Comparative Performance of Four Soil Moisture Sensors in Arid Conditions: Low-Cost and Commercial Options

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This do-it-yourself guide details how to build a low-cost soil moisture logging system. The design includes three main units: a power unit, a sensing unit, and a control unit. The power unit consists of a 6V solar panel charging a 3.7V 60000 mAh LiPo (18650) battery through an Adafruit LiPo charger. Power boosters including TPS61023 and TPS61040 are used to supply 5V and 12V outputs, respectively. The sensing unit features four sensors: low-cost sensors (TR-HTSE, DFRobot 1, DFRobot 2, and Dracal I2C-M8-TRH320) and a commercial Acclima TDR-305N. This guide provides instructions to replicate the system and produce data referenced in this brief paper. The Arduino code is available in our GitHub repository.

GitHub repository: https://github.com/OnanAgaba/low-cost-soil-moisture-datalogger

The schematic design of the low-cost soil moisture logging system is illustrated in Figure 1.

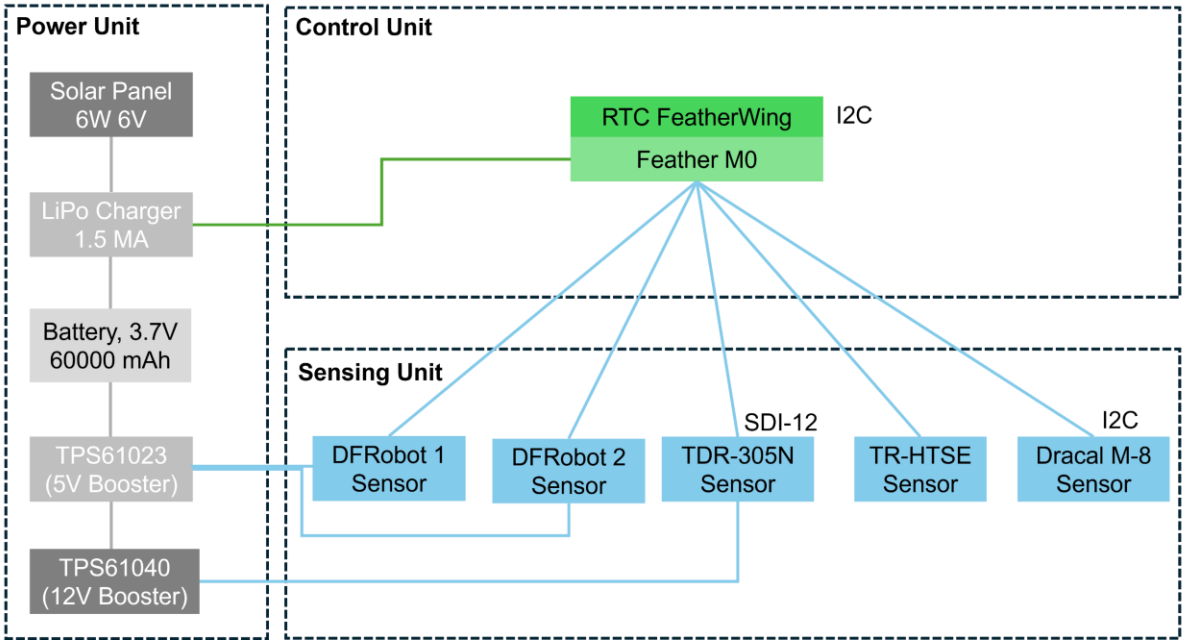

Figure 1: Main units of the system

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1. Hardware

1.1 Components

Table 1 summarizes the hardware components, specifications, and costs for the system's control, sensing, and power units.

Table 1: Hardware components, costs and their specifications

Component	Dimensions (mm)	Mass (g)	Protocol	Quantity	Cost (USD)
Hardware components for the control unit					
Feather M0	51 x 23 x 8	5.3	Serial, I2C, SPI	1	19.95
FeatherWing	50.8 x 22.9 x 1.6	5.1	I2C, SPI	1	8.95
Hardware components for the sensing unit					
TDR-305N	150 x 33	121	SDI-12	1	322.00
TR-HTSE	145 x 45 x 15	1800	FDR	1	59.00
Dracal I^2C	1800	80	I2C	1	71.99
DF Robot 1	175 x 30	15	Capacitive	1	18.90
DF Robot 2	175 x 30	15	Capacitive	1	18.90
Grove ADC	-	-	I2C	1	11.60
Hardware components for the power unit					
TPS61023	17.8 x 11.3 x 5.6	1.0	-	1	3.95
TPS61040	15.2 x 10.0 x 2.9	0.1	-	1	2.95
Solar Panel	110 x 140	90	-	1	34
LiPo Charger	-	-	-	1	14.95
LiPo battery	69 x 54 x 18	155	-	1	24.50
Grand Total					**611.64**

1.2 Hardware Preparation

1.2.1 The Control Unit

Step 1: Preparing the Adalogger Feather M0

- Solder long-legged male and female header pins onto the Feather M0 microcontroller to enable stacking with other modules and easy sensor connections.

