Project Proposal

Autonomous Gardening Rover

Ryan Thammakhoune, Tanishq Aryan Myadam, Dhruv Sanagaram

Problem

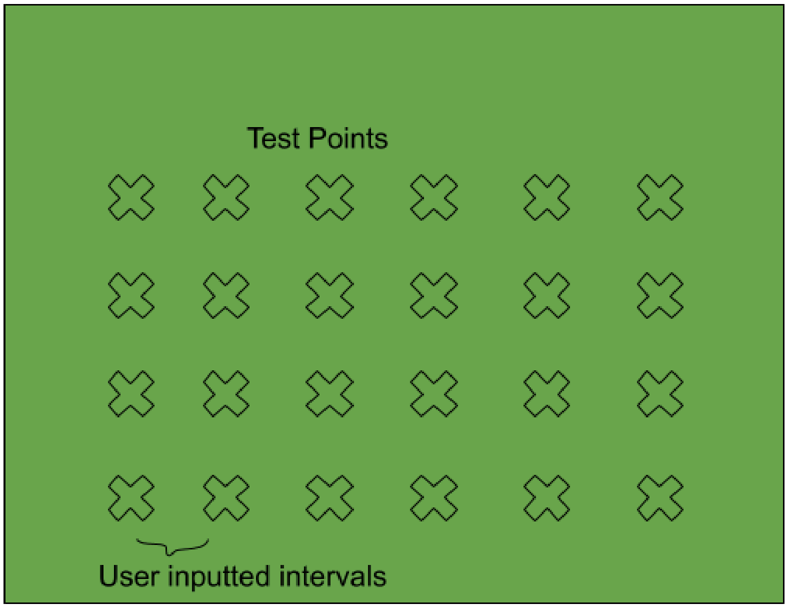
Soil monitoring is a pressing problem for hobbyist gardeners and commercial farmers alike. Many soil monitoring solutions employ a number of stationary probes that are planted in intervals. However, placing these probes is an arduous process and does not accommodate the varying plot sizes and planting intervals. The article demonstrates how maintaining soil probes can be difficult due to electrical problems and physical damage [10]. The second article is John Deere's autonomous tractor solution [4].

Solution

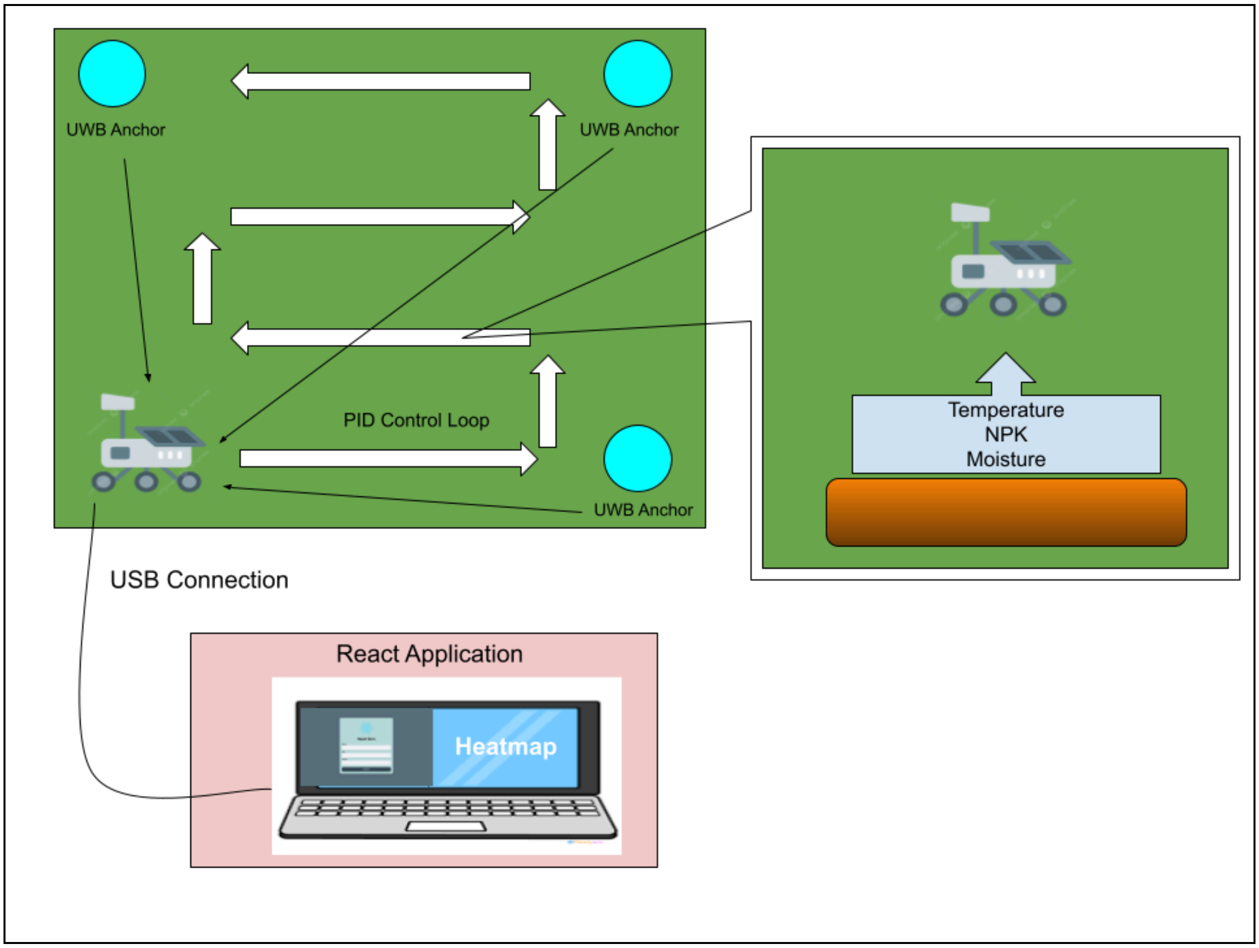
One to two paragraphs describing the solution. Give a high-level idea of what your solution is, then delve into detail as to how it is implemented. You do not have to commit to a particular implementation at this point, but your description should be explicit and concrete.

