Miniature Nutrient Plant Sensor

PROJECT PLAN

Team Number: 19

Client: Dr. Liang Dong

Advisers: Dr. Liang Dong

Team Members/Roles:

Manufacturing and Testing : Jonathan Hyugen and Clayton Flynn

Software design and Testing: Jeremy-Min-Yih Chee and Samuel Keely

Circuit Design: Ritika Chakravarty

Team Email:sddec19-19@iastate.edu

Team Website: https://sddec19-19.sd.ece.iastate.edu

Revised: 24th April, 2019, Version 2

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1. **KCl:** Potassium Chloride
2. **KM:** Kilometer (1 km = 0.62 miles)
3. **mm:** Millimeter ($1/10^3$th of a meter).
4. **N:** Nitrogen
5. **NaCl**: Sodium Chloride
6. **nm:** nanometer ($1/10^6$ th of a meter).
7. **P:** Phosphorus
8. **ppm**: Parts per million.

List of Definitions

1. **ADC:** A device that converts Alternating Current (AC) into Direct Current (DC).
2. **Biofilm:** A thin film of organic matter, that is formed by secretions from decaying plants and insects, in a habitat.
3. **CSV**: Comma Separated Values.
4. **Etching:** Here, the use of strong acids and bases, to dissolve parts of a silicon wafer.
5. **IP:** Ingress protection standard
6. **IEC:** International Electrotechnical Commission
7. **IEEE:** Institute of Electrical and Electronics Engineers
8. **Lifetime:** The number of days a sensor can last in the field, without requiring a change of batteries.
9. **LoRa/ LoRaWAN**: Long Range Wide Area Network used for long range communication.
10. **MCU:** A microcontroller unit like an Arduino.
11. **Midrib**: A large strengthened vein along the midline of a leaf.
12. **Margin**: The edge or border of a leaf.
13. **Needle sensor**: A sensor that is 2.5 mm thick and 12mm long, and is inserted either at the stalk or root of the plant.This is the device that records the nutrient levels in plants.
14. **Nutrient levels:** Here, we are concerned with Nitrogen, Phosphorus and water levels in a plant.
15. **PCB:** An electrical board with a circuit printed on it.
16. **Sensor**: A 3 inch silicon wafer with 100 needle point sensors (of various sizes) printed on it.
17. **Unit**: Here, the seven sensors and one Arduino, make a unit.
18. **ISM**: Ion Selective Membrane that allows NO_3 to pass through.
19. **NaCl/KCl**: Sodium Chloride or Potassium Chloride layer on the reference electrode.

1 Introductory Material

1.1 Acknowledgement

We would like to thank Dr. Dong for his time and effort in meeting with us weekly, so that we are able to get a better understanding of the project. Aside from that, we would not have managed to complete this project plan without additional insights provided by Dr. Dong during our weekly discussions.

We are also very thankful for the assistance provided by Yuncong Chen and Xinran Wang. We would have wasted time and resources if it was not for their knowledgeable insight regarding the project design and, the workings and usage of the machineries that we will be interacting with throughout the entire project.

Beside that, we would also like to thank the people who had been working on the project before us. Without them, we would not have the foundation and current understanding of the design process of the plant nutrient sensor.

1.2 Problem Statement

<u>Problem Statement:</u>

Soil conditions are never the same of two patches of land adjacent to each other. One patch could be dense in NO_3 (Nitrates), while the other could be dense in P (Phosphorus). For the best yield per acre, farmers need accurate data about the current nutrient levels in soil, in order to determine the right type and amount of fertilizer required for that acre. However, inaccurate data and the long waiting time on soil analysis results, often leaves farmers with incomplete information about current soil conditions.

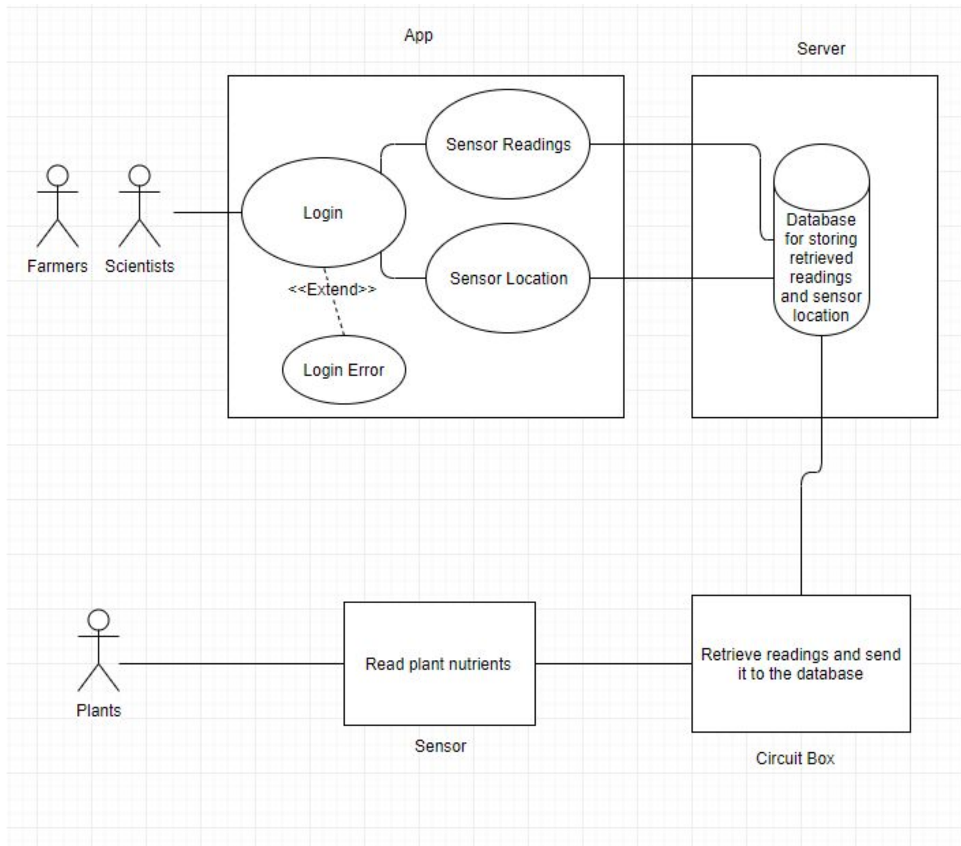

Fig 1: Use Case Diagram

Solution Approach:

The solution to the problem is to provide farmers with a portable tool that reads and provides accurate data about current soil conditions on the field at any given time. With this solution in mind, the miniature nutrient plant sensor and its app were made, where the sensor can accurately detect NO_3 levels in soil on a daily basis, and to ensure that farmers are well informed about current soil conditions, data collected by these sensors are readily available on the app.

