Abstract: Current methods of acquiring agriculture data are expensive; the data is generally from a single location, rarely out in the actual field. In many cases the data is delayed and irrelevant by the time the farmer has access to it.

Because of the cost, very little data is ever collected and by very few farms, which means that the analysis is not near as effective and accessible as it can and should be.

There is a need for an inexpensive and reliable way to collect in real-time, and analyze location specific data to deliver lower water, power, and fertilizer expenses.

I. INTRODUCTION

The ability to gather data that attributes to crop yield can be very valuable. Over watering or under watering can have devastating effects on crop yield. Typically farmers will drive to their fields daily to ensure proper moisture content in the soil. Tracking soil temperature at different depths can also aid in predicting the most efficient time to plant crops from year to year. Keeping track of local weather conditions such as wind direction and speed could help meet regulatory needs of shutting off pivot fed fertilizer application during windy days. Monitoring air temperature could help determine when to apply volatile fertilizers. By monitoring rainfall a farmer could use that data to automatically shut down pivots during excessive rainfall periods or counter act a dry spell.

We desired to design an RF sensor that could be used by farmers to remotely check on field conditions real time. The idea was to design sensor nodes inexpensive enough such that a farmer could place many in a field to get high-resolution data to make decisions with.

II. NETWORK SPECIFICATIONS

The design of any wireless sensor network starts with some very important considerations such as:

A. Resolution

How many members or “nodes” would be required for a fair representation of various field parameters? The answer to this question depends greatly on the type of data we are trying to capture. It can also depend greatly on a field’s topology and soil make up. If we think of two different parameters such as wind speed and soil moisture content, we can see how these two parameters can be fairly represented with two different resolutions.

We determined that since the average size of a field is roughly a 1 mile square (1 x 1 miles) there would only be a need for one weather station node. Soil parameters however, are very localized. Geological topology has a great effect on moisture content of the soil when we consider fields that have dips, valleys and hills that can cause over-saturation or drought within a fine resolution. In the end however resolution limitations are reflected by cost and ease of deployment of each sensor node and overall budget.

B) Topology / Range

1. Topology

The symmetry found in most agricultural fields aid us in choosing the most reliable and cost effective network topology for our network design. Fields also have very little obstructions that could potentially block our transmissions from sensor nodes to “base station”. With the design of a sensor node that is capable of transmitting and receiving over a one-mile range, a direct link Star topology seemed to be most logical. By using this topology, we reduce the complication of using mesh networking and avoid potential data loss due to a single node failing, as could be seen in a Tree network topology.

2. Range

The range capability of each sensor node determines which type of network topology we can consider. Range capabilities also play a major role in power consumption of each node. We wanted to design a network that was very inexpensive and reliable thus, we wanted to avoid routers and range extenders. Although there are many fields in the U.S. that are much larger than a mile square, there are virtually no pivot systems that extend beyond a mile in radius. For us to maintain a point-to-point communication we needed a range of at least a mile to accommodate most fields.

Extended range was also desired for the ability to push data up to an Internet accessible database. To do this we chose to use a Global Systems for Global Communications (GSM) module that could plug into our Base Station. This would provide limitless range provide that the field was within cell network coverage.

RF Sensor Network
Jason Parmenter, Jonathan Klassen

Jason Parmenter is with College of Science and Engineering Idaho State University, Department of Electrical Engineering, Pocatello, Idaho 83209, USA (email: parmjas2@isu.edu).

Jonathan Klassen is with College of Science and Engineering Idaho State University, Department of Electrical Engineering, Pocatello, Idaho 83209, USA (email: klasjona@isu.edu).
Above all, the main reason for choosing the Star network topology was due to power constraints of the network.

C) Power Consumption

The Star network configuration also gives us the ability to turn the radio of each sensor node off while it waits for its next command to collect and send data. The ability to do this, leads to the option of battery-powered devices that should be able to last an entire year of operation without the need or added expense of solar charging. Our goal was to provide a year of operation on three AA batteries.

The base station on the other hand would have an unlimited supply of power since it would be located at the pivot center and would tie directly into the power supply of the pivot.

D) Data Collection Frequency

Data such as moisture content and temperature is not likely to change rapidly. We estimated that reading of soil parameters every five minutes would be an absolute maximum frequency needed to keep track of what is going on with the field.

However weather conditions can change dramatically in a very short time span. Weather data should be sent as frequently as possible to ensure automated pivot manipulation based on rainfall, temperature, and wind speeds. Due to the high frequency demands of weather data we concluded that the weather station would also be located near the pivots power supply.

The frequency at which we need to collect data from sensor nodes plays a huge role in power consumption. Reading every five minutes vs. every thirty minutes can translate into an entire year decrease in operation.