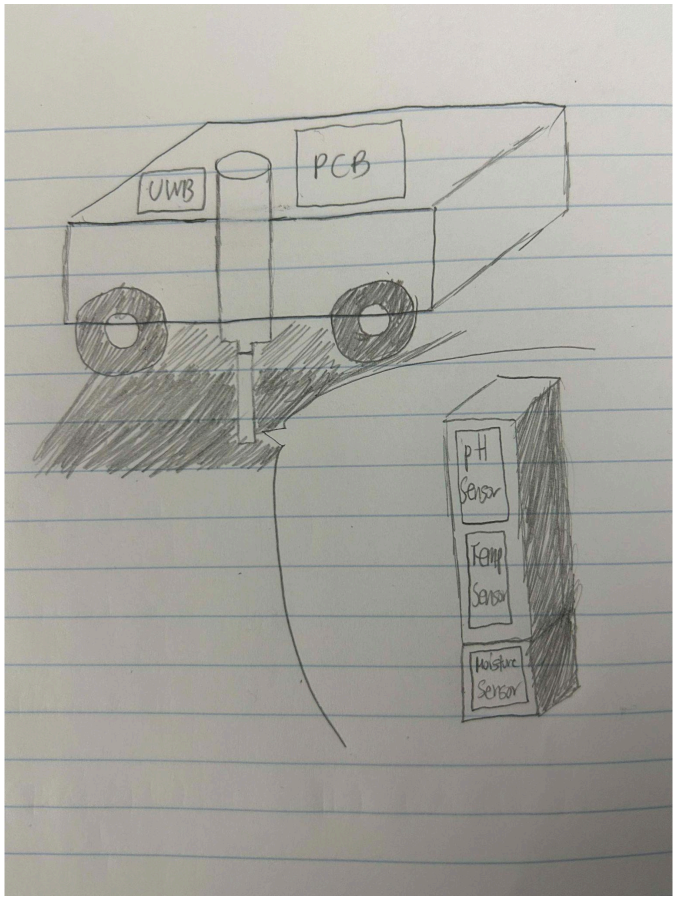
Our project offers an autonomous soil monitoring rover that can be calibrated by the user through a React application. The user will be able to specify the plot size and soil monitoring interval, and the rover will plan its motion across the field, following this plan using measurements from its environment. The rover will periodically take measurements of the temperature, NPK, and moisture of each interval and formulate a soil quality profile to inform the user's treatment of the soil. Many existing solutions are built into industrial tractors so this provides the same utility for smaller gardens. Additionally, the rover moves instead of the aforementioned probes which do not.