Purpose of the Project:

Even with the current prototype of the sensor and app, there is room improvement. As of now, the data from the sensors is not fully accurate, as the surrounding temperature and chemical compounds adversely affect the nitrate reading. Furthermore, the sensors also need to be equipped to deal with environmental hazards (dust, dew). Currently, the app only interprets and outputs the readings of the sensors via bluetooth or cellular service.

We are tasked with optimizing the sensors and the app, such that the sensors can read the nutrient levels accurately without being manipulated by their environment, and the app, can perform additional functionalities like sensor tracking or expanding its data transmission range. We are also required to find a way to encase the sensors, in order to prevent them from being damaged by environmental hazards, while ensuring that the integrity of the data is not compromised.

For this project, we are hoping to create sensors that are adaptable to their respective environments and are able to read nutrient levels in the plant accurately, without hindrance from environmental factors. At the same time, we hope to produce an app that provides convenience to the users, such that users will be able to track the location of the sensors and retrieve the data from the sensors from without being at close proximity to the sensors.i.e. long range data transmission.

1.3 Operating Environment

The sensor will be operating in the field where, needle sensors will be inserted into the stalk of a plant. The location of the needle sensors is determined by their lengths. The shorter needle sensors are used to detect nutrient levels in the roots and leaves of the plants, while the longer needle sensors derive data from the stalk of the plant.

This means that the sensor will have to be rugged, temperature insensitive and resistant to dirt and water. This implies that the sensor will be exposed to environmental hazards like extreme temperatures, water and dust. Aside from that, the sensors will also be exposed to biofilms, that can develop on the surface of the sensors, and deactivate the data collection capacities of a sensor altogether. It must also survive water from rain and irrigation. The sensor will also be subjected to work in a controlled environment, like a laboratory, for testing purposes, mainly to test the accuracy of the data collected by the needle sensors.

1.4 Intended Users and Intended Uses

Our end products consist of a plant nutrient sensor and an app. One of our intended users are farmers working in fields. By using the sensors, farmers will be able to obtained accurate live data regarding the nutrient content of the soil in the crop field. Researchers/scientists can also use these sensors to obtain real time data from plants, to help their research.

Aside from that, the app will provide a user interface which allows both the farmers and researchers to obtain the sensor data, quickly and effectively. This data can be obtained by the app via cellular network or bluetooth at their convenience.

1.5 Assumptions and Limitations

<u>Assumptions:</u>

1. Each sensor will have an average lifetime of 60 days, so the number of times the battery has to be changed can be minimized.
2. The data log of the sensor can be stored in a database. This will help users track the plants nutrient data over a significant period of time and correlate the nutritional needs to the time of day, seasons etc.

3. The casing of the sensor provides protection against environmental hazards. This will protect the sensors from damage ,thereby ensuring the accuracy and integrity of the data.
4. The circuit box consists of rechargeable batteries, that can be charged using solar panels. Solar panels ensure that the batteries always remain charged and the sensors don't shut down (and stop data collection) due to a sudden current deficiency..
5. The sensors must be small enough for users to be able to carry it around easily. The ease of portability ensures that the sensors can be transported to different parts of the field with minimal investment in manpower and machinery. This significantly affects the overall financial investment in the project.
6. The sensor will not be constantly exposed to extreme environments. For example, we assume that the sensor will not be submerged in water for an extended period of time. Depending on thee seasons, weather and time of year, the sensors can be subject to any type of environment. Since, the sensors can easily be plugged into and taken out of the stalks of the plants, it is safe to assume that the sensors will not be subject to extreme weather for a prolonged period of time (a few months, a few years etc.).

Limitations:

1. High power consumption of the sensor. (1 W/ unit). Given the number of needle sensors on a sensing unit, it is difficult to significantly minimize the power consumption per unit.
2. The configuration/build of the sensor is based on the environments experienced in the Midwest. Given that the sensors are being manufactured here, the design requirements are adaptive of the weather and climate conditions here. If this sensor were to be used in more tropical climates or colder climates, the accuracy of the data will be largely affected due to the possibility of malfunctioning circuit components.
3. The app is only compatible with Android. Due to budget constraints, our app was only tested and installed on Android phones (bought in bulk). Anybody with an Apple OS, may not be able to access the benefits that the app has to offer.

1.6 Expected End Product and Other Deliverables

The end product of our project consists of four main components.

1. The circuit box
2. The sensors
3. A digital wireless data communication hardware
4. The app.

The circuit box consists of a microcontroller unit (MCU), filter circuits, amplifiers and power supplies. The sensors are required to measure the nutrient levels accurately, such that they are within the acceptable error margins. Both the MCU and power supplies will remain the same, from its previous design, as they are the best possible options we have available to us. The sensors will be encased in waterproofing polymer coatings, to prevent water damage to the sensors..

As for the digital wireless data communication, we are expected to deliver a calibrated version of LoRa, where it can interact with the sensor, MCU, database, and the app. The expected end product, will allow users to request/retrieve data from the sensors within a 100 KM range, without relying on the bluetooth or cellular data.

