Smart Agriculture:
Remote Monitoring of Soil Quality and Sunlight Using Embedded Sensors

Nicolas Moreno, Nazia Mehjabin, Mason Harris, Heidi Schaefer, William Mansey, Graeme Paine
Schulich School of Engineering, University of Calgary

Abstract

Achieving optimal soil health is paramount for sustaining crop productivity, particularly in remote regions facing escalating climate challenges and heightened global food demand. However, existing soil monitoring solutions often present accessibility and cost barriers for small-scale farmers. To address this, we propose an innovative and cost-effective soil monitoring system tailored specifically for remote agricultural environments.

Our integrated solution combines a suite of sensors to measure key parameters including soil moisture, fertilizer levels, surface and subterranean temperatures, light intensity, humidity, and atmospheric pressure. These data are seamlessly transmitted via LTE to a user-friendly web dashboard accessible to farmers for real-time monitoring and decision-making.

To streamline sensor integration, we have developed a custom conversion board bridging the protocol gap between the Murata soil sensor and Simply Embedded's Wrangler board. Power management is facilitated through a rechargeable battery, solar panels, and charging power boards, ensuring continuous operation. Additionally, the system is housed within a durable insulated enclosure, providing protection against environmental elements. Furthermore, this system directly interfaces with a web based dashboard via the MQTT messaging protocol for seamless data transmission. This enables users to query and visualize telemetry values efficiently, aiding in comprehensive decision-making processes in crop fields.

Introduction

The projected global population increase to 9.1 billion by 2050 mandates a 70% escalation in food production. Agriculture faces impediments due to climate change, affecting crop yields and rural economies. Despite these challenges, many farmers persist in using conventional methods, leading to diminished productivity.

Proposed solutions entail the adoption of automated systems like soil sensors, temperature sensors, and environmental sensors. These systems monitor various parameters such as soil electrical conductivity, volumetric water content, and ambient temperature, as well as sunlight levels in the natural environment. By continuously adjusting and optimizing these factors, they aim to achieve optimal plant growth, maximize yield in agricultural fields and to minimize the challenges associated with the system by minimizing human involvement as much as possible.

The system integrates multiple sensors, solar panels, an ADC, a microcontroller, and a cloud platform. If any climatic parameter exceeds a predefined safety threshold crucial for crop protection, the sensors detect the deviation. Then, the microcontroller retrieves this digital data from its input ports and enable the farmers to stay up to date on the conditions on the field and respond accordingly.

Methods and Materials

Hardware

Power Delivery: Charge Controller, Buck and Buck-Boost Converters

The Wrangler board operates on two different voltage rail levels; 3.3V and 1.8V. A buck-boost and buck converter have been implemented for each of these voltage levels respectively. The converters ensure that the voltage output from the charge controller matches the requirements of the rails by stepping it down (bucking) or boosting it up, maintaining stable and efficient power conversion. Our chosen charge management controller, the ST SPV1040, includes MPPT functionality, adjusting its operating voltage and current to keep the solar panels operating at their optimal power output, maximizing energy harvest. The controller and converters additionally offer features like overvoltage and overcurrent protection, safeguarding the system and contributing to its stability under varying conditions.

Battery Charging (CCCV)

Constant current constant voltage. The lithium battery charges at a constant current until the cell voltage reaches 4.1V. The voltage remains constant while the current decays to 10mA, at which time the end of charge protection kick in. The SPV1040 uses MPPT to charge the battery regardless of solar panel fluctuations for consistent energy storage.