Visual Aid



Crop Field


UWB Anchor
UWB Anchor
PID Control Loop
UWB Anchor
Temperature
NPK
Moisture
USB Connection
React Application
Heatmap

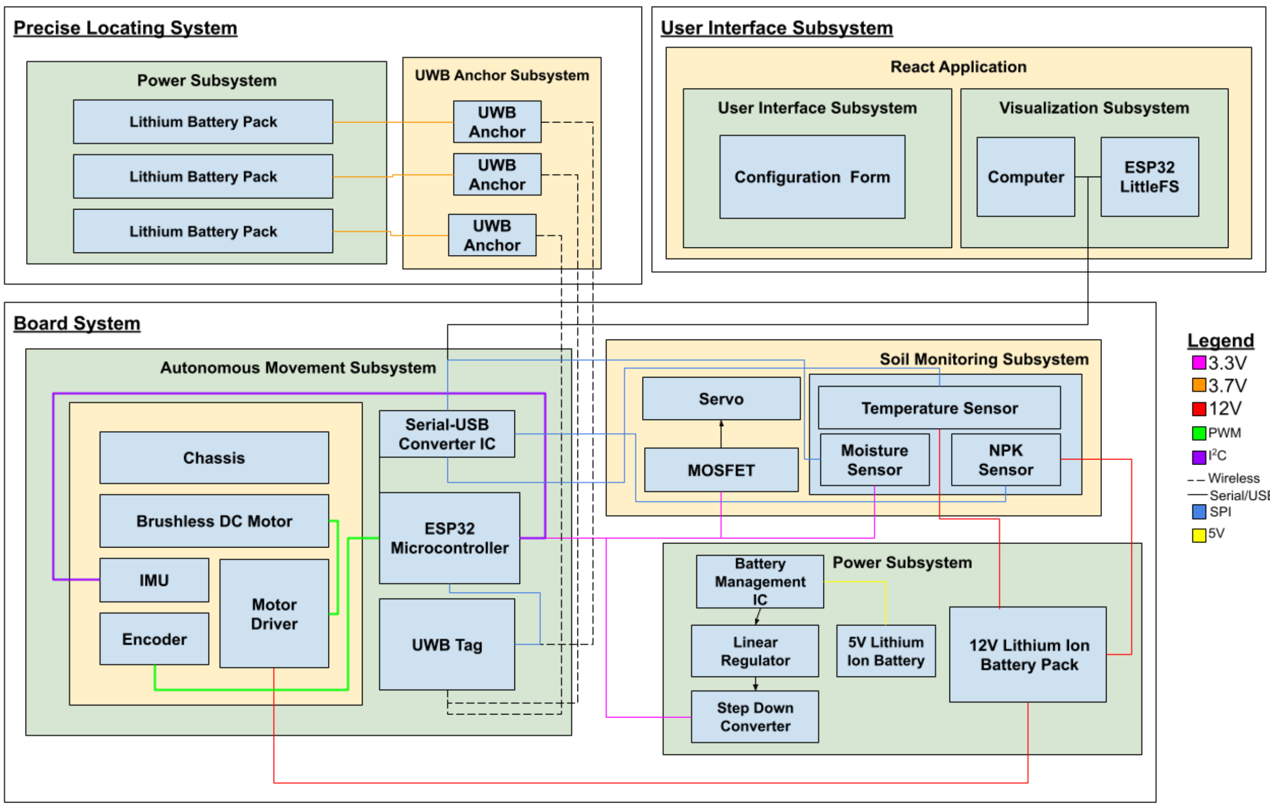


High Level Requirements

- Root Mean Squared Error(RMSE) of 20% of the predefined motion plan based on PID control algorithm and time-of-flight corrections.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (Predicted_i - Actual_i)^2}{N}}$$

- Soil Monitoring Subsystem should be accurate within 25% for all moisture, pH, and temperature measurements compared to stationary probes used as reference.
- Users are able to input plot dimensions and intervals through React application and flash this configuration to the rover within 2 minutes. Users are able to retrieve and observe soil quality profile in web application in 2 minutes upon retrieving rover.



Subsystem Overview: A brief description of the function of each subsystem in the block diagram and explain how it connects with the other subsystems. Every subsystem in the block diagram should have its own paragraph.

Precise Locating System: This subsystem is responsible for tracking the rover's position using Ultra-Wideband (UWB) technology. The UWB anchor system comprises multiple anchors placed in a grid-like fashion that communicates with a UWB tag in the Autonomous Movement Subsystem, ensuring precise location tracking on the garden/grid plot. The anchors rely on power from the Lithium Ion battery packs which are needed to provide independent power to the anchors placed apart from the rover. The location data gathered here is critical to coordinating the rover's autonomous movement and functionality.

