

MEMO

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Date: 4/1/2025

Subject: Safety **Check 3** (Down2Earth: TerraProbe and 11:30AM to 1:20PM T & TH)

Project Title: TerraProbe

We intend to build TerraProbe, a soil sampling robot designed for small-medium size agricultural farmers. The system will efficiently burrow into the soil through rack and pinion mechanism, extract samples at various depths, and provide real-time data through an integrated dashboard, displaying critical soil properties such as NPK (Nitrogen, Phosphorus, Potassium Concentrations) and moisture. Our vision is to revolutionize soil sampling and monitoring by delivering an on-demand, portable, and labor-efficient solution that offers real-time analytics across different soil depths. The device will not only provide a method to accurately excavate and extract soil samples but also provide data on-site instead of requiring testing at the lab. We will be using a pinion rack mechanism to provide force to dig through the soil.

a. Brief description of the experiment(s)

What machine will you be testing/operating – describe it.

What specific tests do you propose?

The experiment involves testing and operating two machines: TerraProbe and the Soil Testing Probe. TerraProbe is a compact, motor-controlled soil sampling device (10" W × 12" L × 17" H, 35 lbs) designed for multi-depth soil collection. It uses a rack and pinion mechanism powered by two 12V DC motors to drive the soil-collecting payload into the ground. Ball bearings ensure smooth motion, while a limit switch prevents over-extension. Foldable foot pedals allow for added force in dense soil, and a removable top lid simplifies maintenance. The Soil Testing Probe is integrated into the inner payload chamber and analyzes soil moisture, Nitrogen, Phosphorus, and Potassium in real time. It features five horizontal slits for multi-depth analysis without disturbing the soil profile. TerraProbe's frame and structural components will be water jet cut from sheet metal, while welding is used for assembly and milling and lathe work for refinement of mechanical components. The Soil Testing Probe casing and select mounts will be 3D printed for lightweight durability.

The testing process will begin by validating individual components, including motors, controllers, and sensors. The motors will be tested for speed control and closed-loop performance using PWM signals and PI controllers. Once assembled, the motor-pinion-rack system will be tested in a tub (~18" tall) filled with potting soil to ensure the system provides enough force to move the racks up and down smoothly, effectively penetrating the soil. The Soil Testing Probe's sensors will be calibrated and integrated into the probe before being tested in controlled environments to ensure accurate measurements of moisture, Nitrogen, Phosphorus, and Potassium. The probe will then be inserted into soil for real-time measurement validation and data transmission tests.

After validating individual components, the full system will undergo integration testing. This will include environmental stress testing in different soil types (loose, sandy soil and dense, clay-like soil) to ensure system performance under varied conditions. Performance metrics such as depth of penetration, force applied, and sensor accuracy will be assessed. The system will be placed in a controlled soil environment to simulate real-world testing scenarios.

