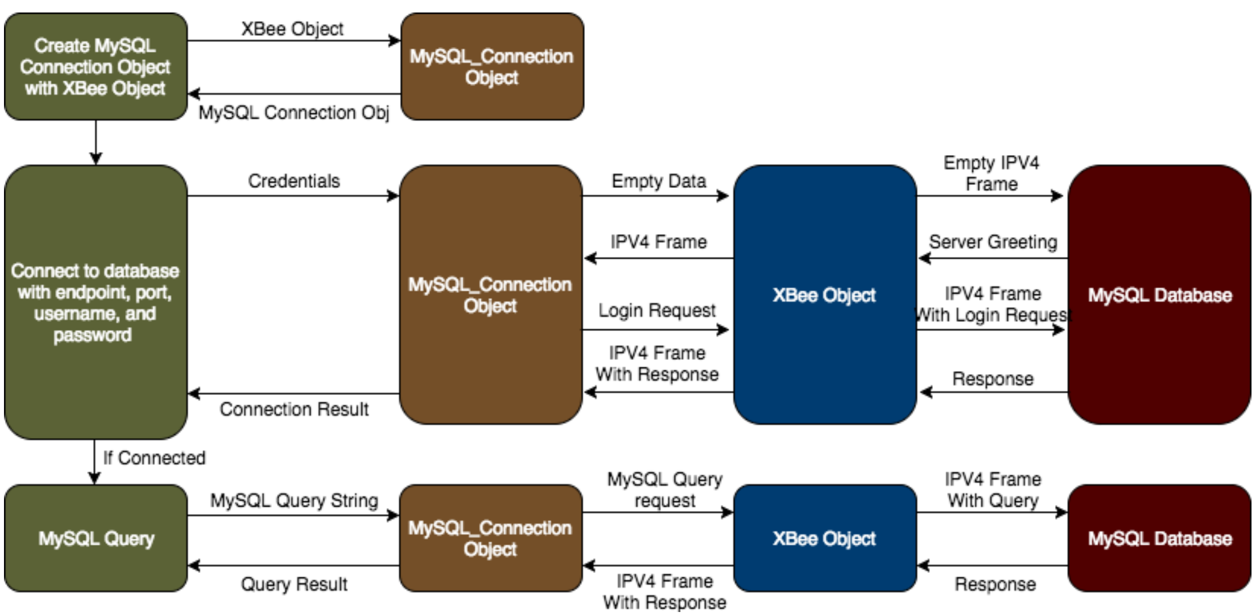
The library for utilizing the XBee API with Arduino did not have software for the IPV4 frame format. Therefore, new classes were written following the libraries conventions to allow the XBee API to be used with the Teensy.

5.3.2.2. MySQL API

MySQL databases have their own API to facilitate connecting and executing queries on a database. Although MySQL is an open source database, a license must be purchased to actually view the source code. There are also a variety of MySQL clients and language specific software which help facilitate connecting to MySQL databases. However, these libraries are precompiled and do not provide specifics on the protocol. Thankfully, a repository on Github by ChuckBell provided implementation details of a MySQL client. Utilizing this repository, a regular client, and Wireshark allowed a client to be built which utilized the XBee's IPV4 functionality.

Although, this report will not go through the details of the MySQL handshake and query protocol, it will explain the class, *MySQL_Connection*, which does utilize these protocols. The functionality of the *MySQL_Connection* class can be described through the creation, connection, and query events of the class. When initialized, the class requires a reference to an XBee object. Once initialized, the class can connect to a database given the endpoint, port, username and password. The class abstracts the XBee API for an IPV4 connection. The class then preforms the appropriate handshake procedure to establish a connection with the database. Once the connection is established, queries can be performed on the database as needed. The diagram below shows the process described above.

