LoRaWAN Sensor Network IoT4Ag Integration

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***Abstract*— The work contained in this paper details the integration of a LoRaWAN sensor network into an existing IoT4Ag drone base station and information system. Low power sensor nodes are designed for permanent installation and supported by wireless charging and communication. Targeted installations bury nodes 35 cm underground within a 1-mile radius from a central gateway. The nodes collect and report soil conditions and node system health data. The data transmits using a 433 MHz LoRaWAN channel to the central gateway. The gateway issues an acknowledgement packet on a 434 MHz channel and provides the drone port's mini-PC with re-packaged data using UART. The mini-PC hosts the LoRaWAN authentication server and Node Red application server. The data provides the foundation for calculating and improving the efficiency and effectiveness of the current irrigation system.**

Index Terms—

GUI	Graphical user interface
IoT4Ag	Internet of things for agriculture
LoRaWAN	Long range WAN
NPK	(Nitrogen)(Phosphorus)(Potassium)
WAN	Wide area networks

I. INTRODUCTION

IoT has been growing as a global industry for the past two decades and one of the most prominent and impactful areas of work in the industry are IoT applications for agriculture, i.e. IoT4Ag. Much of the research done so far in this flourishing sub-category of IoT has been improving processes around agricultural landscapes for managing resource use and maintenance such as tool inventory management systems and egg tracking systems. However, soil monitoring is an area with much less research due to the trouble soil causes when looking at high data rate wireless communication needed to establish a WAN that can penetrate soil with low path loss.

This is precisely the challenge we are attempting to overcome with our research into using a low power low data rate communication protocol like LoRaWAN that advertises a 10 kilometer long free space transmission distance at much lower data rates and power consumption compared to other protocols like Wi-Fi, Bluetooth, and ZigBee. For our application, it will be more important however to test how far the transmissions can be made through soil to reach a receiver above ground.

E. Previous Work

The agriculture industry needs an efficient solution for collecting, organizing, and distributing sensor data in a natural environment. In [5] sensor data is shown to provide the industry with the ability to recognize, target, and treat yield-effecting conditions. IoT4Ag is developing a system to meet this need.

In 2020, [3] published similar use of LoRaWAN in IoT4Ag for monitoring food storage. Their process differs in both external systems and environmental constraints. Like our design, their nodes transmit sensor data over LoRaWAN. The sensors monitor food storage in a powered environment, whereas our sensors will operate underground using stored power. Their wireless connection was established in Wi-Fi, whereas ours uses a Starlink modem. Eliminating the idle Wi-Fi connection allows us to achieve lower power use and operate in fully remote environments. Our ambition is to make a LoRaWAN node to operate with the lowest power consumption we can manage whilst still transmitting our sensor data at the frequency we need it.

Then just this past October in 2024, we had the privilege of visiting an existing IoT4Ag research farm in Quincy, FL with Dr. Eisenstadt and Dr. Stapleton and other IoT4Ag researchers to see the existing irrigation system management and monitoring systems. We picked up on a lot of useful and practical information about the environment the nodes will be subject to and certain design specifications that weren't apparent to us before the visit such as an adjusted burial depth of 45cm to account for the deep plows the run across the fields during the plowing process. See the image appendix file to see the fields and existing nodes deployed in the field from previous researchers.

Research paper [6] published by fellow researcher Vernon Crasto of UF's IoT4Ag group details the method of charging that we will employ to charge the nodes wirelessly through the ground. As his paper [6] states, s single rectified receiver can capture power at only an 18% loss from distance versus direct contact, generating 61 mW of power at a motor frequency of 547 Hz. With a quintuple load rectified receiving configuration, the received power jumps up to 182 mW at 490 Hz. This kind of wireless power transfer can be used in our application to charge our underground nodes since low frequency waves can penetrate soil with little signal power loss.

II. LORAWAN NODE DESIGN

The node monitors soil properties and wirelessly transmits this data to a centralized server. This goal requires a device that can remain buried for a year, is compact, has low power requirements, and supports different types of sensors.

F. Design features

- Supplies 3 voltage levels: 3.3V, 3.7V, and 12V.
- Supports a variety of sensors
- Variable battery capacity
- UART, SPI, and I2C compatibility.
- 6xADC channels.
- Large internal space for mounting sensors.