User Interface Subsystem: This subsystem includes a React Application that allows users to interact with the plot settings and visualize the garden data depending on where the rover probes the ground. There are two parts to this subsystem: the user interface subsystem and the visualization subsystem. The user interface subsystem comprises the Config Form for setting the plot parameters. The Visualization Subsystem displays the data and feedback through a computer display and utilizes the ESP 32 LittleFS library to store and manage data. This subsystem is crucial for the user to monitor, configure, and control the rover effectively as it interfaces with the other subsystems through the ESP32 microcontroller.

Autonomous Movement Subsystem: The movement subsystem is driven by a Brushless DC Motor, Motor Driver, and supporting components like the IMU (Inertial Measurement Unit) and Encoder to track the position and speed. The ESP32 Microcontroller manages these components, and the UWB Tag interfaces with the Precise Locating System for location tracking of the rover. The combination of the motor control and the interfacing with the Precise Locating System enables the rover to move autonomously while performing tasks like soil monitoring.

Soil Monitoring Subsystem: This subsystem is equipped with various sensors attached to the linear actuator, including temperature, moisture, and NPK sensors, to collect data on soil conditions. The ESP 32 Microcontroller then manages this data, with a Servo motor controlled by a MOSFET for precision actions like probing the ground.

Power Subsystem: The power requirements for the various components on the rover will be managed and sent from the subsystem. This includes a 12V Rechargeable Lithium-Ion Battery Pack connected to a Battery Management IC. Power is then distributed using a Step-Down converter and Linear Regulator to supply 3.3V, 3.7V, and 12V to components such as the sensors, motors, and IC chips. It also ensures the stable and safe operation of the rover by powering each subsystem and protecting the battery from overcharging or over-discharging.

Precise Locating System:

- **Block Description:** The system ensures the rover's exact position within the garden/plot of land using the Ultra-Wideband (UWB) technology. The anchors work hand-in-hand with the UWB tag that is mounted on the rover, calculating the distance through time-of-flight measurements.

- **Interfaces:** The UWB anchors communicate wirelessly with the UWB tag, and the battery packs in the Power Subsystem supply the power.
- **Requirements:** The UWB system must achieve a position accuracy of at least a meter. The battery packs must also provide at least 3.7 V, and the anchors will have an internal power management system to handle for current and step downing of voltage if required.

User Interface Subsystem:

- **Block Description:** There are two sides to the user interface system. First is the user input, which allows the user to input the dimensions of the field and the distance interval between measurements. Second is the visualization, which occurs after the rover is done traversing the field. The rover will store all the data on board and once it is done, the data can be transferred to our web application.
- **Interfaces:** Transfer between laptop and rover will be done through USB-Serial conversion.
- **Requirements:** The rover should be able to correctly recognize the user input, which we can verify by printing logs on our rover. Additionally, the rover must successfully transfer data to the web application, which we can verify visually by comparing data stored on the rover to the data received in the web application.

Autonomous Movement Subsystem:

- **Block Description:** The movement subsystem is driven by a Brushless DC Motor, Motor Driver, and supporting components like the IMU (Inertial Measurement Unit) and Encoder to track the position and speed. The ESP32 Microcontroller manages these components, and the UWB Tag interfaces with the Precise Locating System for location tracking of the rover. The combination of the motor control and the interfacing with the Precise Locating System enables the rover to move autonomously while performing tasks like soil monitoring.
- **Interfaces:** The movement subsystem interfaces with the Precise Locating System (via the UWB tag) and the Power Subsystem (providing 12V to the motor and 3.3V to the microcontroller). Motor commands are generated based on the sensor inputs from the IMU and the encoder. The Serial-USB Converter IC has runs of a USB/serial protocol to connect to the computer and ESP32 Little FS library.

- **Requirements:** The brushless DC motor must receive a continuous 12V supply to reach the highest torque outputs. The IMU must track positions and speed changes with a 20% accuracy. The motor driver should also be able to handle peak current output.

Soil Monitoring Subsystem:

- **Block Description:** The soil monitoring system will consist of the temperature, NPK and moisture sensors, attached to the end of a linear actuator. Once the ESP32 provides a command to sample the area, the linear actuator will insert the sensors into the soil and sensor readings will be recorded by the ESP32.
- **Interfaces:** SPI connection between sensors and ESP32.
- **Requirements:** The temperature and NPK sensors will rely on the 12V power supply. The moisture sensor will rely on the 3.3V output from the linear regulator.