Last but not least, we are expected to deliver an app that provides additional functionality to the users to grant additional conveniences. These functionalities include a sensor tracker, which displays a sensor's geographical location, and an interactive form of data retrieval from the database, which enhances users' accessibility to the data. The app must be able to interact with the digital wireless data communication (LoRa) as well. The addition of database system will provide a much more efficient system as it provides sufficient memory allocation for storing a large amount of data while at the same time also provide some form of security option where it only allows specific users to access the data. Hence, we are expected to deliver a configured database so that it will store the appropriate sensor's data correctly.

When these components are combined, the users will interact with the app, and the app will look at the latest data stored in the database and display it. As for the sensors, they will periodically measure the nutrient content and store the data into database with the digital wireless data communication (LoRa) acting as the medium for transmitting the sensors data to the database.

By the end of this project (December 2019), we would like to have at least one modified sensor in the field. We will also hope to be able to test one sensor in a Greenhouse for data collection and research purposes, by the end of this semester (May 10th, 2019).

2 Proposed Approach and Statement of Work

2.1 Objective of the Task

The purpose of this project is to provide a robust platform for researchers, crop scientists, biologists, and farmers to gather information about nitrate levels in soil and plants. This data will be delivered automatically to a central network and stored using a cloud service. The data can be accessed remotely. The system must be reliable enough to last approximately 100 days. The system should be scalable and inexpensive.

2.2 Functional Requirements

1. One of the main challenges during the optimization process is the economic sustainability of the sensors. 3D printing these sensors require materials that are quite expensive to obtain. It is important to overcome this challenge to stay within our $500 budget.
2. Although, the current sensors provide good data, they cannot distinguish between NO_3 and other nutrients in soil within the 5% error margin. Another aspect we aim to optimize is increasing the range of the sensor from detecting 1 ppm of NO_3 to 5000 ppm of NO_3 with an error margin of 20%.
3. The sensors currently in use transmit data once a day for 30 days (or till the battery runs out), we would also like to increase the functional time of the sensor to 100 days (and more if possible).

2.3 Non-Functional requirements

1. In terms of security, both the sensors, and circuit box should be secure and protected against tampering by outsiders. Similarly, the database should also be secured and guarded from unauthorized personnel to prevent the data from being manipulated.
2. Since the sensors will be used in the field, it is important that the sensors are waterproofed. By doing so, it will extend the lifetime of the sensors and prevent unnecessary expenditure.
3. The transmission of data should be reliable and accurate to ensure the quality assurance of the sensors.
4. The power consumption of the physical system should be under 2 Watts as reducing or maintaining the power consumption will ensure the sensors operate longer in the field.

2.4 Standards

1. The IP64 standard was chosen as a guide for waterproofing our device. IP stands for ingress protection and is used to rate products for water and dust resistance. The IP64 rating is designated as a dust-proof, and water splash resistant rating [3]. The sensor will be exposed to lots of dust and although it will not be immersed in water, it will need to be protected from heavy rain or generally damp conditions.
2. The IEEE-315-1975 standard was used for helping us design our circuit and represents the symbols for specific components used in the design[5].
3. IEC 60062:2016 will also be implemented in our circuit design as it is the standard used for marking resistor and capacitor values and tolerances including the color code that is familiar to electrical engineers[4].
4. Unicode 12.0 standard was used to design the app and is used as a standard for coding characters [2].
5. IEEE 1264-2015 which is a guide for animal deterrents for electric power supply. This standard outlined the main animals involved in equipment damage and outages. The standard outlines some general guidelines for physical barriers such as fences and even little devices to thwart damage from animals. Fake predatory animals and disturbing noises can also scare off animals from sensitive equipment. The standard even documents the typical effectiveness of these deterrents in the form of a percentage. We have the capability to easily integrate a noise maker to rid animals from the electronics by using the cellular phone or arduino microcontroller [8].

2.5 Constraints Considerations

1. <u>Power Consumption</u>

One of the constraints that we took into consideration is the power consumption of the sensor. Currently, the sensor is consuming power at a high rate where batteries acting as a single power source is insufficient. Therefore, this issue is solved by adding solar panels to the sensor. The reduction of power consumption is possible by replacing the current microcontroller unit (MCU). However, doing so, will result in changing the entire design. This in turn results in our current design constraint.

2. <u>Data Accessibility</u>

Currently, users with cellular network accessibility will only be able to access the sensor's data from long distance. Retrieving the data in an area without proper cellular connectivity will not be possible and the users will need to be near the sensors as the bluetooth range is much shorter than the cellular network.

3. <u>Size of the sensor</u>

The size (dimension) of the sensor is a constraint consideration for our project. The dimension should be small enough where it is convenient for users to carry it around and it does not become a hindrance to passersby. At the same time, it should be large enough where it is easy to notice by the users.

2.6 Previous Work And Literature

There are three main methods for measuring nitrogen levels tissue analysis, optical meters, and ion selective membranes. Tissue analysis involves taking a sample of plant tissue and breaking it down to measure the nitrogen levels. Although this process produces accurate results, it requires the plants to be sent to a lab, making it impractical. Optical meters will measure various optical properties to estimate the nitrogen levels. The method is much more convenient, but is affected by sunlight and can be unable to detect over fertilized corps. Finally, ion selective membranes will create a voltage based on the amount of nitrogen ions present. The method is still less accurate than tissue analysis, but provides a more direct measurement than optical sensors. [7]

Our project should be able to differentiate itself from the competitors. The lab using tissue analysis are inconvenient for farmers looking for immediate results. There are several optical sensors on the market including GreenSeeker and CropCircle. There are also some handheld ISM sensors from companies like Horiba, but they require the plant sap to be made into a solution. Our project should be the only field deployable sensor to measure nitrate levels directly from the plan using an ISM. Our sensor should provide more reliable data then sensors using optical measurements.