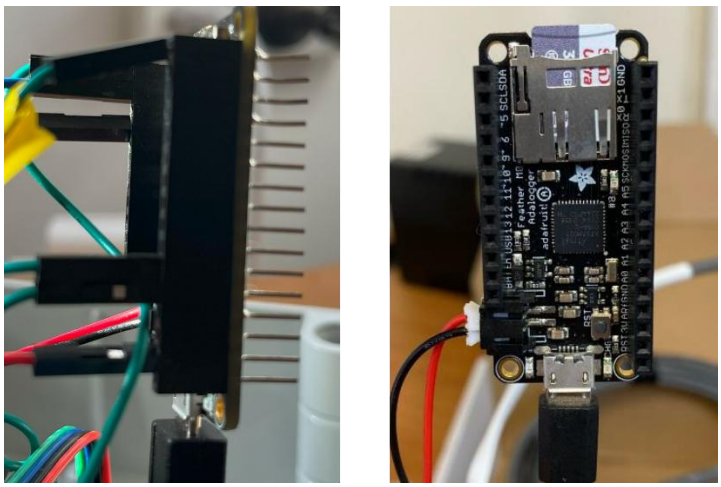

Figure 2: Feather M0 soldered with both female header and long-legged male pins

Step 2: Preparing the Adalogger FeatherWing RTC

- Solder female headers onto the FeatherWing RTC to allow stacking with the Feather M0.
- Insert a coin-cell or small-size backup battery into the RTC module to maintain timekeeping during power interruptions.

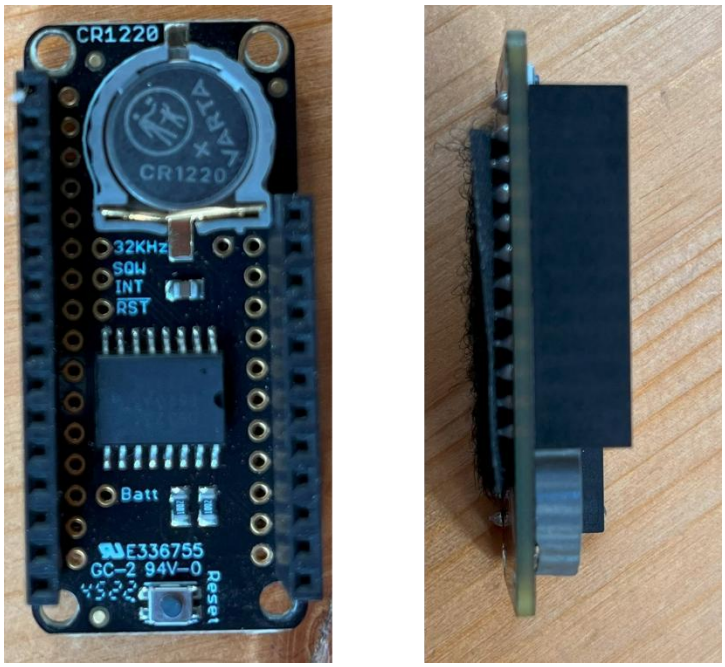

Figure 3: FeatherWing soldered with female headers

1.2.2 The Sensing Unit

Step 1: Prepare the Acclima TDR-305N sensor

- The Acclima TDR-305N has three wires:
    - Red: Power
    - Blue: Data
    - White: Ground (GND)
- Solder each wire to a male pin. These pins will be used to connect the sensor to the control unit

Step 2: Prepare the Dracal I2C-TRH320 sensor

- The Dracal I2C-TRH320 has four wires:
    - White: SCL
    - Black: SDA
    - Brown: Power
    - Blue: Ground (GND)
- Solder each wire to a male pin. These pins will be used to connect the sensor to the control unit

Step 3: Prepare the DFRobot SEN0308 sensors

- The DFRobot SEN0308 has four wires:
    - Red: Power
    - Yellow: Analog
    - Black: Ground (GND)
- Solder each wire to a male pin. These pins will be used to connect the sensor to the control unit

Step 4: Prepare the TR-HTSE sensor

- The TR-HTSE has four wires:
    - Red: Power
    - Blue: Output signal 1
    - Brown: Output signal 2
    - Black: Ground (GND)
- Solder each wire to a male pin. These pins will be used to connect the sensor to the control unit.