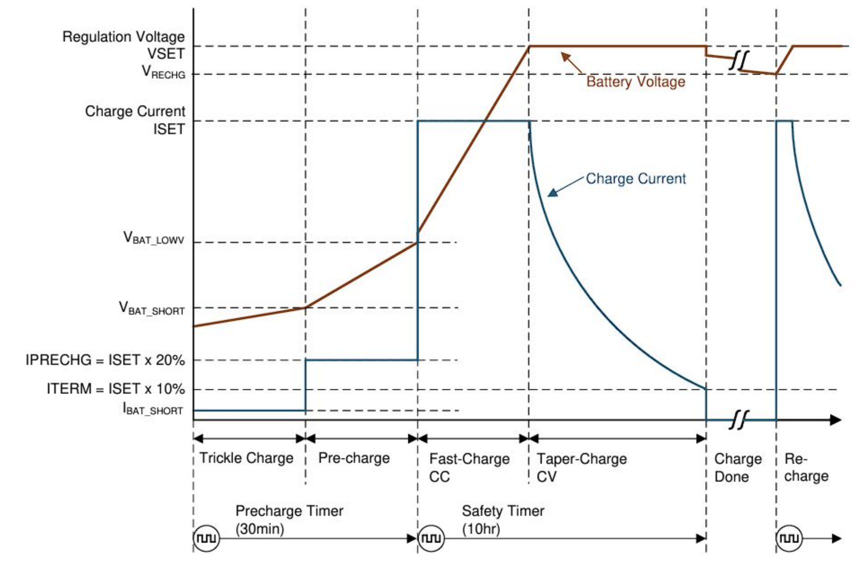


Figure 1: Battery charging profile.[1]

Fuel Gauge

The inclusion of a fuel gauge is pivotal for effective energy management.
The STC3100 monitors the critical parameters of a single-cell Li-Ion battery (voltage, temperature and current) It interfaces with the solar charging circuit to monitor the parameters of the battery. This ensures efficient utilization of solar energy while maintaining optimal battery health for sustained agricultural productivity.
Monitors the state of charge (SoC) and health of the battery, ensuring continuous operation by providing real-time data on available energy reserves.

SP3485-based UART to RS485 Converter

The SP3485 is a low-power RS-485/RS-422 (UART TTL) transceiver. This chip supports Electromagnetic Interference (EMI) sensitive and long-distance (up to 4000 feet) applications. This converter is designed to obtain data from the Murata SLT5007 soil sensor using the RS-485 protocol and then send the obtained data to the Rodeo Board over the RS-422 (UART) protocol.
The 74HC04D is a 6-channel inverter. We used this chip as a buffer to isolate the Rodeo board from this converter for any external hazards caused by the sensor and this converter. This whole converter circuit will be operated with 3.3V.

Firmware

Drivers

The drivers for the three sensors were written entirely in C code. The drivers dictate communication protocols for the sensors according to manufacturer specifications and convert bytes of data received in hexadecimal format from the sensors into decimal value data figures.

Dashboard

The dashboard we are using for the display of data is hosted on Vercel and allows us to display the data transmitted for the board in a digestible format. The transfer of data between the Rodeo board and our dashboard is done using MQTT protocols facilitated by HiveMQ.