III. HARDWARE DESIGN

Based on the network specifications, we set out to design a microprocessor platform that could serve many purposes within our network with the following specifications:

- **Sensor Node**
  - Powered from three AA batteries.
  - The device would function as an RF transceiver to send soil and ambient parameters back to the base station and receive updates regarding reading frequency and configuration.
  - Collect Sensor Data
  - Talk wirelessly up to 1.5 miles with “Base Station” via RF.

- **Base Station**
  - GSM communication for updated network commands and data analysis.
  - Talk wirelessly up to 1.5 miles with sensor nodes for data acquisition and commands.
  - Ability to be powered in several ways depending what is available (local to the pivot).

- **Expandability**
  - Header pins provided virtually limitless expandability based on the design of other modules that could plug into our circuit. Two examples are: Solar / Capacitor power supply and Weather Station.

A) Processor Selection

The Atmega328p was very appealing to us because of its vast use and documentation in the embedded systems community. By using it we could take advantage of an open source Integrated Development Environment (IDE) and a vast ocean of open source libraries. The processor has a separate watchdog oscillator that runs at 8Khz thus providing low power sleeping operations and built in Watch Dog interrupt timer. The processor is capable of drawing single digit micro amps while sleeping with the Watch Dog timer on. There are many processors available that would function just as well or perhaps better than the 328p, however the selection of the processor was based on ease of software development and cost. The processor can be purchased for less than $2.00 and uses very minimal external components.

B) Transceiver Module Selection

The RFM92W/93W transceivers feature the LoRa™ long-range modem that provides ultra-long range spread spectrum communication and high interference immunity whilst minimizing current consumption.

Using Hope RF’s patented LoRa™ modulation technique RFM92W/93W can achieve a sensitivity of over -137.5 dBm using a low cost crystal and bill of materials. The high sensitivity combined with the integrated +20 dBm power amplifier yields industry leading link budget making it optimal for any application requiring range or link robustness. LoRa™ also provides significant advantages in both blocking and selectivity over conventional modulation techniques, solving the traditional design compromise between range, interference immunity and energy consumption.

FHSS modulation is a digital type modulation technique that provides robust links between transmitter and receiver while making it easier for the user to meet FCC requirements. With airways continually becoming more congested it is important to select a module with high selectivity.

C) Power supply

The main objectives for the power supply design were to 1) Introduce very little noise into the sensitive communication circuit and 2) Have the ability to power the circuit for an entire growing season without the need for maintenance.

After exploring many battery chemistries, solar charging, and even a Super Capacitor Solar charging circuit (discussed in “Aguinio Power Shield” section), the choice was made to use three AA batteries paired with a Low Drop Out (LDO) regulator. By using only three batteries we were able to keep the ratio of the input to output voltage small, which increases efficiency dramatically. The LT1763 Series regulators by Linear Technologies have very small dropout voltage (300 millivolts at 100mA) and have a typical quiescent current of only 30 micro amps. These regulators also have built in reverse polarity protection to prevent the
batteries from leaking or exploding upon a reverse polarity battery insertion.

**Energizer® Ultimate Lithium AA batteries** would provide the power for our circuit. The cells chemistry make up is Lithium/Iron Disulfide (Li/FeS2). These batteries have an extremely flat discharge profile and are very robust to extreme temperature fluctuations as may be seen in the field.

Three of these batteries in series would provide from 5.21V (fresh) to 4.1V (end of life). Considering the dropout voltage of the regulator (300 mV) we would need at least 3.6V supplied to the regulator to ensure a 3.3V. This configuration gave us wiggle room and provides regulator efficiencies of approximately 60% - 85%.

**IV. CONFIGURATIONS AND EXPANDABILITY**

A. **Sensor Ports**

Each of the five sensor ports on the “Agduino” provides five pins.

- **Digital IO**
  - Pin (intended to provide power to each sensor when a reading from that sensor is needed).

- **Analog IO**
  - Pin (to read analog signal returned from sensor as voltage)

- **3.3V and 5.5V pins**
  - Intended for sensor that need constant power such as weather data sensors.
  - Provide Power for the base

A typical sensor node configuration for our application requires the use of a Digital IO pin each sensor and an Analog pin to read the analog data.

B. **Header Pins**

The header pins on the Agduino provide a way to expand the device to meet the needs of complex sensors that require multiple digital pins. The headers are laid out in the standard Arduino UNO form factor. This allows our device to adapt to literally thousands of different functions by simply plugging in “shields”. A shield is an external circuit that that plugs into our device through the header pins in a stacking fashion. The “Agduino Power Shield” is an example of such a shield providing a specialized function to the system. These pins allow us to quickly modify our board as needed by providing a semi-permanent adaptation.