Figure 13: MySQL Connection Flowchart

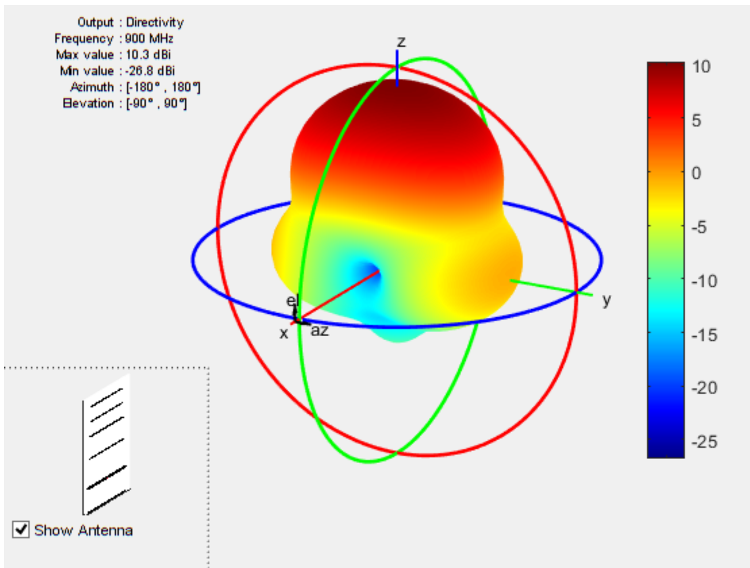


5.4. Subsystem Validation

5.4.1. Antenna

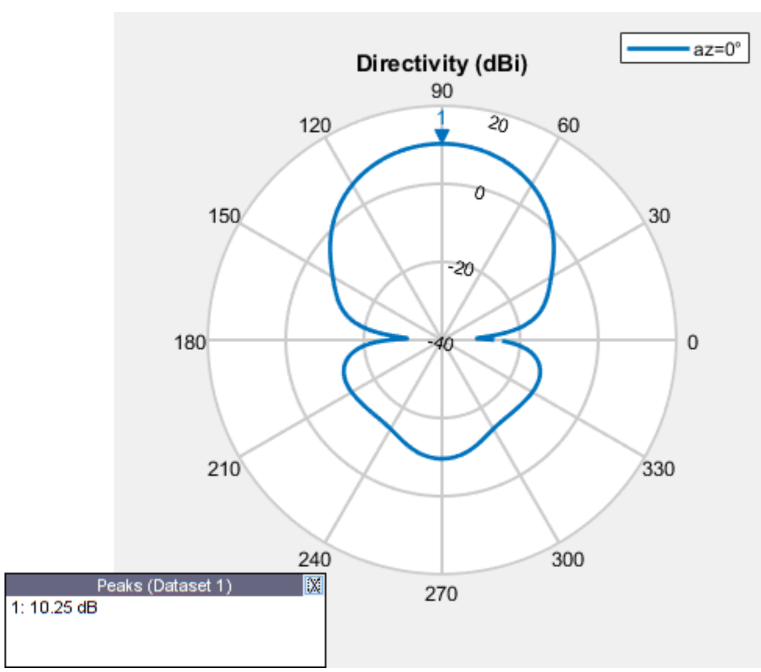
After it was designed, the radiation pattern of the Yagi was modeled in MATLAB. Despite a nontrivial backlobe, the simulation showed a high gain antenna at about 10dB with a moderately wide range of view. This would allow the sensor stations to communicate with the central network node without needing to know precisely where the node is located.

Figure 14: Radiation Model of Yagi Antenna



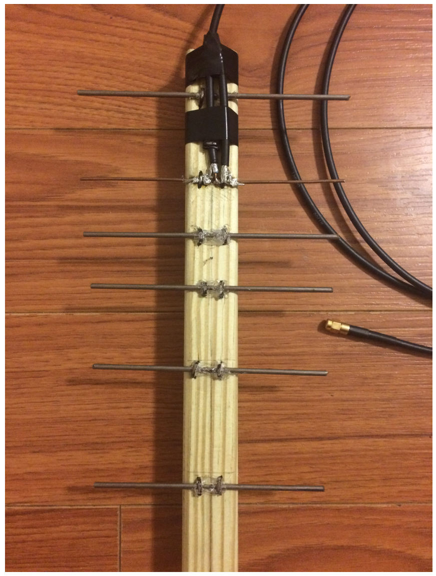
A cross-sectional view of the simulated E-plane is shown below, which further demonstrates the directivity of the antenna that was designed.

Figure 15: Simulated E-Plane of the Antenna



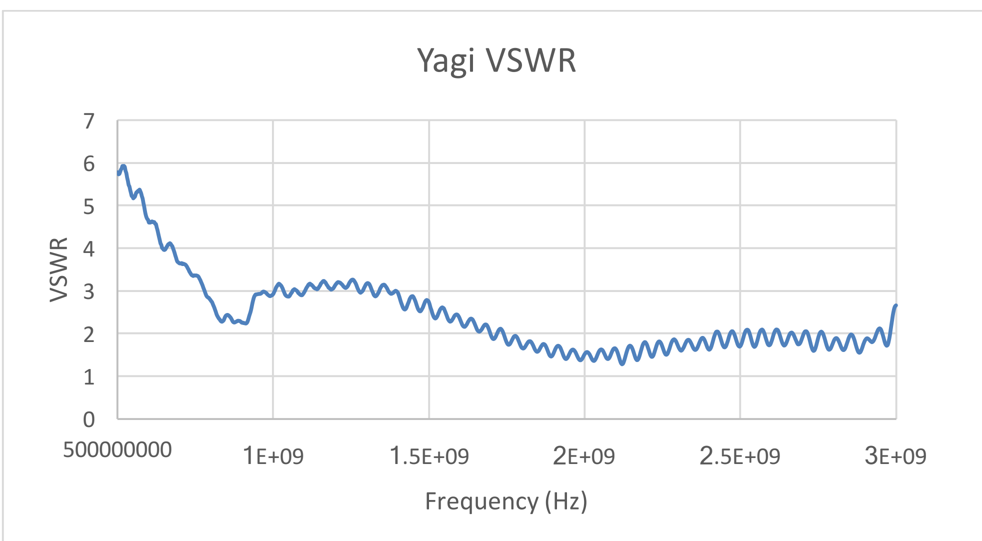
A picture of the antenna is shown in figure 12, where the dipole feed was impedance matched with a quarter wavelength balun to reduce the standing wave ratio and provide more power to the radiation of the antenna.

