Printed Miniature Nutrient Sensors

Project Plan

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ppm: parts per million, expresses the concentration as a ratio of the particles.

NO_3: nitrate, compound used in fertilizer.

Sensor: the nitrate sensor that will be developed in this project.

INTRODUCTORY MATERIAL

PROBLEM STATEMENT

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. Our group is working on optimizing nutrient sensors that can accurately detect NO_3 levels in soil on a daily basis, and ensure that farmers are well informed about current soil conditions. The sensor will also be able to track the interdependence of weather (consequently, the temperature) and the changes in the nutrient levels of the soil.

OPERATING ENVIRONMENT

The Sensor will be operating in the field on living plants. This means that the sensor will have to be rugged, temperature insensitive and resistant to dirt and water. The sensor itself will be attached to the plant directly. One of the challenges of this project is to create a sensor that will be resistant to both water, and the biofilm that can develop on the surface of plants. The entire sensor unit will also be exposed to the elements. It must survive water from rain and irrigation. It will also need to work at any normal outdoor temperature. Dirt and dust can also cause problems in electronics so we must keep that in mind.

INTENDED USER(S) AND USE(S)

For our end products, it consists of a nutrient plant sensor and an app. Therefore, one of our intended users for our end products are farmers working on the 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. Other than farmers, researchers/scientists are also the intended users as they will be able to use the live data obtained from the sensors to further their respective research.

Aside from that, the app will provide a user interface where it allows both the farmers and researchers to have a smoother transition in obtaining and interpreting the live data of the sensors. The live data that the farmers and scientists seeks will be obtainable through the app via cellular network or bluetooth which provides additional convenience to them.

ASSUMPTIONS AND LIMITATIONS

We will be assuming some basic facts about the environment and device. We are assuming that while the device will not be placed in an area where it will not receive sun for extended periods, or will be submerged. The device will also use some form of network storage, we will be assuming that the database will be large enough for our uses.

EXPECTED PRODUCTS AND DELIVERABLES

By the end of this project, we would like to have at least one modified sensor in the field. We also hope to be able to increase the accuracy of the device, such that it can function within the acceptable error margins. Goals for this semester include studying each component of the system and finding ways to optimize each of those components. We will also be testing one of these sensors' in a Greenhouse for data collection and research purposes.

ACKNOWLEDGMENT

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.

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.

PROPOSED APPROACH

HIGH- LEVEL BLOCK DIAGRAM OF SYSTEM

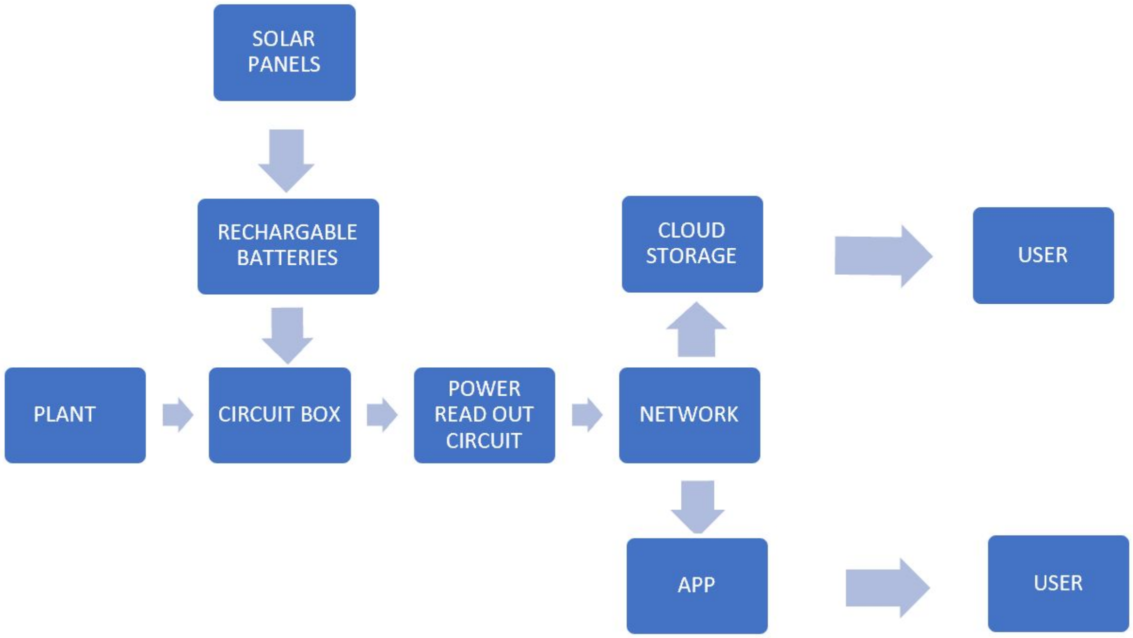

FIG 1: A diagram showing the components of the system.
The system consists of a plant from which we receive data. A sensor is placed to the circuit box, that is attached to the plant. The circuit box consists of an Arduino board, a Bluetooth Board, filter circuits, power amplifiers and AC - DC converters.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

FUNCTIONAL REQUIREMENTS

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.

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%.

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).