2.7 Proposed Design

Top Level Design:

The sensor:Arduino: Phone ratio is 7:1:1. i.e. Every circuit box has seven sensors connected to one Arduino, which transmits data to one phone (via Bluetooth/ cellular data). Each of these units (7 sensors and 1 Arduino), consume 1W of power..

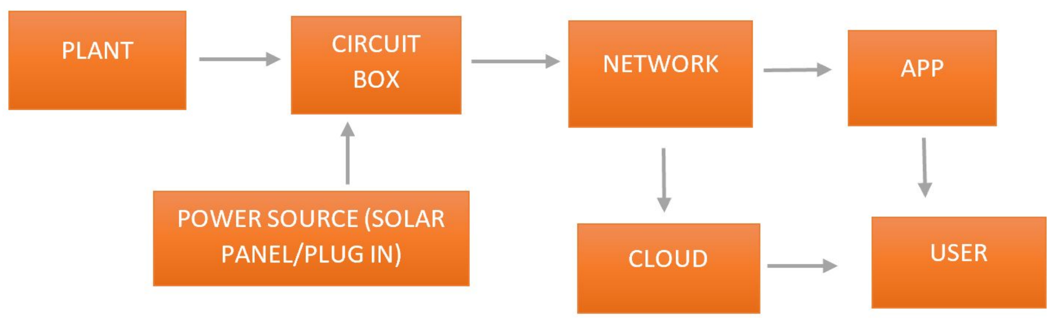

Fig 2: A diagram showing the components of the system.

Working:

1. The system consists of a plant from which we receive data. .
2. A sensor is placed to the circuit box, that is attached to the plant. The circuit box consists of an Arduino board, a Bluetooth Board, digital filter circuits, power amplifiers and AC - DC converters.
3. The circuit box receives power through rechargeable batteries (which are charged by solar panels), when in the field.
4. Data from the circuit box goes into the power read out circuit (which is controlled by an Arduino).
5. From here, it goes into the network (currently via Bluetooth and cellular data) and gets uploaded in ISU's Cloud Storage and the app.
6. The user can now access this data easily.

Structure of the sensor:

The sensor consists of a 3 inch silicon wafer, which is treated with ions to reduce its resistivity (within acceptable limits) . To make it compatible with biological materials, the wafer surface is coated with 115 nm thick layer of Gold, 250 nm thick layer of Silver and 22 nm of Silver Chloride. The sensor is then wrapped in a waterproof polymer from the sides. 8 mm of this wafer forms the current collector, the remaining 2 mm is uncoated for the entire process. Needle point sensors of varying lengths (between 5mm and 12mm) are etched into the sensor. Shown below, in Fig 2, is the sensor and all its basic components. The purple layer on the bottom is the silicon substrate with the gold and silver layers printed onto it. The black pads and lines are the conductors that act as connectors or vias to the circuit box. Wires are attached to the three pads. The blue pads represent the ISM that is deposited onto the gold pads. This is a selective membrane that filters out all ions that are not nitrates. The orange pad represents a NaCl/KCl that is added on top of the silver chloride pad. These pads are used to add extra chloride to the silver chloride layer as it is depleted. The silver chloride layer slowly depletes itself as it produces current for the circuit box. The green layer represents a watertight glue that has yet to be determined. The glue helps hold down the edges of the ISM because over a few days of constant contact with the water in the plant, the ISM begins to detach from the gold plating. The glue helps keep water from getting underneath the ISM layer. The ISM, NaCl/KCl, and glue are deposited using the Nordson Dispensing Robot and the thicknesses of the layers are measured with the same machine.

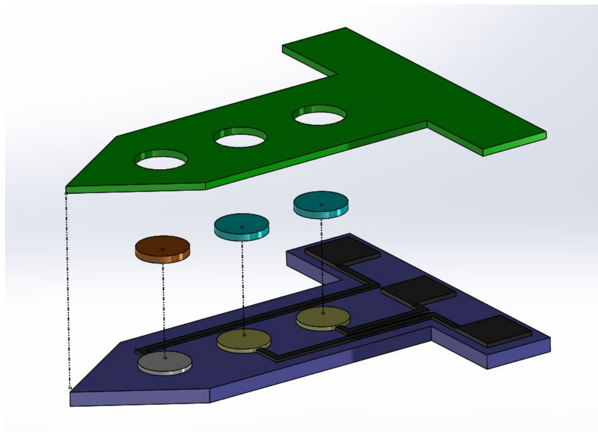

Fig 3: A diagram showing the components of the sensor.

<u>Circuit box:</u>

The circuit box is a 6 inch metallic box, with the top screwed on to the bottom. This provides a certain degree of water resistance and also prevents foreign entities (weather conditions, farm animals) from tampering with the sensitive equipment. The box has a port (on the outside), that connects to either a power outlet (to charge the battery in the lab) or solar panels (to charge the batteries in the field). There is a switch on the side of the box that is used to test the response of the circuit components, to the presence of electricity.i.e. if the components switch on when current flows through the system. If a component does not switch on (in the presence of current), it is taken out for debugging.

The power source (plug in/ solar panels) is connected to the charger. If the circuit box is plugged in, a demodulator circuit is in place to convert the 110 V down to the 5V, required for the functionality of the circuit. Solar panels are used to power the batteries in the field, so that the batteries can last as long as possible without being replaced. As of now, the batteries are good for 2 months (60 days).