Figure 16: Constructed Yagi Antenna



The standing wave ratio was measured on a network analyzer from Dr. Huff's laboratory at Texas A&M. The sanding wave ratio at the operation frequency was just above 2, which indicates that about 65% of the power input to the antenna is being radiated. Further modifications to the impedance matching network would improve this ratio.

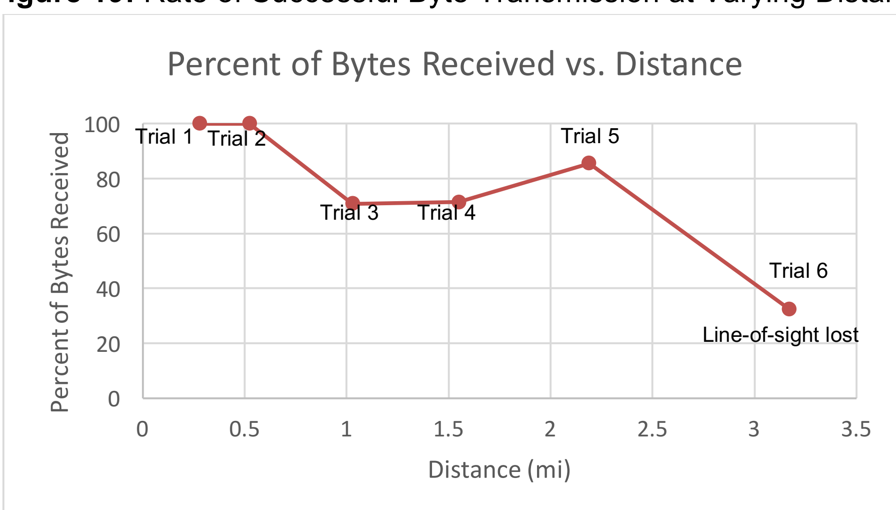
Figure 17: Yagi VSWR



The performance of the antenna was then tested in the field at the locations shown in figure eighteen. The Yagi was located at the base location and transmitted 10 kilobytes to the dipole that would be located at the central network node. The percent of successfully received bytes at each location is shown below it in figure nineteen.

Figure 18: Map of Antenna Testing Locations

Figure 19: Rate of Successful Byte Transmission at Varying Distances



Although there was a significant drop off in the bytes received at the test location for trial 6, this is almost certainly related to the fact that the line-of-sight between the transmitting Yagi and receiving dipole had been lost, which should be expected to contribute to the total loss of bytes received.

While the particular design of the Yagi would need to be modified if a single hub-and-spoke network topology was used, the overall performance of the Yagi validated that it has the potential of enough directionality that, when used with the XBee 900MHz radio modules, it can transmit the required amount of data across the required distances.

5.4.2. Packet Transmission

The validation of the local communication was done by verifying proper transmission between a regular coordinator and end devices. The local communication packets between the XBees in the Climate Tracking Network utilize a packet structure that allows the software to check for proper datatypes, ACK successful transmission, and NACK failures to received properly incremented packets. This helps the control the flow of information and allow the coordinator and end devices to correct errors.

5.4.3. MySQL Query

The validation of the MySQL query was done by verifying the results of successful and failed queries on the database. The MySQL protocol offers error checking on failed queries by responding with okay or error packets. The microcontroller parses these notifications to check whether queries were successful or failed and to take action depending on the result.

5.5. Subsystem Conclusion

The communication subsystem was successfully shown to transmit data between the different stations. Using the antenna, the radius of transmission was shown to exceed three miles, which may be improved with better line-of-sight contact between the transmitter and receiver. Information was packetized to reliably transmit dummy data with timestamps of when it was collected between the transmitter and receiver. It was also able to reliably upload information to the MySQL database, which is the most essential function of the central network node. In the future, the subsystem will be able to support the transfer of real data collected from the sensor subsystem to the central network node and into the database.

6. Information Storage and Presentation Subsystem Report

6.1. Subsystem Introduction

The final subsystem for the Climate Tracking Network manages the storage of data so that it can be easily accessed. A primary means of access provided by the Climate Tracking Network is online through a browser. The details of how this subsystem was implemented are included along with the reasons behind key design decisions.

6.2. Information Storage

Figure 20: AWS Logo

6.2.1. Information Storage Infrastructure

The data gathered by Climate Tracking Network is stored online in a MySQL database. The MySQL database is currently hosted by Amazon Web Services (AWS) which provides support for MySQL in its Relational Database Service (RDS). The service is free for the first twelve months of usage and allows rapid development towards the future state of the Climate Tracking Network.

Figure 21: MySQL Workbench Logo

The database is managed through the MySQL Workbench, a product developed by Oracle. MySQL workbench provides a graphical interface to easily visualize and manipulate database properties. The initial database, tables, and fields were all created using the MySQL Workbench.