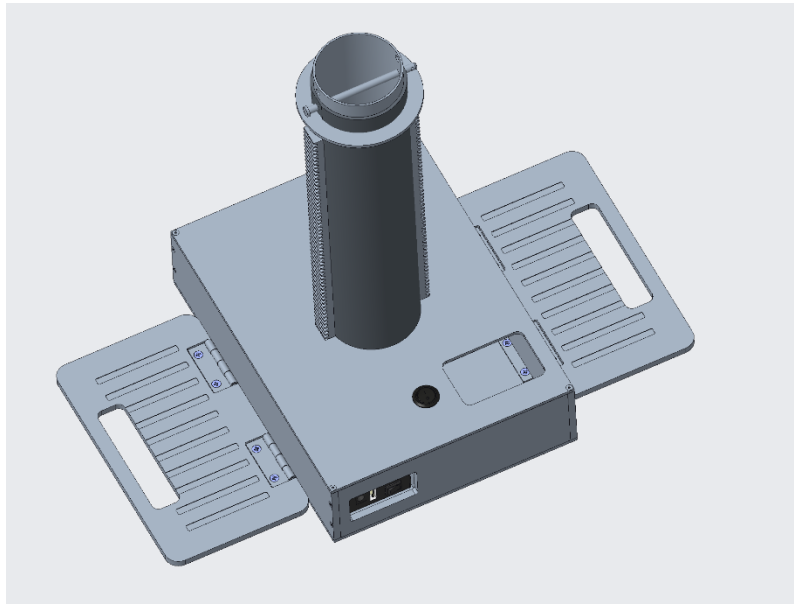


Figure 1: TerraProbe Assembly



Figure 2: Inner & Outer Payload

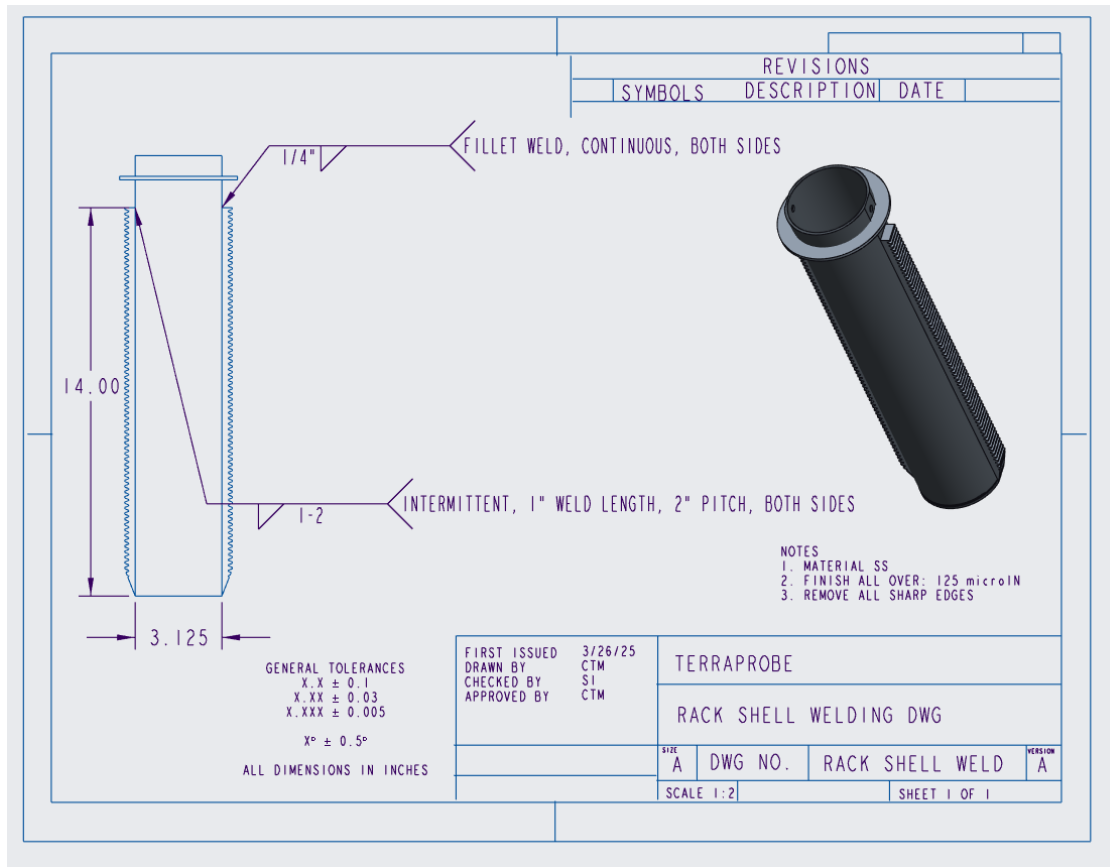


Figure 3: Rack-Shell Welding Drawing

b. Is the experiment safe?

List all potential risks

Present what you have done to mitigate the risks

The experiment has been assessed for potential risks using a Failure Mode Effects Analysis (FMEA). One major risk is motor overheating, which could lead to motor failure or reduced lifespan due to excessive torque demand or prolonged use. To mitigate this, we added thermal some ventilation, along with an automatic stop / e-stop function that after 10 minutes of continuous operation. Sensor failures—such as issues with the moisture or NPK sensors—could result in inaccurate data or total failure of data collection. To address this, we ensured secure wiring by soldering connections for easy maintenance. Soil water ingress poses a risk to the device's electronics, potentially causing malfunctions. This was mitigated by ensuring that electronics are elevated and protected from soil contact so separate mounts and casings were created to house electronics. Loose screws or inadequate welding could result in component detachment or system failure due to vibration or poor assembly. To mitigate this risk, we used thread-locking compounds to secure screws and applied proper welding techniques such as intermittent weld to reinforce critical joints. These measures ensure the TerraProbe and Soil Testing Probe maintain structural integrity, enabling reliable and safe operation under real-world conditions. Additionally, excessive wear and tear or scraping of gear teeth could lead to reduced efficiency or failure of the gear mechanism, especially under high loads or with poor lubrication. To mitigate this, we will perform lubrication procedures and have already done gear theoretical failure analysis with high factor of safety. Additionally, we are using hardened steel gears with high strength to enhance durability and minimize wear. With respect to the casing and payload, improper alignment between the inner and outer

payload could cause jamming, uneven penetration, or the inner payload falling out due to tolerancing issues. To address this, we focused on precise assembly tolerancing and selected high-yield materials for better durability. Furthermore, we improved the assembly process and designed a small slit/insert for easy access to the inner tube, reducing the risk of misalignment and enhancing operational efficiency.

c. How and where will the experiments be conducted?

Start-up and shut-down procedures (design a check-list if needed)?

Who will conduct the experiments?

Where will the experiments be conducted?

(If outside of PEARL Labs, include a written statement from the owner of the space describing what you will be doing and giving you permission to do it in their space)

The experiments will be conducted in the PEARL Labs, which provide the necessary infrastructure for both mechanical and electrical testing of TerraProbe and the Soil Testing Probe. Testing activities will include verifying motor functionality, sensor calibration, and the integration of components such as the probe and soil testing sensors. The final product, including the motor, gear, rack, and shell system, will also be tested in the lab. The device, measuring approximately 10" wide, 12" long, and 17" tall, will be tested by placing a bucket of soil into the lab, and running the system to verify if the rack moves up and down and adequately burrows the soil that is inside the tub.

The experiments will be conducted by the project team, consisting of us as students, who are responsible for assembly, testing, and data collection. Start-up procedures will involve checking wiring connections, ensuring motor and power system functionality, calibrating sensors, and verifying probe integration. Shut-down procedures will include powering off electrical components, disassembling the setup, cleaning the area, and inspecting for any potential issues like overheating or system malfunctions. All experiments will follow PEARL Labs' safety and operational guidelines, with additional space or equipment requirements being coordinated with lab management. If deemed appropriate, we can also test outside in the ME building gravel area which is typically used for spray painting. This might provide us with more space to test the soil and avoid any soil spills.

d. General safety questions

Where are fire extinguishers and how do you use them?

What constitutes an emergency (see course safety documents)?

What should you do in case of an emergency (see course safety documents)?

Fire extinguishers are in each PEARL lab room. To use, we should follow the PASS method: Pull the pin, Aim at the base of the fire, Squeeze the handle, and Sweep from side to side. An emergency is any urgent situation where immediate action is required, either due to medical injury or property damage. This includes scenarios where professional help is needed to prevent further harm or damage. For medical or non-medical emergencies, we should call 911 immediately and stay with injured person until help arrives or leave the area if it's unsafe.