CSCE 996 Independent Research

Controlling Center Pivot Irrigation Systems

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Overview

Excessive, wasted water has prompted the creation of the *Top 10 Water Challenges of Nebraska* [1]. 70% of the world's water usage is related to agriculture [7], more efficient irrigation solutions promise a large benefit for farmers, consumers and the environment. Through a USGS grant, the Cyber-Physical Networking Lab at the University of Nebraska-Lincoln has pledged to complete an autonomous irrigation system to improve the efficiency of center pivot irrigation. As part of this project, an interface between the center pivot controller and the sensors was created. An above ground receiver was integrated with a center pivot controller and controlled by data from the field. Hence a wireless sensor network (WSN) can be used to aid precision agriculture.

The remainder of this report will cover the equipment and process needed to create a communication link between sensor motes in the soil and a center pivot irrigation system. First, the background of precession irrigation will be discussed. Next, the implementation details will be presented with the demonstration setup following. An experiment was done before the final demonstration to assess the quality of communication while burial depth and antenna choice were varied. The results of the final demonstration are presented followed by a conclusion of the work presented. An appendix includes pictures from the final demonstration.

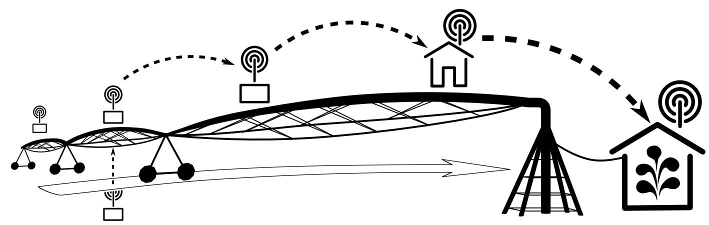


Figure 1: Above ground motes attached to the sprinkler collect and relay moisture messages from underground motes to the base (home) mote. The base mote converts the moisture data to a speed, which is sent via SMS (text message) to the sprinkler's controller.

Background

Previously, center pivot irrigation systems ran at a fixed rate, irrigating a field evenly, though the soil may not be uniform in its moisture needs. More recently, precision irrigation has taken off. Sprinklers, such as Valmont Industries' Variable Rate Irrigation (VRI) system, are examples of this [4]. Speed control allows a farmer to choose how fast the sprinkler travels at each position of its rotation. Zone control allows for the flow of each sprinkler head to be adjusted. This gives a virtual dartboard of control, where each cell can get as much or little water as needed. Thus timing and amount of irrigation can be controlled across a field.

Precision irrigation hardware itself is not complicated, but knowing where extra water is needed is the key. As Jake LaRue, P.E., Project Manager for Valmont Industries, put it, "What becomes critical is the tools for the farmer to use it well" [5]. CropMetrics is a company that specializes in that control interface, providing software tools and analysis to control the center pivot irrigation systems. Their analysis is mainly static occurs once per field, but gives the information needed to program the irrigation systems [2].

Through rough analysis and VRI, water savings of 12% to 13% have been achieved [5]. Whereas CropMetrics provides limited and one-time information about the soil, the parent project of this report proposes to use a real-time wireless sensor network to monitor the soil and control the irrigation system, yielding an even greater water savings. This is due to the fact that the environment is, "highly variable and unpredictable," [6]. [3] shows a 10% yield increase from the farms using soil moisture sensing in the state of Missouri.

Current research in this area suggests promising results. [10] examines the effect of using a wireless sensor network to aid in irrigation. Their approach uses a permanent above ground WSN deployed in a field. This allows for real-time soil moisture collection, but the above ground motes are susceptible to injury or destruction by farm equipment. A portion of the field was watered using traditional means, the other half was watered adaptively using the data collected by the WSN. The goal of this experiment was to keep soil moisture tension (which is related to how well crops can absorb moisture) in an optimal range. The results of the experiment showed that the adaptive half of the field stayed within range more often than the control half, rarely going beyond the set threshold.

Along with water, other soil properties can be measured, such as nutrients or acidity. Some irrigation equipment allows for herbicide and pesticide deployment. Many of these chemicals are expensive and hurt the environment; savings in this area are twofold. [9] was able to save 17-25% of fertilizer through precision agriculture techniques.