6.2.2. Information Storage Design

A single database, *ctndb*, was created for this project. Additional databases can be created if STAR Programs wished to have more than one Climate Tracking Network. The database has eight tables that logically segregate the data. Seven of the tables are for the seven different types of sensor data gathering by each station. Each of these seven tables has four columns. The columns consist of the unique identification key, the data, the date the data was gathered, and the id of the sensor which gathered the data. While there is obvious overhead in storing dates and identification numbers repeatedly, the storage paradigm eases the development system which utilize the database.

Table 11: MySQL Sensor Data Table Fields

Table Name	Column 1	Column 2	Column 3	Column 4
airTemperatures	*idAirTemperatures*	*airTemperature*	*date*	*idSensor*
rainFall	*idRainFall*	*rainFall*	*date*	*idSensor*
waterDepth	*idWaterDepth*	*waterDepth*	*date*	*idSensor*
soilMoisture	*idSoilMoisture*	*soilMoisture*	*date*	*idSensor*
soilTemperatures	*idSoilTemperatures*	*soilTemperature*	*date*	*idSensor*
solarIrradiance	*idSolarIrradiance*	*solarIrradiance*	*date*	*idSensor*
windSpeeds	*idWindSpeeds*	*windSpeed*	*date*	*idSensor*

All of the id's in first column of each table act as the primary key of the table. The data type is a ten-character unsigned integer. Since the integer is thirty-two bits long each, there can be 4,294,967,296 entries into the table. This far exceeds the requirements of the system. No sensor is required to report any more often than every quarter hour allowing the database to last over 100,000 years.

All of the data stored in the second column of each table is stored as a *Decimal(10,5)* in the MySQL database. This data type gives five digits before and after the decimal point. This is sufficient precision for all of the sensors attached to the network

The dates for each entry of the table are stored as the MySQL *datetime* data type. This data type contains the year, month, day, hour, minute, and second. The datatype is structured as a string which matches format of YYYY-MM-DD HH:MM:SS.

Finally, the sensor identification number has the same data type as the primary key. It is a ten-character unsigned integer which is used to correlate the sensor station to the data of that entry.

The final table in the database contains information about the sensor stations themselves. The information in this table can be used to query the other tables based on the sensor identification numbers. The table contains three fields: the sensor identification number, which is also the key for the table, the latitude, and the longitude of the sensor. The coordinate information used to aid in the presentation of the data. Since it was not required in the specifications for the sensors to know their locations, this field can be left NULL when entries are made for the sensor. m

Table 12: MySQL Sensor Information Table Fields

Table Name	Column 1	Column 2	Column 3
sensors	*idSensor*	*Lat*	*Log*

The data types of the sensor information table are quite similar to the ones used in the sensor data tables. The idSensor is again a ten-character integer. The latitude and longitude entries are also decimal data types; however, they are *Decimal(10,6)* to give more precision after the decimal point.

6.3. Presentation

6.3.1. Software Infrastructure Stack

The presentation and use of the data stored in the database helps demonstrate the value of the Climate Tracking Network. The data persists in the database and can be accessed at any point allowing for future users or developers to utilize the data gathered by the Climate Tracking Network is different ways. While the future state of the presentation subsystem is variable and features can be added at any point, a preliminary website was developed to display the data. The website was built using Bootstrap, HTML, Javascript, CSS, and PHP on an Apache server running locally on a computer. An overview of the software used to help develop the website is shown below.

HTML, CSS, and Javascript are the basic foundations of web development. Each language helps play a role in displaying the front-end content to the user. PHP is a server scripting language which must be supported by the webserver. PHP is used to establish connections with databases, issue queries on databases, and insert the results into the document view of the webpage. PHP is the primary tool used in the Climate Tracking Network to deliver data from the AWS MySQL database to the end user.