G. Power Supply Design

The Node's subsystems operate at 4 voltage levels. The STM32 microcontroller and LoRaWAN systems require 3.3V, sensor systems require 3.7V and 13.5V, and the battery charging system requires 4.2V. These voltage levels are indicated in power tree figure.

The optimal choice of a battery for a specific design considers system voltage requirements, maximum current input and output, and amp-hour ratings. The prototype node was designed to support a wide range of sensors; therefore the selection of battery was chosen to be adaptable to the specific implementation. Node prototype contains 3 parallel 18650 2.6Ah lithium-ion batteries. They provide a nominal 3.7V, charge at 4.2 V, and offer a total power rating of 7.8 Ah. The battery line both charges the batteries and provides a power voltage line that varies between 3.7V and 4.2V. Any sensors connected to this power line should be able to tolerate this fluctuation.

The power stages were implemented using TI's BQ25570EVO-RQQR evaluation board (BQ Board) and a board developed to boost 3.7V to 12V based on TI's TPS61288RQQR boost IC. The BQ Board contains a boost converter, a buck converter, and a buck-boost converter, while its logic implements overvoltage and undervoltage protection to safely implement battery charging. The evaluation board was provided and modified by Vernon Crasto's electromechanical wireless power transfer (eWPT) research group.

The eWPT is an inductive coupled power generator that can transmit up to 1A of current over 35cm. The eWPT generates 3 phases of AC power. The Node functions on DC power, therefore a 3-phase AC full-bridge rectifier was designed to convert the power to DC.

ST's NUCLEO-WL55JC2 microcontroller (STM32) was selected both for its integrated LoRaWAN functionality and low power operation. The STM32 can be configured to operate with a wide range of voltage levels using its onboard buck-boost converters and LDOs. To improve efficiency, the STM32 was configured to bypass the power management system and provide 3.3V to the STM32 microcontroller and Semtec LoRaWAN module. This configuration removes power to the onboard ST-LINK, the built-in microcontroller development hardware. Specifically, 3.3V was routed to the STM32's 3.3V power pin CN7.16. Jumpers JP7 and all 6 jumpers on JP8 were removed, as they provide power and data connections to the ST-LINK's programming submodule and are a source of quiescent current loss.

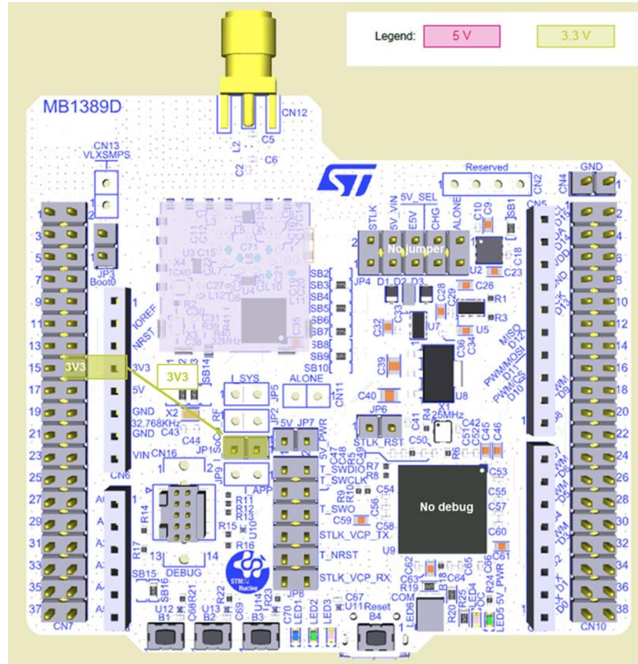

Figure 1 - Power configuration for the NUCLEO-WL55JC2 routes power to pin CN7.16 and removes 7 jumpers that provide power and data connections to the ST-LINK.

Measurements performed using an Agilent E3616A Power Supply showed its low power functionality out of the box. Operating the preloaded software transmitted a LoRa broadcast on a timer. Power consumption averaged 5mA in Standby mode and 20mA during LoRa transmission. LoRa transmissions lasted approximately 1 second.