1.2.3 The Power Unit

Step 1: Connect the solar panel to the LiPo charger

- Cut and strip the solar panel cable. If needed, extend the cable to fit your setup by soldering the red (power) and black (ground) wires to matching wires on an extension.
- Connect the solar panel to the 1.5A USB solar LiPo charger using compatible male-female connectors.

Step 2: Connect the LiPo charger to the LiPo battery and Feather

- Connect a 3.7V 60000 mAh battery to the "LiPo Batt" port using a JST PH 2-pin male connector.
- Connect the Adalogger Feather M0 to the "Load Out" port using another JST PH 2-pin male connector.
- Insert a switch on the red (positive) wire between the charger and the Adalogger Feather M0 to control power flow.

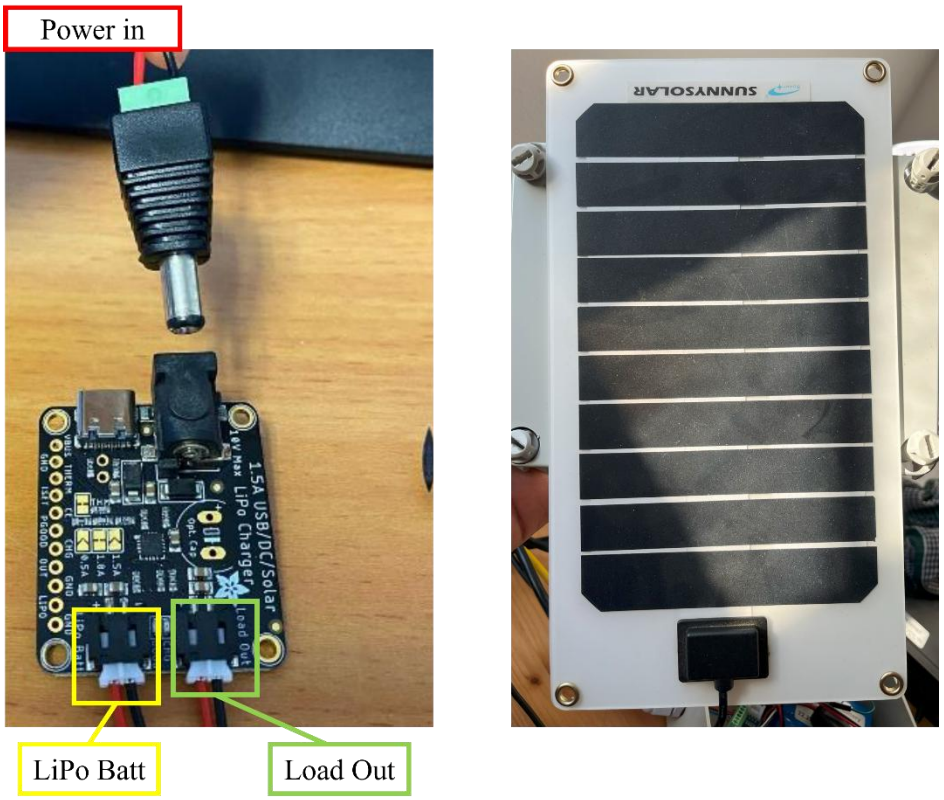

Figure 4: On the left is the1.5A LiPo charger and on the right is the 6V solar panel

Step 3: Prepare the Boosters

- Two power boosters are used in the system: a 12V booster (TPS61040) for the TDR sensor and a 5V booster (TPS61023) for the DFRobot sensors. Each booster has three ports:

- Vin: Power Input
- 12V or 5V: Output Voltage
- GND: Ground

- Solder wires to each port, then solder male pins to the other ends of the wires. These pins will connect the boosters to the power source and sensors within the control unit.

Figure 5: The two boosters used; on the left is 12V booster and 5V booster on the right

1.3 System Assembly

To reduce complexity during setup, connect and test each sensor individually before assembling the complete system. Ensure that each sensor's pins are correctly wired to the appropriate ports on the Feather M0 microcontroller. Initially, power the Feather M0 via USB connected to a computer. Add one sensor to the microcontroller at a time.