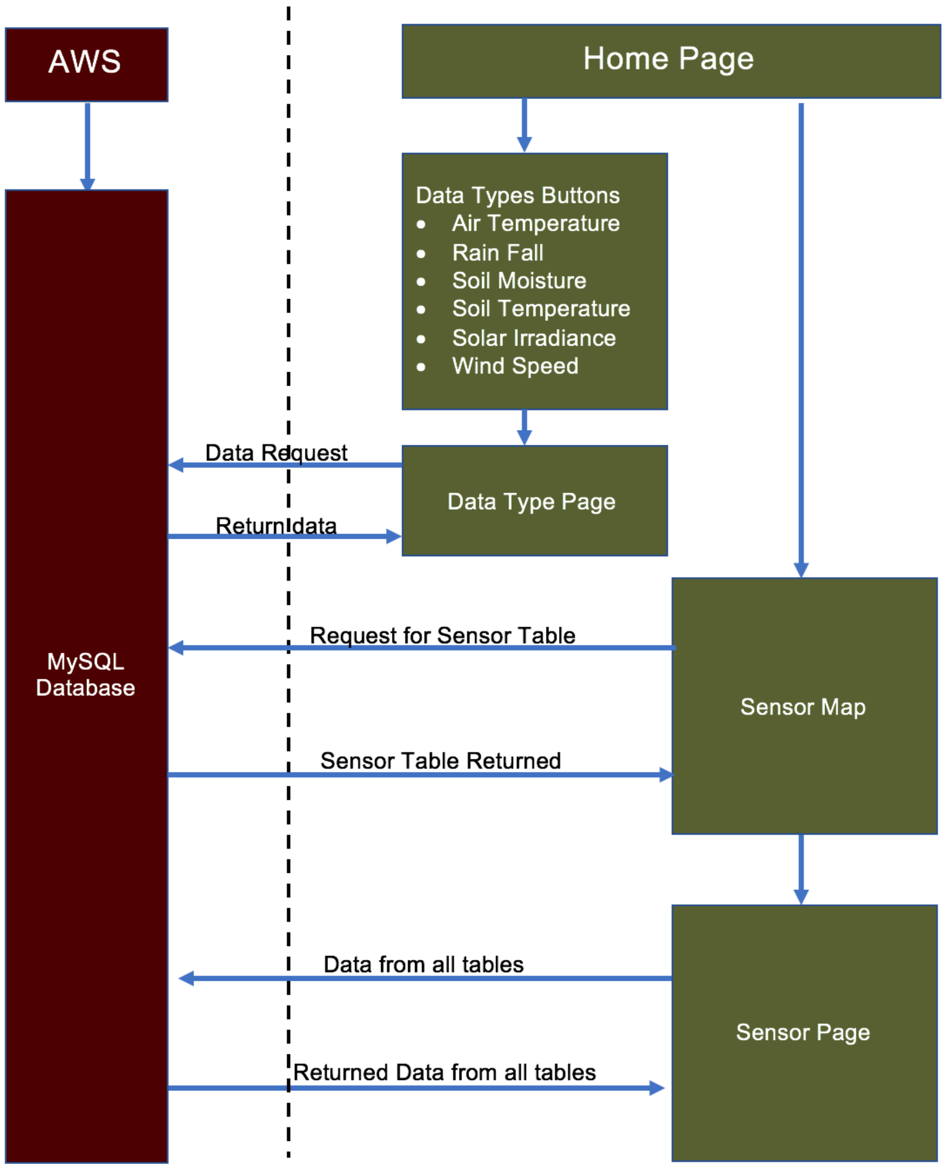
In order to help jump start the development process, the website leverages Bootstrap, a popular library for HTML, Javascript, and CSS. Bootstrap has extensive documentation support by its developers and its community of users. The latest version of Bootstrap, version 4, was used to develop the website.

Figure 22: Bootstrap Logo

Apache was downloaded as the webserver to run local for the development of the website. Apache is also a popular, free software service and allows STAR Programs to avoid the cost of renting a webserver until a more refined future state is needed.

6.3.2. Website Design Interface

Figure 23: CTN Web Architecture



The home page of the website can navigate to show information that each type of sensor gathers across all of the sensors. When one of these buttons is pressed, a new webpage is loaded with the data from the associated table displayed on the screen. The home page can also be navigated to show a map of sensor which places markers on a Google map at the location of the sensor stations. The user can then select a sensor station marker which will display a dialog box over the marker. The dialog contains a link to a new webpage which queries all of the sensor data tables where the sensor matches the sensor selected.

While the current state meets the design requirements of the Climate Tracking network several improvements can be pursued for future states of the project.

- Aesthetically pleasing and easily consumable display of data
- General querying of data for data analytics

6.3.3. Website Design Screenshots

The following are screenshots of the website to help provide a concrete understanding of the current state of the subsystem. They show what was described in the diagram of the previous figure.