**V. ONBOARD COMMUNICATIONS / PROGRAMMING**

There are two main communications that take place onboard to make the device functional 1) computer to MCU and 2) MCU to RF Module.

A. **Computer to MCU Communication**

A Future Technology Devices International (FTDI) chip translates serial data from the RS-232 (Recommended Standard) format from USB port to TTL serial (transistor-transistor logic) needed to communicate with the MCU. The need for the conversion stems from hardware differences such as voltage levels and polarities as seen on the USB side vs. the MCU side. The type of communication is much the same however. Both protocols simply transfer one bit of data at a time at a specified baud rate (usually 9600 kb/s) and mimic the SPI protocol.

Once this communication is established the MCU can be programed from a computer as well as providing two way serial monitor communication for debugging.

B. **MCU to RF Module**

Communication between the RFM69 and microprocessor is done using an SPI bus. The RF module acts as a slave device to the ATMEGA processor. This SPI interface allows us access to configuration registers as well as all Rx and Tx data on the RF modules FIFO buffer. The FIFO buffer is 256-byte buffer. The processor has three major tasks in our application: 1) Writing and reading register values to and from the RF module to configure the module for sending and receiving data, 2) extracting data from and pushing data to the RF module’s FIFO buffer, and 3) controlling external peripherals such as sensor triggering and interaction with shields.

**VI. NODE TO NODE COMMUNICATION**

There are two primary communication links within the network. A) Node to node communication via an RF link and B) GSM to Web Server communication via GSM (2G) network link

A. **Node to Node**

RF node-to-node communication protocols are customizable based on range and security needs. The LoRaTM modem employs two types of packet format, explicit and implicit. The explicit packet includes a short header that contains information about the number of bytes,
coding rate and whether a CRC is used in the packet. The packet format is shown in the following figure.

![Packet Structure](image)

The preamble is used to synchronize receiver with the incoming data flow and is automatically generated by the module. The header provides information of the payload, namely:

- The payload length in bytes.
- The forward error correction code rate.
- The presence of an optional 16-bits CRC for the payload.

The module has many configuration registers available to customize the transmission sequence, all of which are detailed in the data sheet. Generally speaking manipulation of these registers can lead to very robust high-speed links at short ranges and slower and less robust links where longer ranges are required.

### B. Gateway to Webs Server

To retrieve data from the field, a GSM module plugs into the existing RF sensor node. The key feature of the second-generation cell network (2G) module is that the 2G network is very well established and the data plans are very cheap when compared to newer networks. This type cellular module is well suited for sending numerical or other primitive data.

### VII. SOFTWARE FLOW

The RF module is very specific in the way that it is configured. There is a specific procedure that should be followed in the software for configuration of each of the registers for reliable communication between the nodes. There are different methods depending whether data is being A) received or B) transmitted.

#### A. Receive Flow

First thing is to configure the operation mode of the module to Rx mode. When doing this, it must be decided whether to receive a single data packet or to receive continuous. After switching to the mode desired, an interrupt flag is generated that is used to indicate when data has been received. This data is then crosschecked with the network ID and then the node ID is indicated for reporting, and finally the data extracted and stored.

#### B. Transmit Flow

When needing to transmit data, the Tx is initialized. After it initializes, the data that needs to be transmitted can then be written to the FIFO buffer. This buffer is limited in size, so the data that is being transmitted may have to be broken up into multiple packets. After the data is written to the buffer, the op-mode register can then be written to transmit mode. Once in this mode, the module sends all the data on the FIFO buffer and automatically switches back to a standby mode after emptying the buffer. If there are more packets to be sent, the process starts over by writing the new data to the buffer and sending again. Otherwise, the module can be changed to a new mode again.

### VIII. CONCLUSION

We are currently in the process of testing the final design including deployment in an agricultural field to report back various parameters such as soil temperature and moisture content. We are playing around with software settings to maximize sensor node efficiency and range capabilities.

Currently the data is being reported back through the 2G networks and stored in an online database. We have noticed some corrupt data packets on occasion and are looking into CRC error checking and other filtering to eliminate the corrupt packets. However most packets are valid.

The final design of the PCB board is 3x4 inches. It could be more compact however to maintain the standard Arduino Uno header pin layout the size is fixed. There may be a revision in the future that separates the base station model from the sensor node model. This would allow us to clean up the design and make the sensor nodes more compact. However this would also lead to the design of two separate PCB boards. Below Figure 5 shows the final design of the embedded system, which is used for all of our applications including sensor node, base station, and any other adaptable application via header pins.

![Final PCB design of Sensor Node](image)

### REFERENCES