Step 1: Connect the Acclima TDR-305N sensor to the Feather M0

- Connect the blue (data) wire to port D6 on the Feather M0.
- Connect the white (GND) wire to the GND port.
- Connect the red (power) wire to 12V, supplied through a voltage divider linked to the TPS61040 booster.

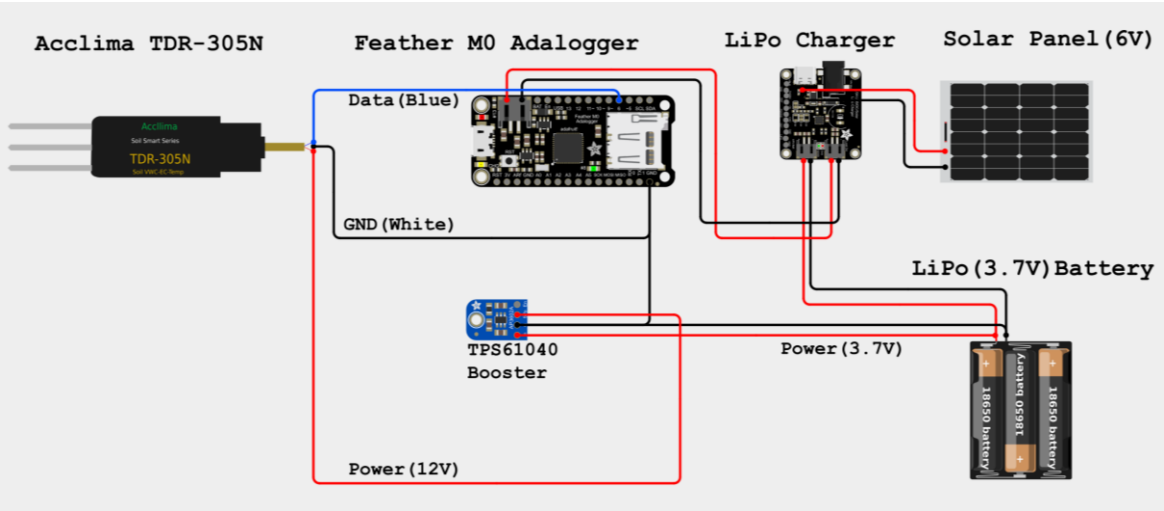

Figure 6: Connection setup for the Acclima TDR-305N

Step 2: Connect the Dracal I2C-TRH320 sensor to the Feather M0

- Connect the white (SCL) wire to SCL port on the Feather M0.
- Connect the black (SDA) wire to SDA port.
- Connect the blue (GND) wire to the GND port.
- Connect the brown (power) wire to the 3.3V port on the Feather M0.

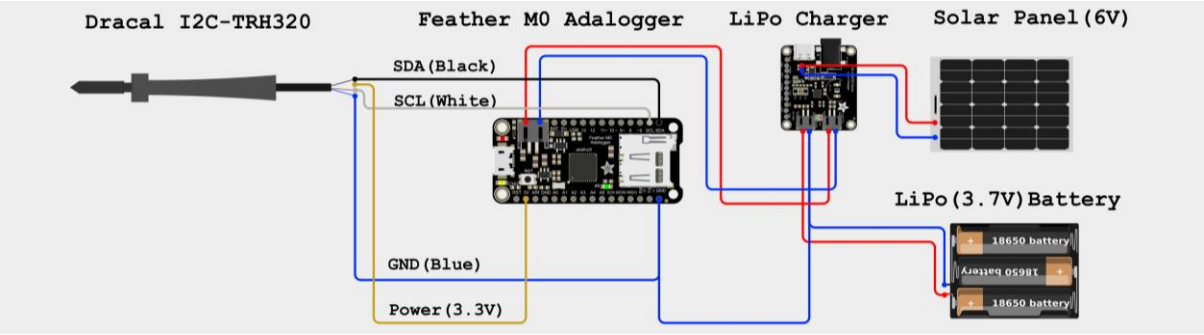

Figure 7: Connection setup for the Dracal I2C-TRH320

Step 3: Connect the DFRobot SEN0308 sensors to the Feather M0

- Connect the yellow (analog) wire to A0 (DFRobot 1) and A1 (DFRobot 2) ports on the Feather M0.
- Connect the black (GND) wire to the GND port.
- Connect the red (power) wire to 5V, supplied through a voltage divider linked to the TPS61023 booster.