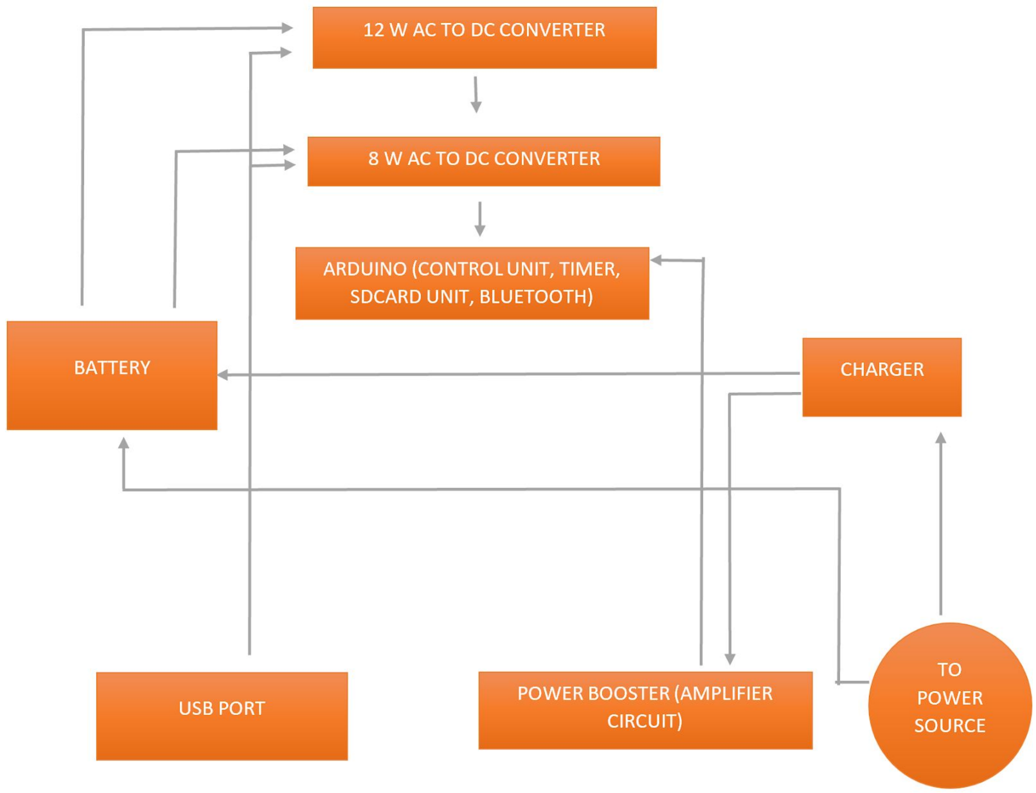

Fig 4: Flowchart of components in the circuit box

<u>Working:</u>

1. The charger supplies current to the battery and power booster circuit, when the battery is not fully charged. When fully charged, the battery supplies power to the circuit and the charger supplies power to the power booster circuit. At night, the battery supplies power to the circuit and the power booster as well.
2. The battery unit is two Li-on batteries connected in series, each of which provides a charge of 3500 mAh.
3. The USB port uses a micro-USB to USB cable to transmit data from the sensor (attached to the plant) to the circuit box. The micro-USB side connects to a micro- USB port on the PCB, onto which the sensor is glued.
4. The data from the sensors come in at different power levels. Therefore, we have two ADC units (12 W and 8 W respectively). These units are connected to the Arduino.This system is mounted in the order shown in Fig 2 (12W ADC at the bottom, 8W ADC in the middle and Arduino on the top), and is connected via pins. The 12 W ADC, forms the power read out circuit.
5. The Arduino uses digital filters to remove any major fluctuations in data. Time stamps are put on the corrected data and then sent to the app.
6. The Arduino does not have enough power to transmit the data over Bluetooth by itself. So, a power booster (buffer amplifier circuit) is connected to the Arduino to help with data transmission over Bluetooth. Data is also stored on the SD card.

Software (app.) component:

The software component of the system consists of the app, the cloud (database), and network.

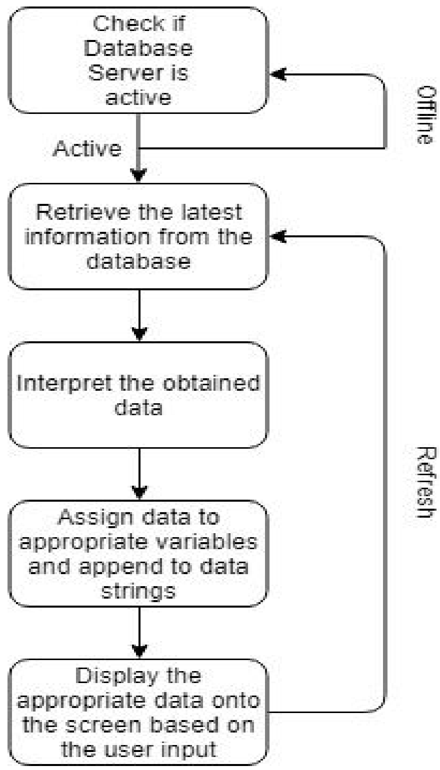

Fig 5: Software Flow Diagram

The diagram above portrays the sequence of steps that occur when a user wishes to retrieve the nutrient measurements from a sensor in the fields. Fig 3 assumes that all of the necessary hardware/software is calibrated properly and is working correctly. For example, we assume that the database is up and running and the sensors is able to store the data into the database correctly. Initially, when the user retrieves the data, the app will try to connect to the database. If the database is offline, the app will constantly refresh its access into the database until the user cancels their request or the database is online. If the server is online, the app will retrieve the latest measurements of each sensors based on the timestamps. Upon retrieving the measurements, the app will interpret it in such a way that it is readable to the user. Once the measurement is interpreted, the data is assign to their appropriate variables and is appended to the data string. The appropriate data strings is then printed/outputted onto the screen of the terminal of the user. If the user wishes to refresh the results, they can click on the refresh button on the app to retrieve the latest results. When the refresh button is pressed, the app will retrieve the latest measurement from the database again and the process is repeated again.

Database Structure:

Login Table	
User Name	String
Salt	String
Password Hash	String

Sensor Data Table	
Owner	String
Sensor ID	String
Sensor Lat	Integer
Sensor Long	Integer
Date of Data	Integer
Sensor Data	Integer

Table 1: Database Structure

As of now, we have decided to use either mySQL or Etg Database to store the sensors' data and PHP language to retrieve the data from the database to the app. With the sensor tracker functionality, we have decided to use Google Maps API for tracking the sensors' location. As for the app itself, we have decided to use android studio instead. The reason for this is because android studio provides convenience to us with its wide variety of libraries.