TABLE I

NUCLEO-WL55JC2 Power Consumption

Mode	Current (mA)	Power (mW)
Standby	5	18.35
Tx	20	73.4

The Node is designed to accommodate a wide range of sensors. Many low power sensors operate near in the 3.7V range, however specialized sensors can have higher voltage requirements. This implementation connected an analog capacitive soil moisture sensor and a soil NPK sensor.

The soil moisture sensor operated between 3.3V and 5.5V. The sensor's onboard LDO permits the 3.7V to 4.2V voltage fluctuation that occurs on the battery charging line. This direct connection simplifies the power management for the moisture sensor, ensuring efficient operation without additional voltage regulation.

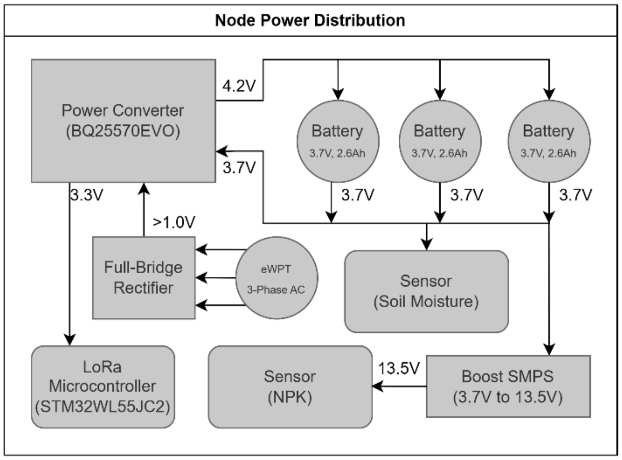

Figure 2 - Node power distribution, indicating the relevant voltage levels at the source.

Conversely, the NPK sensor requires a higher voltage range of 12V to 24V, necessitating the implementation of a DC-DC step-up converter. This converter boosts the 3.7V battery voltage to meet the NPK sensor's requirements, ensuring reliable performance.

The use of a high-efficiency boost converter minimizes power loss, thereby extending the battery life and maintaining the overall device efficiency. Designing a boost switch mode power supply satisfied the need to achieve high efficiency and meet the 3.7V input and voltage output greater than 12V. TI's Power Designer Studio web-application simplifies design of the power supply schematic and provides key design tips follow when creating the PCB footprint. The application generated "perfect" values that satisfied the design goals. While these ideal values are a useful starting point, the supply chain dictates what values are available. Initial parameters created a 12V boost converter, but modification of the resistors to more common values caused the output to increase to 13.5V. These values were accepted because this higher voltage was within the design parameters.

D. Overview of Operation

The BQ25570EVO-RQQR operates by boosting the input voltage to charge the battery. It uses a pulse-frequency modulation (PFM) boost converter to step up the voltage from the energy harvesting source to 4.2V, and current flows into the battery. When no voltage appears at the input, the board disables the boost converter, and the power rail drops to 3.7V. For this reason any devices using this power rail need to handle the 3.7V to 4.2V fluctuation. An integrated buck converter steps down the voltage on the 3.7V-4.2V rail to provide a regulated 3.3V output for powering other components in the system.
The input voltage for the BQ25570EVO-RQQR comes from a three-phase coupled inductive motor. The three-phase AC voltage is rectified using a full-bridge design constructed from diodes and capacitors to convert it into a DC voltage suitable for the boost converter.

The three-phase AC voltage is fed into a diode bridge rectifier. This rectifier consists of six diodes arranged in a bridge configuration, with each phase connected to two diodes. The diodes allow current to flow only in one direction, effectively converting the AC voltage into a pulsating DC voltage. The diode outputs parallel a capacitor and connect to the BQ Board. Capacitors store charge, which provides charge during the slight dips in the rectified output. The large 470uF capacitor filters the pulsing current and provides a smooth DC voltage to the BQ Board.

E. FCC Regulations

Radio frequency devices are regulated by the Federal Communications Commission (FCC) and printed in the Code of Federal Regulations, Title 47 Section 2.106 "FCC Online Table of Frequency Allocations." LoRa transmission in the 433MHz and 434 MHz spectrum are licensed for use in the United States to amateur radiolocation and Earth exploration-satellite, therefore the use of these frequencies will require FCC approval.