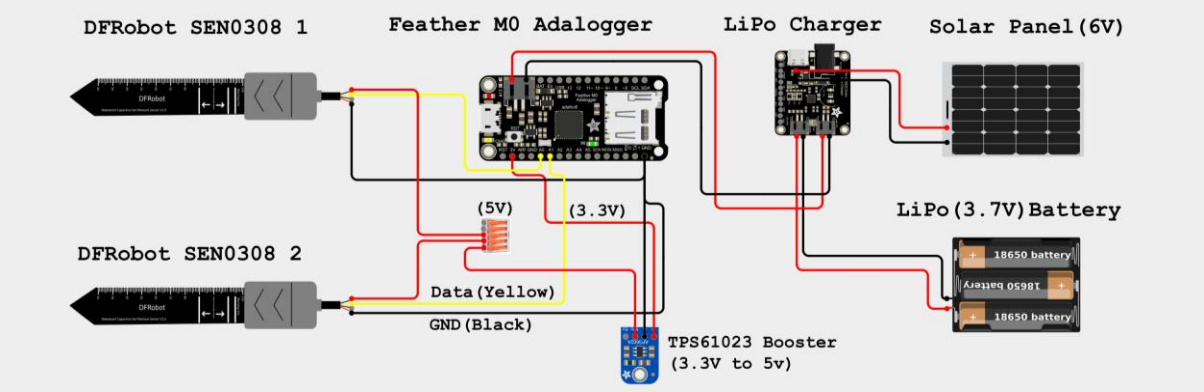

Figure 8: Connection setup for the two DFRobot sensors

Step 4: Connect the TR-HTSE sensor to the Feather M0

The TR-HTSE sensor outputs analog signals, which are converted to digital values using a Grove 16-bit ADS module before reaching the Feather M0.

1. From the TR-HTSE sensor to Grove 16-bit ADS

- Connect the black (GND) wire to GND port on the Grove ADS.
- Connect the blue (output signal 1) wire to A0 port.

- Connect the brown (output signal 2) wire to A1 port.
- Connect the red (power) wire to VCC port on the Grove ADS.

2. From Grove 16-bit ADS to Feather M0:

- Connect the SCL wire to SCL port on the Feather M0.
- Connect the SDA wire to SDA port.
- Connect the GND wire to the GND port.
- Connect the power (VCC) wire to the 3.3V port on the Feather M0.

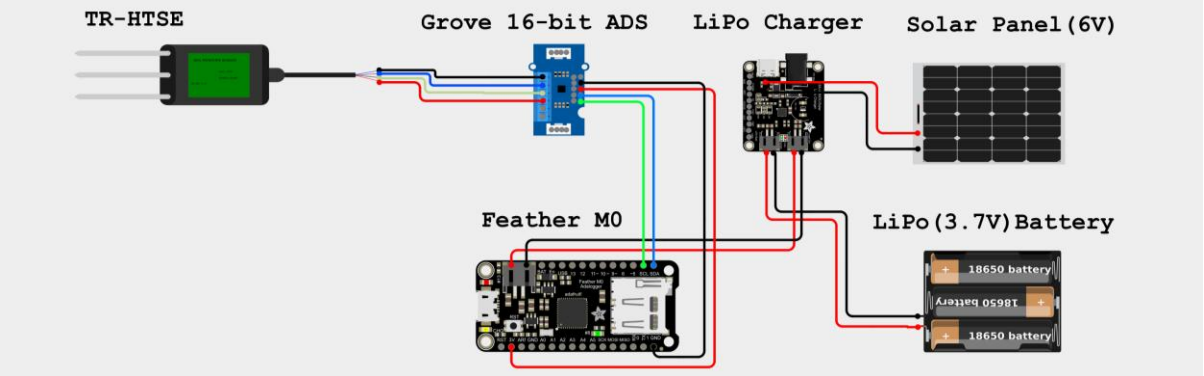

Figure 9: Connection setup for the Grove ADS and TR-HTSE Sensor

Step 5: Completing the system assembly

After all sensors are individually connected and tested, the final connection diagram and fully assembled system including the power unit, sensing unit, control unit are shown in Figure 10.