The standards that we will be using for the implementation of the app is GNU and JCP while the standards for the PHP language that will be using falls under PHP license itself. If we choose to implement the database with mySQL, the standards will fall under GNU and under a variety of proprietary licenses.

Other variations:

Since this project has been worked on by many groups in the past, there are many variants of this sensor.

1. Mobile phone and prongs:

   An updated version of this sensor consists of a mobile phone with prongs attached to it. These prongs house the needle sensors. They can be directly inserted into the stalks of plants and detect their nutrient levels. This data is then uploaded to the cloud. Therefore, this version does not have a circuit box.

2. LoRaWAN:

   If LoRa were to be used for data transmission, the circuit would just consist of the 12 W ADC board connected to the needle sensors on one end and LoRa on the other.

2.8 Technology Considerations

1. 3D Printer
   The 3D printer will primarily be use to create the case of the sensor where it will encase the sensor. With the 3D printer, we are required to use waterproof material with the 3D printer, in order to protect the sensor from water elements when it is placed in its operating environment.

2. Nanomaterial Printer
   The nanomaterial printer will be use to print the electronic and circuit component of the sensor. Since the required dimension of the sensor is relative small, the presence of the nanomaterial printer eases the process of creating and integrating smaller electronic components into the sensor.

3. User Interface for sensors' data
   Some form of user interface(app) is required to retrieved and interpret the live data outputted by the plant nutrient sensors. Currently, the framework for the app has been created using python. However, additional optimization is required for the app to enhance the users' experience.

4. Cellular Network and bluetooth module
   The use of cellular network allows wireless connectivity for the user to retrieve the live data of the sensor via the app. By using wireless connectivity, the users are granted the flexibility to retrieve the live data from anywhere so long as they have access to the cellular network or is within the bluetooth range.

5. LoRa (digital wireless data communication technology)

The integration of LoRa will provide additional functionality to the sensors where the users will be able to access the sensors' data on the field without relying on cellular network or bluetooth. At the same time, LoRa will help reduce expenses and provide convenience to the users.

6. Microcontroller Unit (MCU)
   The microcontroller unit (MCU) is the main component of the sensor where it functioned as a microprocessor. The MCU is used to store the data of the sensors and controls the functionality of the sensors.

7. Cloud Storage
   Cloud storage provides a form of storage for all of the sensor's data where the users can retrieve it any time. The presence of a cloud storage also provides safety measure for data losses.

2.9 Safety Considerations

Our system will not have any high voltage, moving parts, or other dangerous parts. Basic lab safety and field safety should be our only safety concerns. Wildlife and specifically animals could be affected if these sensors are not placed properly in the fields or disposed properly after use.

2.10 Task Approach

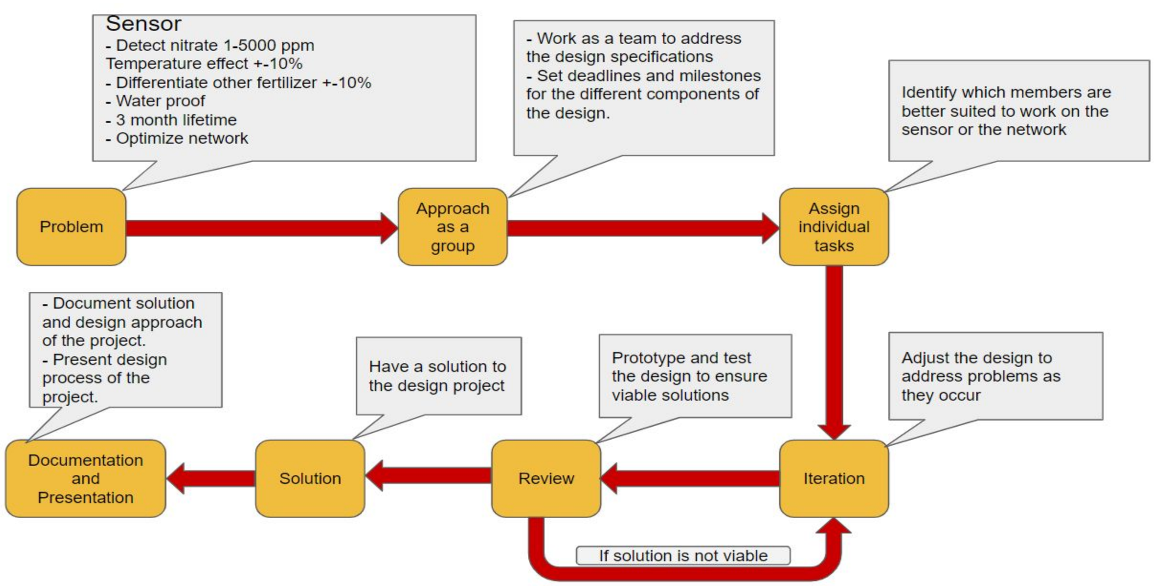

Fig 6: Flowchart for Approaching Task

For testing the sensor for moisture permeability, we will be exposing the sensor to various conditions to make the sensor fail. The sensor's faults have been previously defined for this project. Once the reason for failure is detected, we will design new methods for 3D printing to eliminate the problem. We will incorporate various seal designs and also experiment with various orientations of the sensor. To reduce power consumption, we will determine the base power usage and set a reasonable goal. The goal should be to last approximately a few days in order to last long enough if the weather is poor. One way to do this is to implement an external clock that turns the MCU on and off so the MCU doesn't need to remain on for long periods of time. The range of data transmission will be altered if possible by using LoRaWAN technology which is a long range wireless system that has typical ranges of near 1 mile.

2.11 Possible Risks And Risk Management

Risk : Environmental hazards

Descriptions : Since the sensors will be used in both crop field and greenhouse, it will constantly be exposed to the elements. These environmental hazards consists of water, dirt, living beings, humidity, etc. Without proper precaution or protection, the lifetime of the sensor will significantly decrease. This in turn will result in excessive wastage and users dissatisfaction.