Implementation

This research project is one piece of the larger automated irrigation system. A mock center pivot irrigation system was controlled by real-time data via a WSN and short message service (SMS) messages (a.k.a. text messages). A base station was controlled by a Mica2 sensor mote[1] which received (moisture) data relayed from underground motes. That data was then converted to a sprinkler speed, which is equivalent to adjusting the water flow. Figure 1 shows this concept. Access to an actual center pivot system was not available, but this project interfaces with any controller that will accept SMS control.

The speed of the sprinkler was controlled through messages sent from underground motes to a base station and then via a Mica2-to-center pivot interface. Zone control was not included in this project. The interface between the mote and the sprinkler is:

- Mote to SMS (text messaging)
- SMS to sprinkler controller

The first part of the interface uses a a Mica2 mote connected to a Telit GSM (Cellular) radio. The base station mote facilitates this communication and translation. The second part will receive SMS messages and forward these to the sprinkler's controller; this portion is often implemented by sprinkler manufacturers or sprinkler controller add-ons. A cell phone was used as a replacement for the actual controller. A person holding the base station was responsible for responding to incoming text messages. Throughout the rest of this document, "sprinkler" will refer to a person moving around with the base station responding to those text messages.

Mote to Mote Messages

Relay Mica2 motes set on the sprinkler (above ground) sent soil moisture information via TinyOS wireless messages to a *base* Mica2 mote. Each of those above ground motes transmitted at high power to extend their communication range. The relay motes received soil moisture information under the sprinkler and immediately relayed them to the base mote. Underground motes have a very limited communication range, only a few meters. The base mote used these messages to adjust the speed of the center pivot sprinkler.

Each Mica2 mote has a short-range radio, but only the base Mica2 mote has a cell phone class radio.

[1] A mote is a small, cheap, low power computer with wireless communication abilities. Many of these working together form a wireless sensor network (WSN).

Moisture to Speed Conversion

As the base mote receives moisture updates, it can decide on a more appropriate speed. There is a lookup table (or conversion equation) that is preprogrammed at this mote. Thus soil moisture is directly converted to speed.

Mote to SMS Messages

Every time a new speed is chosen, an SMS message was sent to the sprinkler controller. These message would be formated using the application programming interface (API) provided by the sprinkler manufacturer, but since none was available, speeds were sent as a percentage of maximum speed (i.e. 50 meant travel at half speed). Direction was also included, either clockwise or counterclockwise: negative numbers corresponded to moving counterclockwise.

A custom printed circuit board (PCB) was created to interface the two devices (Mica2 mote and Telit radio), as well as power each devices at the appropriate voltage.

Demonstration Setup

Two demonstrations were performed to show the functionality of this system. There names are "Marco Polo" and "Pong". They were run independent of each other. As the speed of the sprinkler is slow, only a slice of the field was used for these demonstrations. In each experiment, two motes were buried underground, they were called "East" and "West."

Marco Polo

The goal of the first demonstration was to show that data collected from the field can be sent over the air to the base station. Two motes were buried underground and had partner motes above ground (as seen in Figure 2). The above ground partners were static. At random time intervals, each underground mote requested that the sprinkler come to it. These messages were relayed using the above ground motes. Thus the sprinkler would travel toward one mote after it was requested. As soon as the base station heard another request message, the sprinkler would move to that mote.

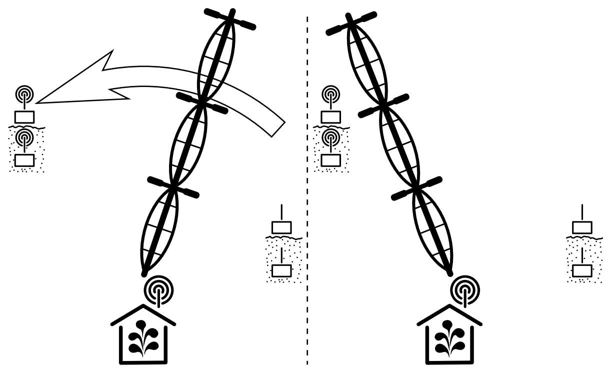


Figure 2: Marco Polo Demonstration: the sprinkler travels toward a mote on request. Each underground mote has a partner above ground to relay these requests.