CONSTRAINTS CONSIDERATIONS

- **Power Consumption**
  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.

- **Data Accessibility**
  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.

- **Size of the sensor**
  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.

TECHNOLOGY CONSIDERATIONS

- **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.

- **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.

- **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.

- **Cellular Network and bluetooth**
  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.

- **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.

- **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.

- **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.

TECHNICAL APPROACH CONSIDERATIONS

This project requires 3D printing techniques that will allow the sensor to be protected from environmental agents such as rain and dust will need to be replicated using different equipment in future production. Solving the issues at hand will require a technique for creating an impermeable boundary between printed layers of our project but also not limiting the production to only 3D printability. Future plans outside of our scope may involve different technologies with higher efficiency but limited capabilities. Our solution will require scalability for large scale manufacturing.

The limitations on cellular communication for this project's purpose are null but for future expansion of this product, the possibility to create sub-networks to communicate with our cellular transmitter will be necessary. This portion of the project also requires future scalability for larger sensor networks.

TESTING REQUIREMENTS CONSIDERATIONS

We will be required to test our sensor for both survival time and nitrate sensitivity. Nitrate sensitivity will be tested both in the lab and in the field. Survival time will have to be tested using some methods to simulate time in the lab, as we will most likely not have 3 months to test the finished product.

SECURITY CONSIDERATIONS

This project will not have heavy information security concerns. The application and database will most likely have an integrated login/password system, but it will not be a major concern.

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.

PREVIOUS WORK / LITERATURE REVIEW

Previous to this sensor, farmers and researchers would have to collect field samples and send them to a lab. The lab would then test the plant for nitrate levels. This could take a large amount of time. Most farmers simply use the recommended amount of fertilizer for the seeds they have purchased. These sensors would allow a farmer to tailor the fertilizer amounts for their field and current crop.

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.

PROJECT PROPOSED MILESTONES AND EVALUATION CRITERIA

For this semester, our milestones are almost strictly design. The milestones have not yet been set, as that in itself is a milestone. 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.

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.

STATEMENT OF WORK

1) OBJECTIVE OF 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) TASK APPROACH

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.

3) EXPECTED RESULTS

The sensor has a very limited life and is mostly disposable. Longevity, cost, and ease of use are the only goals of this project. The sensor is required to last 100 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.

ESTIMATED RESOURCES

1. PERSONNEL RESOURCE 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 1: Personnel resource

2. 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. 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.

PROJECT TIMELINE

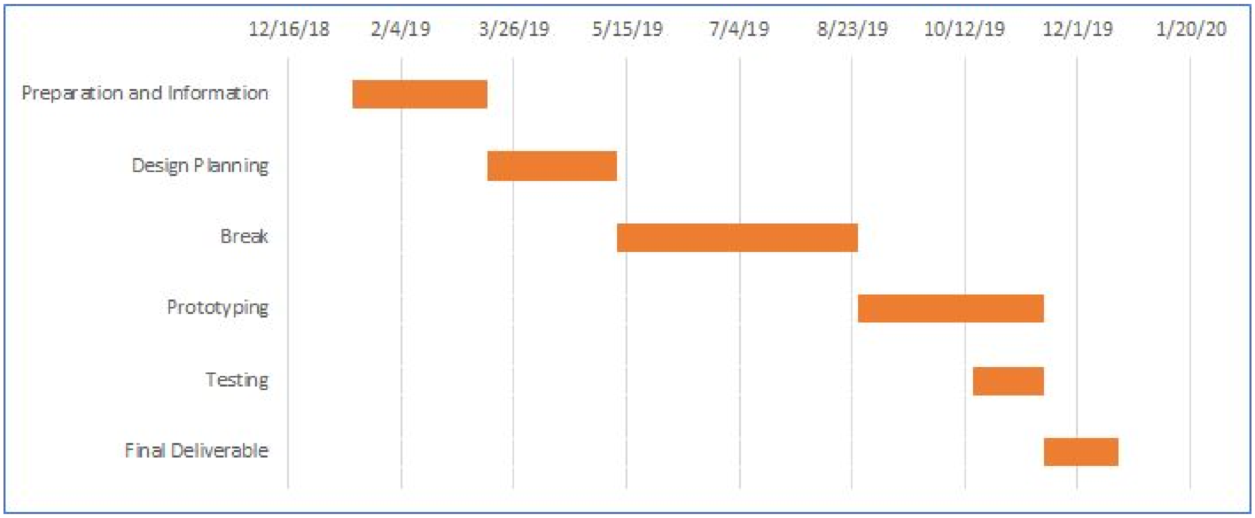

FIG 2: Project Timeline

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.

CLOSURE MATERIALS

CLOSING SUMMARY

With farmers experiencing long waiting time and acquiring inaccurate data on soil analysis results, the assignment of optimizing the current plant nutrient sensor is assigned to our group. By identifying the potential risk and its respective risk management technique, we are able to identify the components that requires optimization. Through the process of optimizing the sensor and app, the anticipated end product will be a sensor that detect the NO_3 content of the soil accurately without having its reading being manipulated by its surrounding environment. With the optimized app, farmers will have the flexibility of acquiring the data without a long waiting time.

REFERENCE

APPENDICES