Mitigation : In order to mitigate this particular risk, a case surrounding the sensor was proposed. The proposed case should be made with waterproof material and the case should be strong and secure so that the sensor is protected against environmental hazards.

Risk : Incomplete/inaccurate data in data retrieving process

Description : There will always be the risk of receiving incomplete data or incorrect data when retrieving data through the APP. The risk of retrieving an incomplete data may result in the APP interpreting and display the data incorrectly. This may result in the users making the wrong decision based on the received data and at the same time may result in profit loss. The risk of receiving incomplete or inaccurate data may have occurred from a malfunctioned sensor or connectivity Interruption.

Mitigation : There are a couple of ways to mitigate this particular risk. One of them is creating an algorithm where it will check the status of the sensor and report to to the user when sensor is malfunctioning. As for incomplete data during a connectivity interruption, a somewhat similar algorithm can also be create to inform the user of the network interruption. At the same time, it will also check if the completed data has been retrieved.

2.12 Project Proposed Milestones and Evaluation Criteria

For this semester, our milestones are almost strictly design. Our team was instructed to first, find areas of improvement in each portion of the design. This involves aspects of sensor adhesion to the plant, lowering the cost of the sensor, decreasing water penetration of the sensor, improving power consumption, and eliminating costly network devices if possible. The evaluation criteria is simple, lower the cost as much as possible, and the system needs to be robust enough in all manners to last 100 days in the field. The major milestones are listed below.

1. Get current system working and test for issues and bugs
2. Refactor code for cell based network
3. Incorporate LoRaWAN into the system to increase range
4. Find an epoxy resin that can withstand water penetration for 60 days
5. Finalize a pattern for depositing the ISM and resin onto the sensors
6. Debug current sensor boxes
7. Begin greenhouse testing

2.13 Project Tracking Procedures

Our project timeline will be traceable using online file sharing services such as github, Google Docs, and Google Calendar. Each team member will be responsible for regular updating of the calendar and the team will review the scheduling matters each week in the team meeting. Github will be used to track changes in computer code. Weekly meetings are non-negotiable and each meeting will consist of a team review of the scheduling and milestone achievements. Google Docs will be used for various portions of the project when shared documentation is required.

2.14 Expected Results and Validation

The sensor has a very limited life and is mostly disposable. Longevity, cost, and ease of use are the main of this project. The sensor is required to last about 60 days, and be as cheap as possible. The app will be perfected for ease of use and increased functionality. Because the system runs off of batteries that are charged by solar panels, the system needs to be able to last through a cloudy period which could be a few days.The results that are expected of the final system are listed below.

1. Data can be transmitted effectively from the field to the app, within Ames.
2. The sensor must differentiate between Nitrogen and other particles in the soil precisely.
3. The sensors must be able to cope with a large range of temperatures, under which they work without any glitches.
4. The accuracy of the data is directly proportional to the amount of incoming power. A slight change in power should not have detrimental effects on the accuracy of data.
5. The units, when embedded correctly in plant stalks, can run for 60 days, without needing a change of batteries.

2.15 Test Plan

2.151 Functional Testing

The tests will verify the accuracy of the sensor based on the requirements of the client.

Test Number	Test	Desired Result
1.A	Measure Nitrate Between 1 to 5000 ppm	± 10%
1.B	Temperature Invariance	± 5%
1.C	Differentiate From Other Nutrients(e.g Phosphorus)	± 10%

Table 2: Functional Testing

Test 1.A Measure Nitrate Between 1 to 5000 ppm

1. Obtain or dilute nitrate solution to between 1 and 5000 ppm.
2. Insert needle sensor into solution and connect to readout circuit box.
3. Obtain voltage value from arduino adc pin.
4. Compare value to calibration curve for nitrate concentration.
5. Repeat steps for various solutions in concentration results.
6. If data is outside error range adjust the calibration curve and repeat steps.

The goal of the test is the have the sensor box read the nitrate concentration within 10% error.

Test 1.B Temperature Invariance

Repeat test 1.A, but vary the temperature between 1℃ - 40℃. After the sensor needle is inserted into the solution, the system should be moved to a temperature chamber. The calibration curve will be adjusted with the temperature values and voltage value from the sensor. The error for temperatures in the range should be within 5%.

Test 1.C Differentiate From Other Nutrients(e.g Phosphorus)

Repeat test 1.A, but after preparing the solution add other plant nutrients like phosphorus. If the test isn't within 10% error the printing of the needle will need to be adjusted to only provide a voltage for nitrate ions. The goal of the test is to ensure the sensor materials are only responding to nitrate within 10% error.

These tests will fulfill the user requirements for the sensor.

2.152 Non-Functional Testing

Test Number	Test	Desired Result
2.A	Waterproof	The sensor operates after exposure to moisture
2.B	Transmission Range	Transmission Without Cell Network
2.C	Operational Lifetime	3 (Months)
2.D	Power Consumption	< 2 (Watt)

Table 3: Non-Functional Testing

<u>Waterproof</u>

The sensor will be set up in a test field. The sensor will be setup to continuous transmit data to the server. The sensor should continue to transmit data after rainfall has occurred in the field. If the sensor fails the seal on the sensor needle will need to be adjusted. The sensor can be tested under various water conditions including a mist spraying continuously on the sensor. The sensor should have an adequate seal to prevent moisture creeping underneath the ISM and NaCl or KCl coatings located on the needle. The spray mist test will determine if the glue has properly sealed around the wires bonded to the vias. The plant will be wet for the duration of the use of the sensor and the glue will have to prevent water from penetrating underneath the ISM layer for the life of the sensor. We will also test various mounting orientations of the sensor to ensure that the sensor performs under a variety of conditions. The sensor can be mounted near the midrib of the leaf or on the margin. It can also be mounted on top and underneath the leaf.