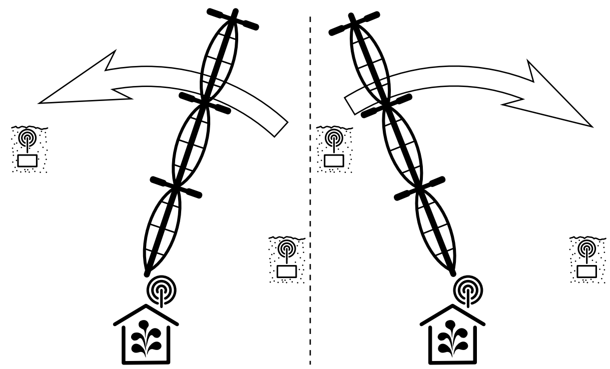


Figure 3: Pong Demonstration: the sprinkler travels until reaching an underground mote, at which time a relay mote on the sprinkler will tell the sprinkler to reverse its direction.

The drawback of the Marco Polo setup is that stationary, above ground motes are needed. This is not feasible in an agricultural setting as they may be damaged by agricultural equipment, especially during plowing or harvesting times. Adding an above ground mate does, however, allow for data collected underground to be shared at any time, not just when the sprinkler is near. Irritation systems without a moving sprinkler could make use of this communication scheme.

Pong

The second demonstration was to show that data can be communicated from underground to the sprinkler without extra stationary devices in the field. Again, two motes were buried underground, but this time, only one relay mote was used; its location was on the sprinkler itself. This demonstration had the sprinkler traveling initially.

As the sprinkler moved towards an underground mote, the relay mote would establish communication. Once the data has been transfered, the relay mote will relay this information to the base station causing the sprinkler's direction to reverse. Thus the sprinkler will 'bounce' between the two underground mote areas (as seen in Figure 3).

The Pong setup does not require any excess equipment above ground, allowing farm equipment to function normally. The downside is that underground data can only be collected when the sprinkler travels near that underground mote.

Pre-demonstration Experiment

In preparation for controlling a center pivot irrigation system from underground motes, the two demonstrations described above were performed in my backyard in Lincoln, Nebraska on May 6th, 2011. Multiple antennae were used and the underground motes were buried at different depths.

Three different antennae were used: a planar antenna, a $\frac{1}{4}$ wavelength whip antenna and a full wavelength high-gain antenna. The planar antenna was in the shape of a circle with a radius of 3.0 cm (as seen in Figure 4). These antennae are ultra wide band, which help adapt to the frequency verifications signals experience as they pass through the soil [8]. Each of the underground motes had one of these for all variations, though sometimes they were tapped to the top of the container and other times they just laid in the container. The $\frac{1}{4}$ length whip antenna was 17 cm long and only used at the base station. The aboveground, relay motes used the high gain antenna and the planar antenna in separate experiments.

Plastic containers were used to bury the under ground motes (as seen in Figure 5 c). The antenna and mote were both in the box, no direct soil contact was made.

Environment

My backyard was used as the site of these experiments. It is flat and the soil is of unknown makeup, though it did not seem to be very sandy. The volumetric water content of the soil was around 30% that day. This was found by weighing a sample of soil and then baking it at 400°F (204°C) for 7 hours and 15 minutes and then reweighing it. The volume of the soil was also measured. It had rained about 36 hours before the start of the experiment.

Marco Polo Results

The Marco Polo configuration did not work. Messages were received from the ground, but could not be relayed across the yard to the base station. The aboveground motes used the planar antennae only. Only when the base station was less than 4 m away, would messages reach it. Due to these aboveground difficulties, other burial depths were not tried. In an attempt to reach the 13 m distance, these relay motes were sometimes picked up and their antenna angled such that they were facing the base station, these attempts never reached the 13 m distance. Only one high gain antenna was available, and was not used, as multiple relays would each need one.