Title 47 Section 15.231 "Periodic operation in the band 40.66-40.70 MHz and above 70 MHz" describes regulations of periodic transmissions. LoRa operates in the divides its frequency spectrum into 125 kHz bandwidth channels, with 200 kHz channel spacing. Regulations in subsection (e) permit any operation in this range if the field strength transmission of fundamentals is limited to 1,500 to 5,000 microvolts per meter and spurious emissions to 150 to 500 microvolts per meter at 3 meters.

Title 47 Section 15.211 permits devices to operate in tunnels at any frequency. Regulations that limit frequency transmission are made from the tunnel opening. Considering soil to be a complex network of tunnels would allow node broadcast signal strength to be measured as an isotropic radiator from the soil surface.

The Node is designed to broadcast from underground. Device hardware limitation prevent radiated power from exceeding 19.7 DBm at the antenna. Theoretical soil path loss suggests a -60 DBm signal at the soil surface, and 1 microvolt/meter at 3 meters.

III. LORAWAN NETWORK

To simplify the process and make it easier for others to recreate our research, we chose to employ an open source LoRaWAN server client made by Petr Gotthard (here is a link to the GitHub repository). This was also the server recommended on the STM32 tutorial for setting up a LoRaWAN server for our specific hardware [4]. This tutorial gave us the foundation for setting up our network server including the appropriate IP address' and AT commands to configure the gateway. We expanded on this tutorial to fit our application by modifying the channel configuration to be our chosen 434 MHz band instead of the 890 MHz band that they used, the gateway properties on the server were modified to get our communication established (see the configuration settings in the appendix Figures 4-8).

A. Network Server Challenges

Challenges we encountered when testing our network connection were vast and tedious to debug. Our first issue came from connecting the gateway to the server, which stemmed from a few smaller issues:

- The ethernet port must have the IP address appropriate for our application.
- The channels must be configured with the right bandwidth and buffer.
- The Device EUI and MACs must match what we see in the serial terminal, etc.

After getting the gateway connected, our most pressing challenge became connecting the node to the server and getting communications established. This was a very drawn out and tedious challenge for us due to the lack of resources to help us debug the exact issue we faced, because we were able to get the node connected to the server quickly but there was no communication due to what the server called a repeated reset error. We later found out through much trial and error and messing around with our settings that it was due to the RX1 and RX2 join delays of our network being too short, not allowing our node to establish communication, causing the node to repeatedly reset on every attempt to join the network.

The last part of the network configuration that was required to demonstrate our research was connecting to a backend application server client that could be portable across many PCs and not cloud based. With all of these in consideration, we chose to use the node.js IDE Node-Red as our application server.

B. Application Server

To interpret and utilize the data collected by the node being sent over the network, we needed to employ a separate server to send this data to and manipulate to make it useful for the end user. To do this, following the second part of the tutorial used to configure the network server, we used a node.js block-based IDE called Node-Red [4].

Node-Red is nice in that it can be run locally on the host PC that the network server is running on, and it does not need internet to boot since it is not a cloud-based server. It is also quite easy to set up since most of the backend coding is handled for you in what they call the node palettes. These palettes are groups of nodes dedicated to a single function, here are some examples:

- Debugging nodes
- Dashboard nodes used to create a customizable UI
- Function nodes that you can put your own JavaScript code into to manipulate data
- Data conversion nodes can turn a JavaScript object into any external object like a .txt or .csv file.
- MQTT broker transmitting and receiving nodes.

C. MQTT and UI

We used the MQTT broker node palette to handle the middle communication between the network server and Node-Red. You can see our application server architecture as well as examples of what the code used in our function nodes in the image appendix.

The last part of the application server that is worth explaining is the configuration of the dashboard, our custom UI made entirely from Node-Red. The Node-Red dashboard palette comes with nodes that show up on the dashboard UI that act as event triggers such as buttons and sliders, but what we used primarily were the nodes that instantiated data-collecting UI items like line charts and gauges to display the formatted data. See our final UI used for our demonstration in the image appendix.

IV. NODE ENCLOSURE

A. Preliminary Considerations

The finishing touch to our final product that would come out of our research was an environmentally friendly, insulated, and durable container for the node. For our preliminary model we used an environmentally friendly 3D printed material PLA that has been used in other applications as a bio-degradable filament for 3D printing antennas [1]. Although the material is not airtight enough to protect the electronics inside, some biodegradable paint can be applied to the outside and solve the issue.