<u>Transmission Range</u>

The sensor is currently operational using cellular network. The goal is to have an alternative transmission method to the cellular network using LoraWAN. The sensor should be able to transmit data from the test field using only LoraWAN.

<u>Operational Lifetime</u>

The sensor box will be deployed in a greenhouse environment. The sensor should provide continuous measurements for a three month period of time. The three month lifetime is only for ideal greenhouse environments. The sensor will also be deployed in a test field. The goal for the test field sensor is a 1-2 week operational period.

<u>Power Consumption</u>

The current sensor operates on 0.8 Watts. The goal is to keep the power consumption of the circuit box under 2 Watts. The power will be measured using a multimeter. The goal of the test is to ensure the continuous operation of the sensor with the current solar power source. The test will be conducted underfull power consumption where the sensor is collecting data and during the transmission of the data.

3 Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline

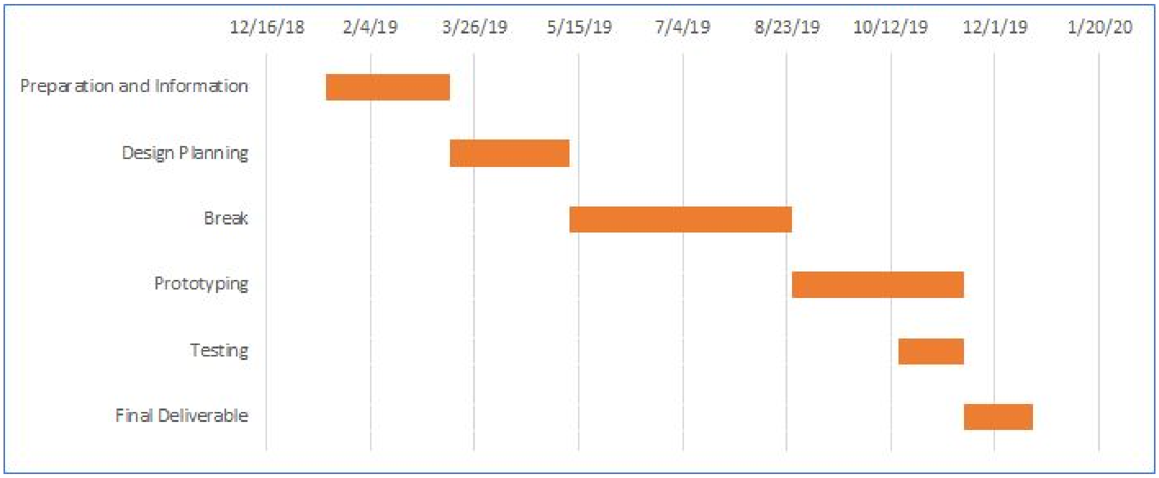

Fig 7: Project Timeline

Preparation and Information - Work on completely understanding how the current state of the project functions.
Design Planning - Design a plan for improving each part of the project; sensor, network, app.
Break - No work will be completed over the summer break.
Prototyping - Implement the design changes into the project.
Testing - Test the prototypes and makes changes as necessary.
Final Deliverable - Finish the final product for the project.

3.2 Feasibility Assessment

The project will include a few hurdles that could arise later. These problems have been identified and the noteworthy predictions are listed below. These problems need to be solved or our project could be considered a failure.

1. The sensor cannot differentiate between Nitrogen and other particles in the soil precisely.

2. The sensors have no estimated range of temperatures, under which they work without any glitches.

3. The accuracy of the data is directly proportional to the amount of incoming power. A slight change in power has detrimental effects on the accuracy of data.

4. The units, when embedded correctly in plant stalks, can run for 60 days, without needing

a change of batteries.

5. Data can be transmitted effectively from the field to the app, within Ames.

3.3 Personnel Effort Requirements

Task	Description	Estimated Time
Test sensor	Test Sensor for moisture permeability	60 hrs
Waterproof sensor	Print various designs and concepts and refine for future manufacturing	120 hrs
Reduce power consumption	Implement external clock for MCU	60 hrs
Increase short wave transmission range	Research LoRaWAN, incorporate into system	200 hrs
Update app		200 hrs

Table 4: Personnel resource

3.4 Other Resource Requirements

All lab equipment including 3D printers and nano printers will be provided through Iowa State University through the Biosensor Lab. Information regarding technical specifications for biological sensors will be provided by chemistry and biology graduate students.

3.5 Financial Requirements

Cellular network subscriptions will be covered under the 2 million dollar project grant. This project has a budget of $500 budget but can be adjusted if needed. Printing materials will be minimal and they will be provided for this project by the grant and will not come from the $500 budget. The equipment such as the MCU’s and cell-phones have already been purchased.

4 Closure Materials

4.1 Conclusion

The goal of this project is to optimize all the components of the nutrient sensor system. The needle point sensors need to be made more reliable and be invariant to other stimuli. The sensor boxes need to be more weather- resistant. The transmission channel and range has to be modified such that it does not depend solely on cellular network for data transmission. The app has to be updated to be more user- friendly.

These goals will be accomplished by dividing the project goals into smaller, more realistic and achievable goals . This individualized attention on each goal, will allow us to focus on the problems in each area, and use our skills to overcome the same. After improvements have been made, the components can be connected to our established interfaces.

By the end of this project, we hope to have a nutrient sensor that can accurately track the nutrient levels in the soil, and an app can store this data for easy retrieval in the future. By the end of next semester, we will have done enough testing in labs and in fields to be able to understand the scope of these sensors, in terms of the temperature range they work in, soils they are best suited for, climate and other environmental factors that impacts the accuracy of data.

Farmers with inaccurate data about their field's nutrient levels will not be able to make decisions that benefit their soil quality and more importantly, the yield per bushel. With these nutrient sensors and app, we hope to be able to overcome this discrepancy in vital data, and ultimately help farmers maintain their fields in a sustainable manner.

4.2 References

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