Power Subsystem:

- **Block Description:** The subsystem supplies stable power to the rover's electronics, including the motor, sensors, and microcontroller. The subsystem comprises a Rechargeable 12V lithium-ion battery pack, a 5V battery pack, a step-down converter, a battery management IC, and a linear regulator to provide the required and safe voltage levels for the various components.
- **Interfaces:** It provides 12V to the motor and motor driver, 5V to the step-down converter, and to the other components and sensors for the soil monitoring subsystem and the autonomous movement subsystem
- **Requirements:** The power subsystem mus.t deliver 500mA at 5V and 12V to most components of the rover. The step-down converter must efficiently convert 5V to 3.3V to its sensors.

Tolerance analysis

Using the LM1117 linear regulator, we can calculate the junction temperature to see if it is reasonable. Only the ESP32, moisture sensor, and IMU require 3.3V input from the linear regulator.

ESP32 Current Draw: 500mA

Moisture Sensor Current Draw: 15mA

IMU Unit: 7.3mA

$$T_j = i_{out}(v_{in} - v_{out})(\Theta_{ja}) + T_a$$

Variable	**Value**
max(T_j)	150C
i_{out}	515mA
v_{in}	5v
v_{out}	3.3v
Θ_{ja}	23.8 C/W
T_a	Assume around 38C

$T_j = 0.515(5 - 3.3)(23.8) + 38 = 58.84$, which is within our operating range.

The MPU6500 has a tolerance level of ±3%. We can do analysis to see how this would affect our predicted position of the rover.

$$d = \frac{1}{2}at^2$$

$$d_e = \frac{1}{2}(0.03)at^2$$

Let us assume an acceleration of $5m/s^2$ for $1s$

The maximum error in distance would be $d_e = \frac{1}{2}(0.03)(5)(1^2) = 0.075m$

Ethics and Safety:

The Autonomous Gardening Rover project raises a few ethical and safety concerns that must be addressed during the robot's development and use cases. These issues include compliance with safety standards, responsibility for technology and data, and considerations for environmental impact. This project aligns specifically with the IEEE Code of Ethics and ACM, particularly by prioritizing safety, environmental sustainability, and responsible use and privacy of data. However, some inherent potential ethical breaches must be avoided and assessed.

One of the main issues that we will address is **data privacy**. The soil quality data collected by the rover should only be used for soil monitoring for its plot of garden and land. Misusing this data, such as sharing it without the user's consent, would violate ethical standards, especially regarding data security in the ACM 1.6 Code of Ethics [7]. To address this, if our product were to be commercially produced, we would need to ensure our software is protected by proper encoding and firewall.

Environmental responsibility is also a main concern in the Code of Ethics. As a device used in outdoor environments, the rover should not harm the surrounding ecosystem. Its operation should not result in environmental degradation, such as chemical spills or soil contamination, as referred to in ACM 1.1 Code of Ethics [7] and IEEE Code of Ethics I-1 [8]. To address this, we will have to ensure that our rover has a low failure rate, as the robot contains components such as batteries that can harm the environment. We will use a battery management IC to ensure the batteries do not fail and cause harm to the environment. Additionally, we will have to design the rover to use rechargeable batteries so that it can rely on renewable energy sources.

To further mitigate safety concerns associated with our project, we will reference established safety procedures outlined on the MIT website for lithium batteries [9], which include guidelines for handling batteries. Our design decisions will be justified to demonstrate that they sufficiently protect users of the product and the designers from unsafe conditions arising from the project. These measures will ensure that our rover operates safely in various environments, minimizing risks to people, wildlife, and the ecosystem while maintaining compliance with safety standards.

Citations:

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[2] "ESP32 UWB(Ultra Wideband)," *Makerfabs*. https://www.makerfabs.com/esp32-uwb-ultra-wideband.html

[3] "The PID Controller & Theory Explained," *Ni.com*, 2024. https://www.ni.com/en/shop/labview/pid-theory-explained.html?srsltid=AfmBOook93h03_PQdVQa59aJ5dJax06Y5kuDwhY26GM03lREoaMBLiCG

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[6] "MPU-6500 | TDK." https://invensense.tdk.com/products/motion-tracking/6-axis/mpu-6500/

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[8] "ACM Code of Ethics and Professional Conduct," *Association for Computing Machinery*, Jun. 22, 2018. https://www.acm.org/code-of-ethics

[9] "Lithium-Ion Battery Safety Guidance," MIT EHS. Available: https://ehs.mit.edu/wp-content/uploads/2019/09/Lithium_Battery_Safety_Guidance.pdf

[10]"Troubleshooting, Maintenance Techniques, and Installation Requirements of Soil Moisture Sensors," *Niubol.com*, 2023. https://www.niubol.com/Technical-Support/Soil-Moisture-Sensors-Techniques.html