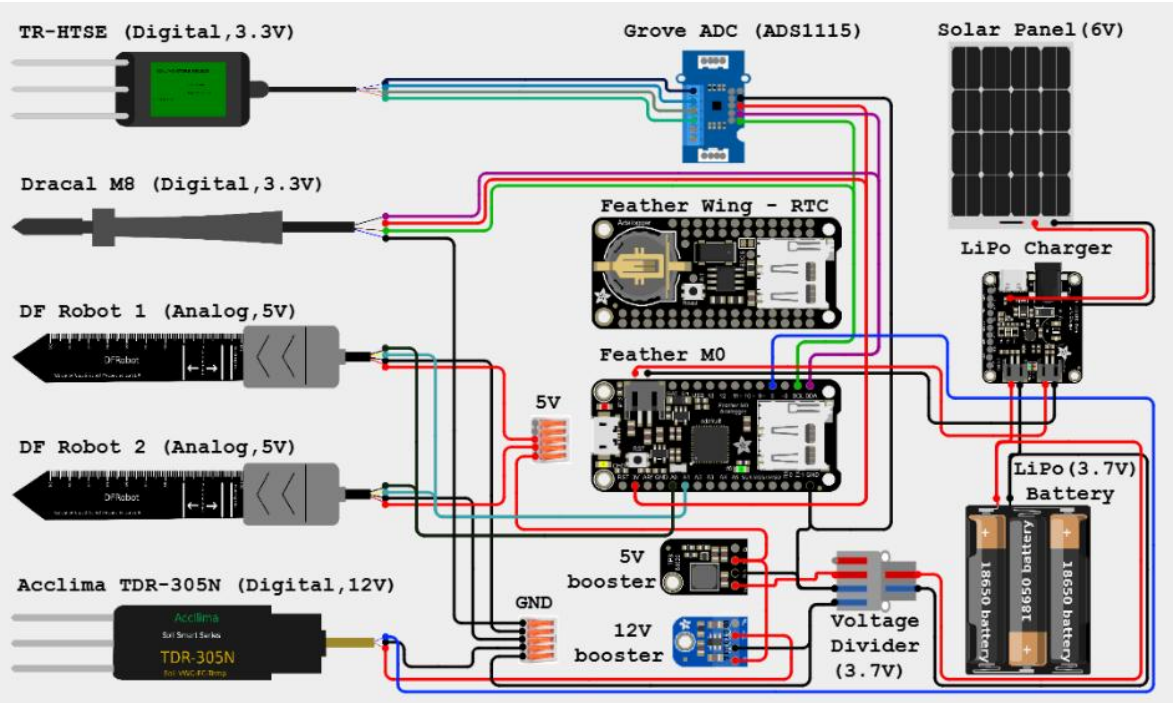

Figure 10: Complete connection diagram for system ready for deployment and data logging