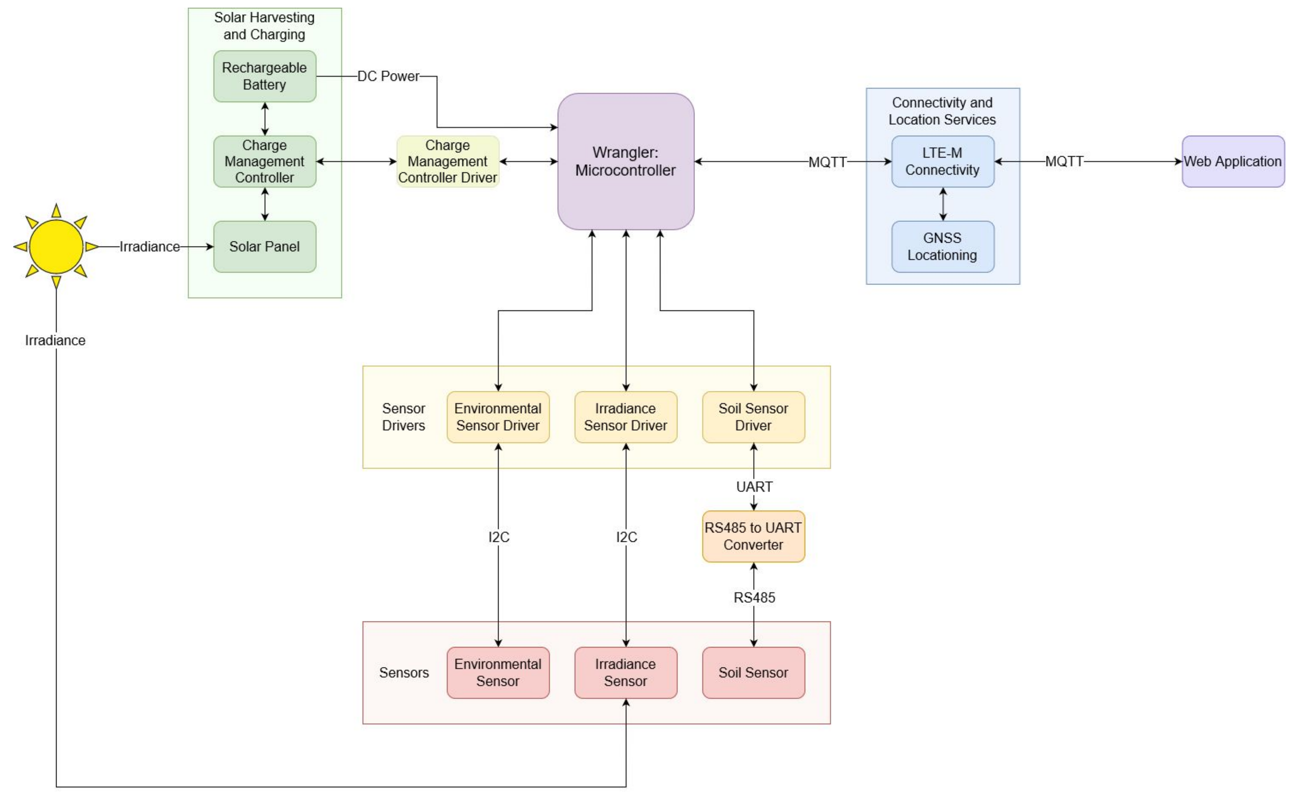
Testing and Results

Solar circuit results:

Solar Cells were confirmed to produce DC power.
The cells would produce max 41 mA at 4.1V, 171mW from a theoretical maximum of 51mA, 4.1V at 210mW.
Charge Controller was breadboarded and connected to the battery to ensure charging capability. Battery drainage was observed using a resistive load and LED. Charge controller was then fed a constant 2V input from a barrel jack and when tapped with an oscilloscope, displayed an appropriate output waveform for charging the battery back up.

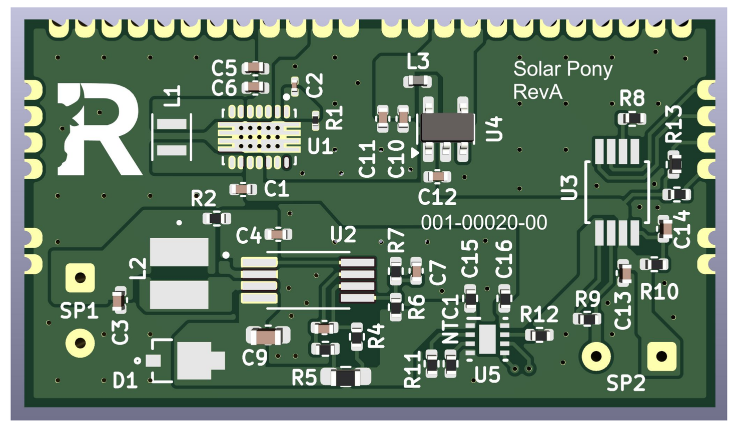
Sensor Measurements

Temperature: The underground temperature of the soil is measured by the Murata soil sensor and the surface temperature is measured by the BME688 environmental sensor.
Volumetric Water Content: Indicates the amount of water in soil, helping conserve water and optimizing irrigation.
Electrical Conductivity: Indirectly indicates the amount of nutrients available for plant uptake and salinity levels. This measurement signifies the fertilizer levels in the soil.
Pressure and Humidity: The BME688 sensor measures the local atmospheric pressure and humidity, which are aspects that are significant for the health and longevity of crops.
Light Intensity: Measures the light levels that are experienced by the crops and solar panel.



Discussion

- The system uses very small amounts of power. A solar charging module has been designed to charge the lithium-ion battery and support the operation of the system over a long period of time. Due to the system's sporadic current draw in sending out data (peaks of 1.5A for a few seconds), the battery will drain rapidly and recharge over the remainder of the day.
- We started the design from the battery out due to the temperature requirements of the battery. The Tadiran TLI-1530A was chosen due to its operating range bottom end of -40C[2].
- The acquisition of the Tadiran battery has proven to be a challenge. We have not been able to secure a unit as of yet. Therefore, we purchased a battery from Amazon as a backup option with similar characteristics. This battery does not have the same temperature rating/characteristics as our chosen battery so we will ultimately need to secure a unit of the Tadiran.



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Contact

Name: Heidi Schaefer
Email: heidi.schaefer@ucalgary.ca

Sponsor: Simply Embedded