B. Mechanical Design

The mechanical design of the container was a simple, box structure with an elevated top to guide moisture and foreign objects off the top of the container to the bottom where the sensors extrude out. The bottom of the container has small platforms for screwing in the PCB to keep it from moving around and for extra support. This was accomplished in OnShape with its assembly functionality that allows to bring in multiple designs into one part studio, which allowed us to create a custom enclosure to fit a 3D model of the PCB. There are some openings on the side and lid to allow for the soil sensors to poke out and access the soil as well as the antenna to eliminate any signal power loss passing through the PLA material would cause. The last consideration was to create a good enough seal between the lid and container to insulate the electronics inside, which we accomplished by adding a gasket indent around the edge of the box and add screw holes around the outside of the gasket to screw on the lid after adding the gasket seal. A model of the container and lid can be found below.

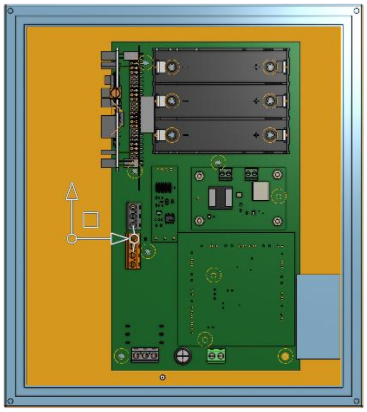

Figure 3: 3D model of PCB fitting to scale inside box enclosure.

V. CONCLUSION

To conclude this paper, our LoRaWAN node-gateway network structure is ideal for solving the problems faced with establishing a wireless node network that involves high-interference environments, i.e. being underground. This is due to the low power, frequency, and data rates advertised alongside its long range capabilities. For future extension on this research we would like to consolidate the power management system, expand the node's internal monitoring, expanding the sensing capabilities of the node and possible introduce some to the gateway.

We also considered adding another layer to the network that we'd call the relay layer that would act as a packet forwarder for the node to the gateway and would allow for less total distance traveled per transmission and less transmitted power to the open air to safely stay under the FCC regulated ambient power limit. This would be enacted by either the rotating irrigation pivot that rolls over the nodes, tractors that drive over the nodes, or even the drones that fly/drive over the field.

APPENDIX

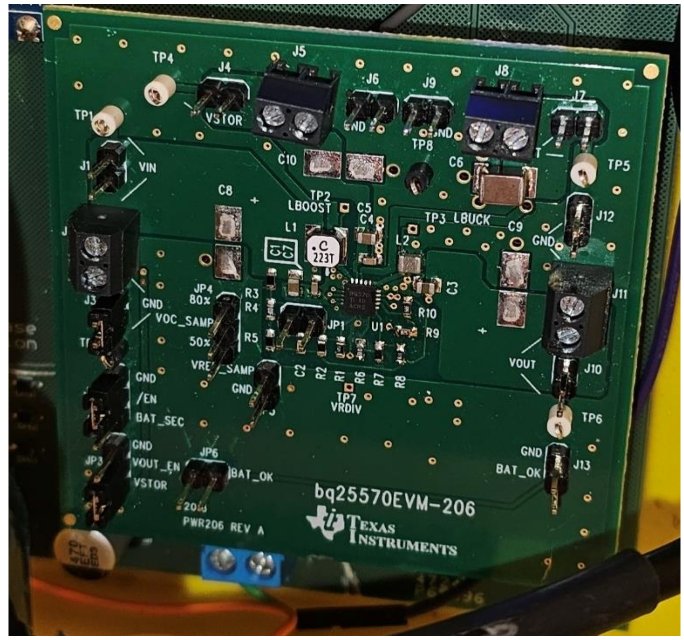

Figure 4 - TI's BQ25570EVO-206 power harvesting board configured to provide 3.3V VOUT, 3.7/4.2V at VBAT.

REFERENCES AND FOOTNOTES

A. *GitHub Repository*

Source code and supplementary images and documentation are provided in the following repository: https://github.com/DAN-PISTORINO/LoRaWAN-Drone-Port.git

B. *References*

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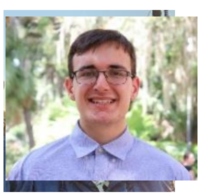

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