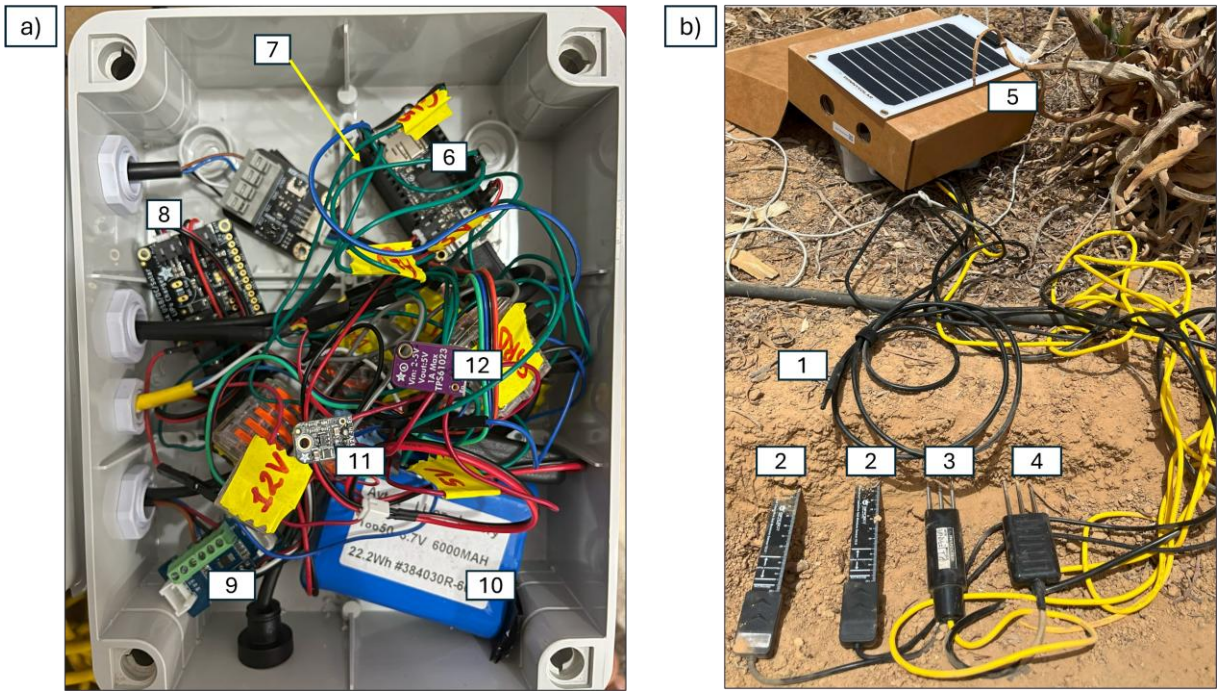

Figure 11: The soil moisture logger set-up: a) components installed in the field: 1) Dracal M8, 2) DFRobot sensors, 3) TDR-305N, 4) TR-HTSE, 5) Solar Panel and 6) Feather M0; b) internal system components housed within a protective enclosure: 7) RTC on FeatherWing, 8) LiPo Charger, 9) ADC, 10) LiPo battery, 11) TPS61023 5V booster, and 12) TPS61040 12V booster.

Step 6: Stack the Feather M0 with all sensors to the RTC FeatherWing

Carefully align the long male header pins on the Feather M0 (with all sensors connected through male pins) with the female headers on the RTC FeatherWing. Gently press them together to secure the connections, enabling proper communication and real-time clock functionality.

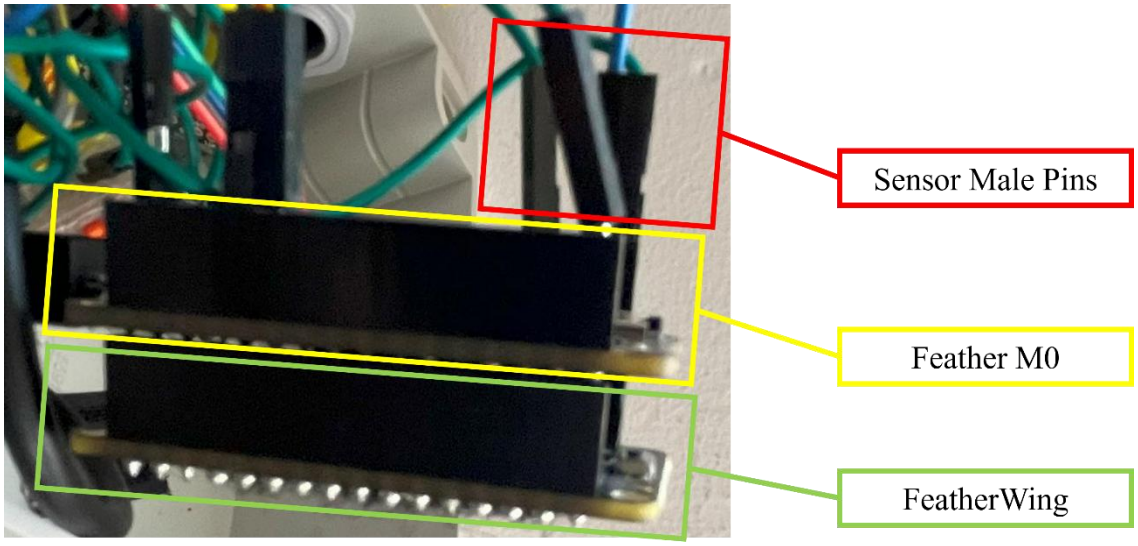

Figure 12: Stick the Feather M0 with all sensors connected to the FeatherWing

Step 7: Power the assembled system

Connect the Feather M0 to the "Load Out" port on the LiPo charger using a JST PH 2-Pin male connector. The LiPo charger powers the system and charges the 3.7V 60000 mAh battery connected to the "LiPo Batt" port through another a JST PH 2-pin male connector (Figure 4).

2. Software

The software was developed using the Arduino Integrated Development Environment (IDE), which is compatible with Windows, Linux, and macOS. The code was written in C++ using Arduino libraries and open-source resources. For each sensor connected to the Feather M0, specific code was written and tested to ensure the sensors function properly. Once all sensor codes were verified, they were combined into a single program that runs in a continuous loop, reading sensor values every 15 minutes (Figure 13) and saving the data as a CSV file on a microSD card. Individual and complete system codes, along with libraries, licenses, and logged sensor data, is available on GitHub at https://github.com/OnanAgaba/low-cost-soil-moisture-datalogger.