Figure 24: CTN Homepage

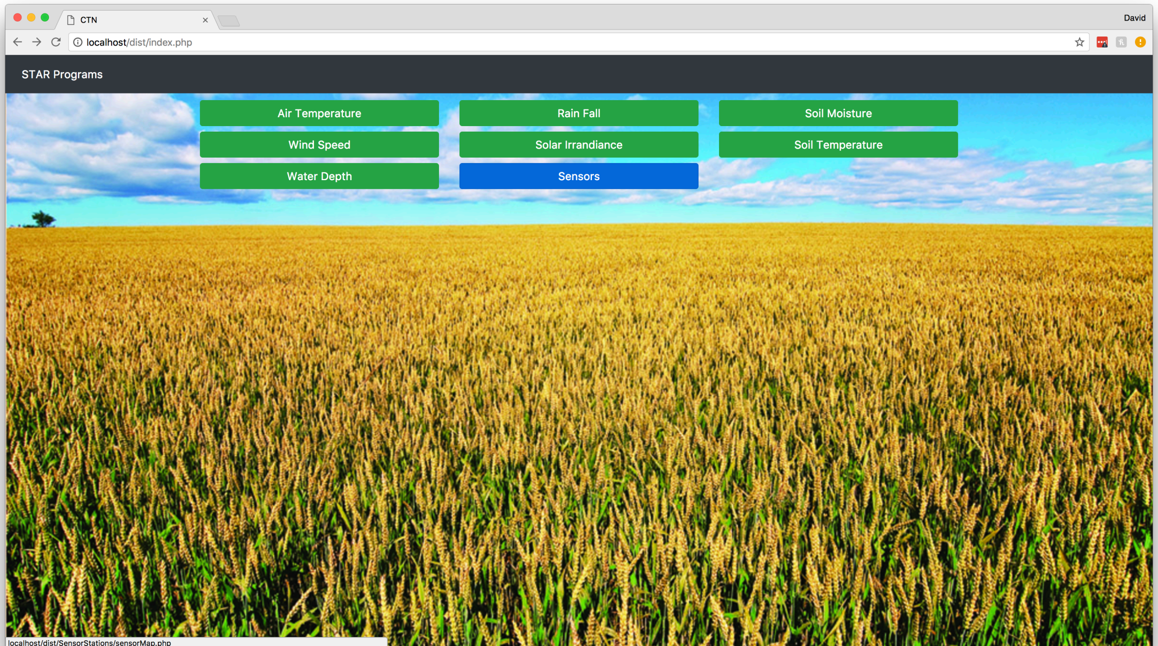


Figure 25: Air Temperatures Data Page

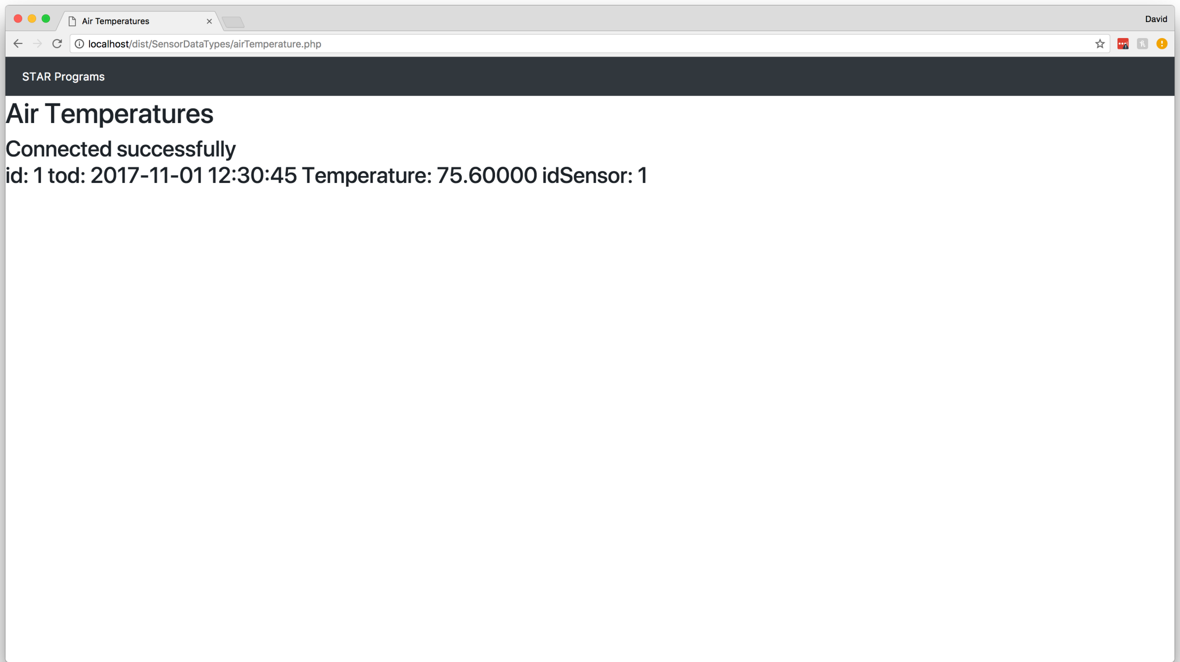


Figure 26: Rain Fall Data Page

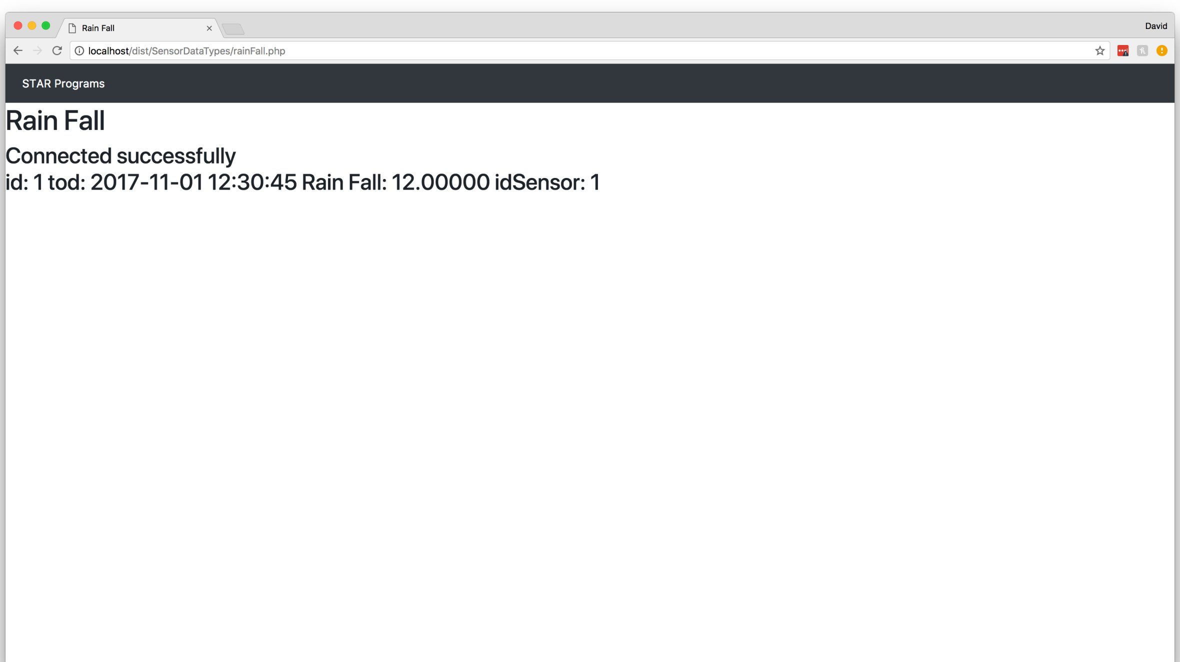


Figure 27: Sensor Map

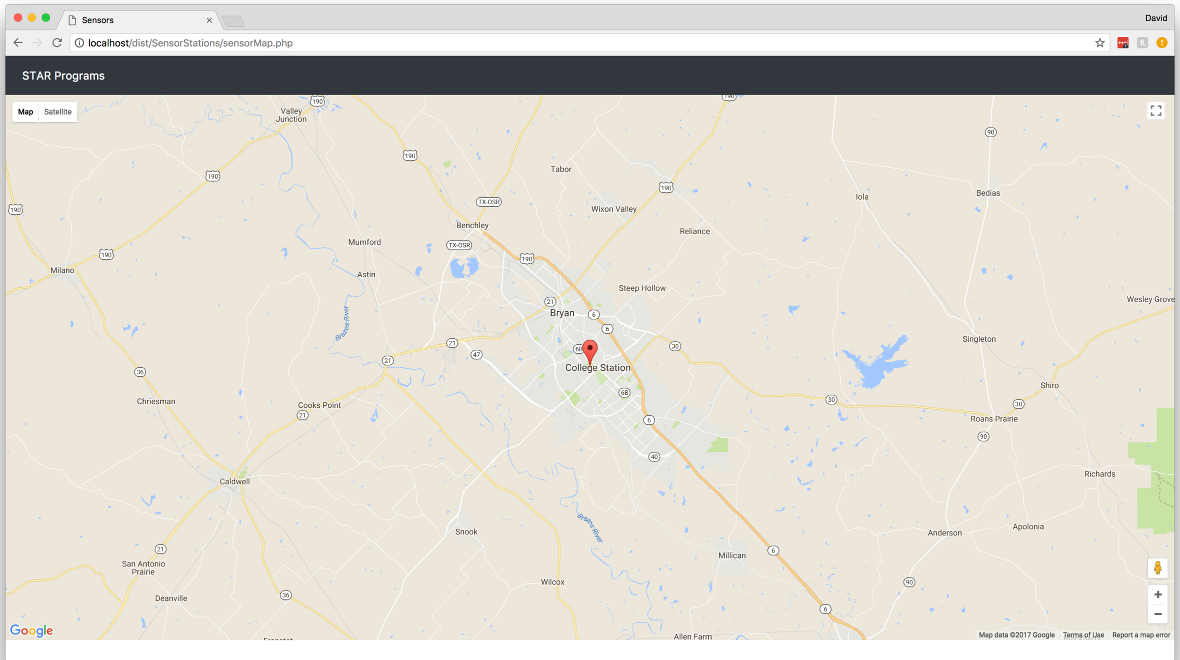


Figure 28: Sensor Dialog Box

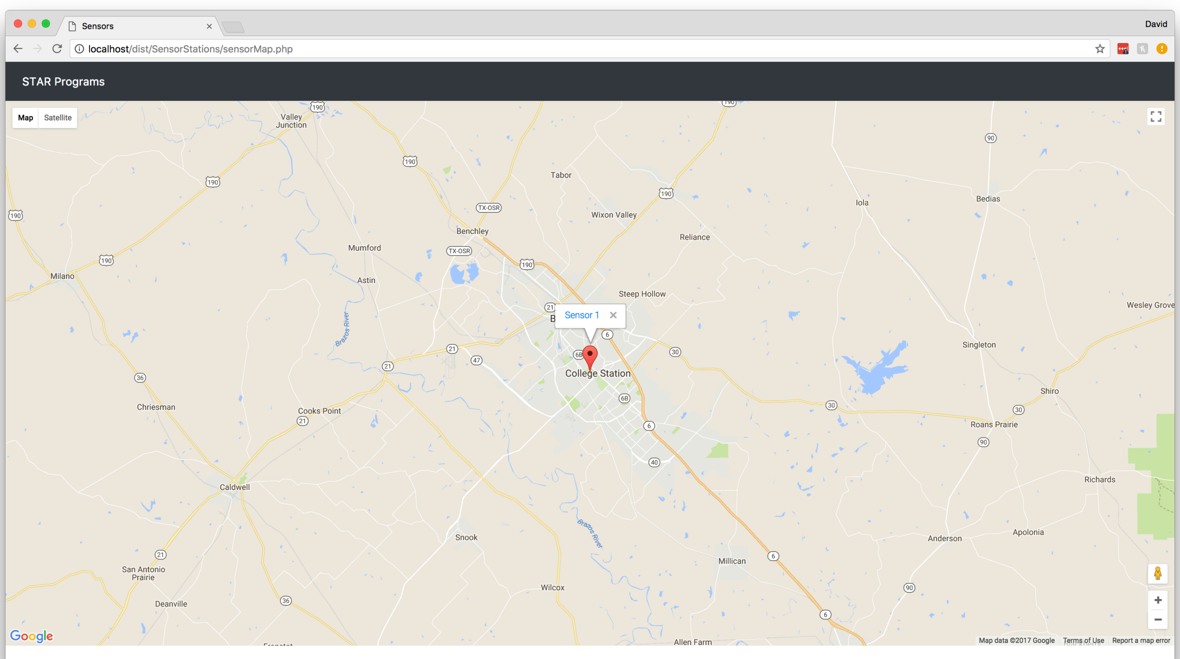
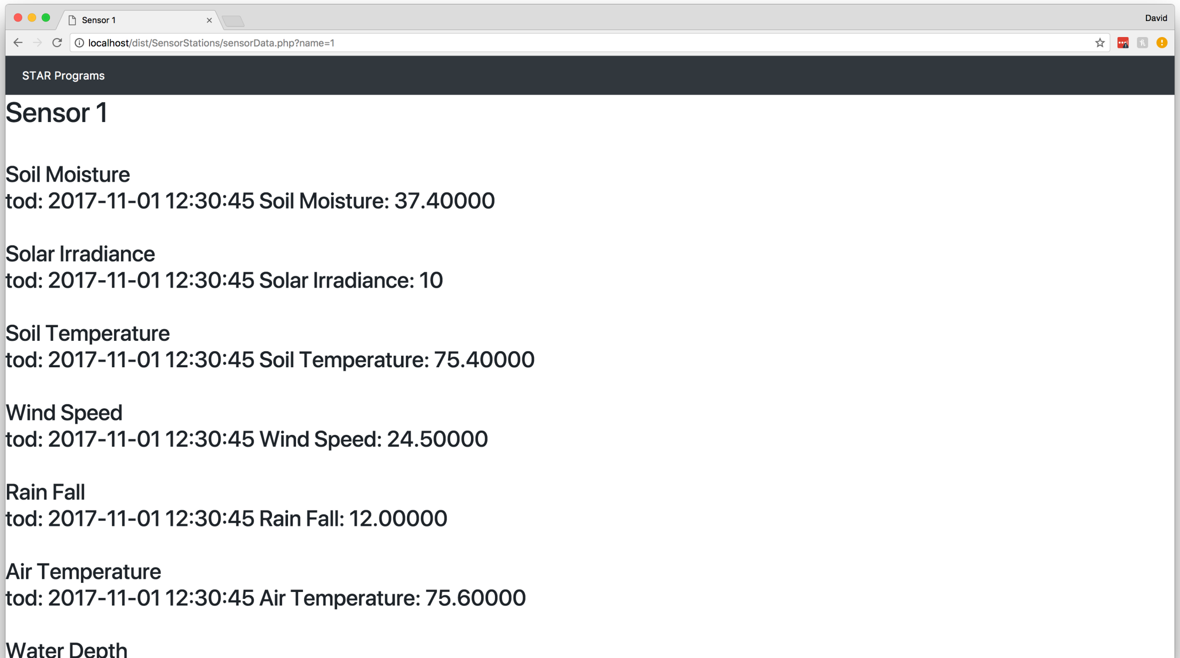


Figure 29: All Sensor Data from Single Sensor Station



6.4. Subsystem Validation

The MySQL database itself is hosted on enterprise servers managed by Amazon. Amazon automatically provides redundancy for information security and decreased downtime in the event of a failure. Although Amazon provides validation on their servers, a regular MySQL client was able to connect with and successfully query the database indicating that it was functioning properly. The website was validated with user testing for each given functionality. While a production website would need full unit tests, simple user testing will identify common bugs and missed functionality as the development progresses.

6.5. Subsystem Conclusion

The information storage and presentation subsystem currently contains all of the required functionality, but it still needs additional design work to present the information in digestible way for the end user.