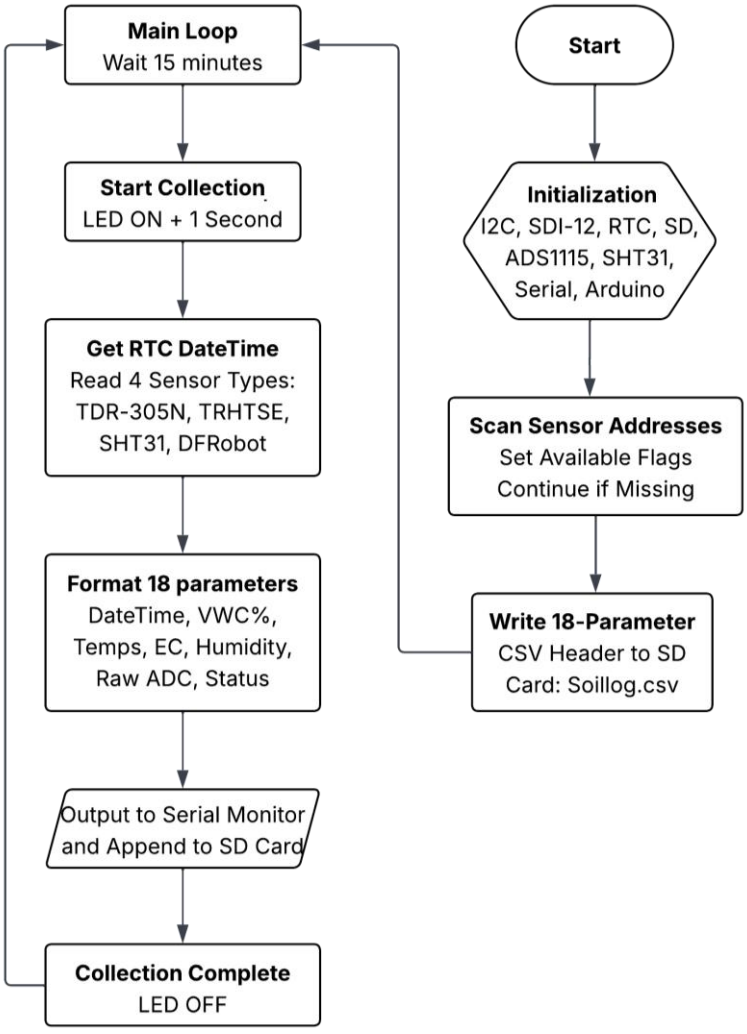

Figure 13: Soil moisture logging flow chart

Step 1: For First Time Users

These instructions guide beginners to connect one sensor at a time to the Feather M0 microcontroller and program it. Our repository also provides the individual codes.

- Connect the Acclima TDR-305N to the Feather M0 Adalogger, ensuring the sensor receives the correct voltage (12V), then connect the setup to your PC.
- Launch the Arduino IDE on your computer.
- Select the appropriate board and communication port within the IDE.
- Install the SDI-12 Arduino library in IDE.
- Open and upload the SDI-12 example sketch located at File > Examples > Examples from Custom Libraries > SDI-12 > e_continuous_measurements.
- Click Verify to compile the code. If prompted to install missing boards or libraries, install them one by one, verifying after each installation until there are no errors.
- Repeat this procedure for each sensor by installing its corresponding library and uploading the appropriate example code.
- Once you are confident that all individual sensors work properly, combine them and run complete system code available on our GitHub repository.

Step 2: For Returning Users

- Connect the Acclima TDR-305N sensor to the Feather M0 board, then connect the setup to your PC as described in the 'First-Time User' section.
- Open the Arduino IDE on your computer.
- Upload the example code to the datalogger by clicking the Upload button.
- Open the Serial Monitor to verify that the sensor readings (VWC, SoilTemp, BulkEC, PoreEC, and Perm) are displayed correctly. To observe changes, gently lower the sensor into water or insert it into the soil.
- Repeat these steps with any other sensors you are using.
- When you are confident all sensors function properly, upload and run the combined system code

3. Recommendations

- Connect all sensor grounds together to ensure proper system functionality.
- Test each sensor individually to verify both hardware connections and software operation.
- Be consistent with the manufacturer's manuals, especially to understand what each pin or port on any given component does.

- The provided code logs data every 15 minutes by default; however, this interval is configurable and can be adjusted to suit your needs.