Pong

This version of the experiment was carried out at multiple depths with both antenna types (planar and high gain) used at each relay mote. The relay mote's antenna (which was never more than 2 m away from the base station) was held at various heights, the minimum height needed to receive an underground message was recorded in Table 1. Both antennae were held horizontally.

It can easily be seen that the western underground mote transmitted worse than the eastern mote. It is also noteworthy that the planar antenna outperformed the high gain antenna as the underground depth increased, though both seemed equivalent when the underground mote was not buried.

Antenna Depth	Antenna Type	Height (West)	Height (East)
40 cm *	Planar	< 30 cm	< 30 cm
40 cm *	High Gain	On Ground	On Ground
38 cm	Planar	45 cm	45 cm
38 cm	High Gain	On Ground	On Ground
23 cm	Planar	91 cm	122 cm
23 cm	High Gain	91 cm ˆ	122 cm ˆ
Aboveground	Planar	45 cm	122 cm
Aboveground	High Gain	45 cm	122 cm

Table 1: Minimum relay antennae height above ground to receive packets. Antenna type refers to that of the relay mote.
* antenna not taped to lid of box.
ˆ took multiple attempts

Demonstration Results

The final demonstration was performed at the University of Nebraska-Lincoln Ferguson Grounds in Lincoln Nebraska on May 23^{rd}, 2011. Both versions of demonstration were carried out.

The Marco Polo version's relay motes used one planar antenna and one high gain antenna, each placed about 30 cm above the ground. The Pong version used only the planar antenna. The soil makeup and moisture is unknown. The underground motes were buried approximately 15 m apart and 30 cm underground. Figure 5 a in the appendix shows the field. The base station consisted of a car battery connected to the custom PCB that held a Mica2 and Telit cellular radio; this was all placed inside a cloth bag. The base station was carried around by myself. My academic advisor had my cell phone and gave me directions as text messages came in; this simulated the sprinkler and its SMS enabled controller. Figure 5 show the base station and underground motes.

The Marco Polo demonstration worked as expected. The relay mote with the high gain antenna was able to communicate with the base station across the field (15 m), but the mote with the planar antenna could not. Both communicated with the underground motes without error. This made the experiment fairly one sided, but did show the differences between antennae.

The Pong version worked fine. The relay mote (with a planar antenna) was hung off of the base station's bag. I carried the base station from one underground mote to the other, each time getting a text message instructing me to go the opposite direction. The bag was held at various heights so that the relay mote's antenna was between 60 and 120 cm above the ground; each time a message was received.

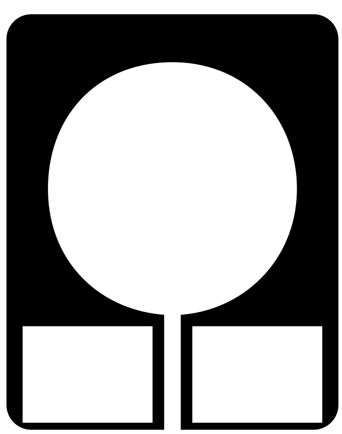
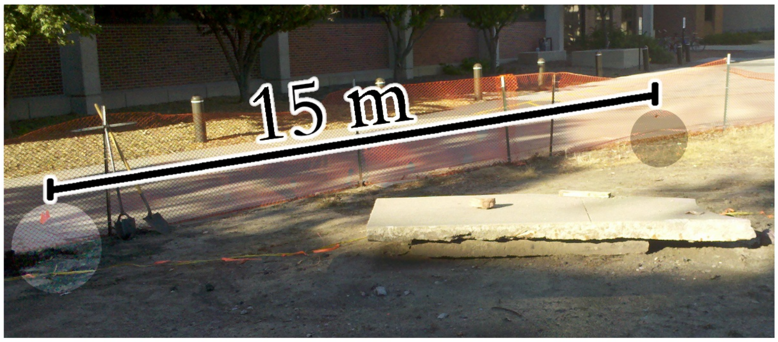


Figure 4: Planar Circular Disc Monopole Antenna with a radius of 3.0 cm with ground planes shown.

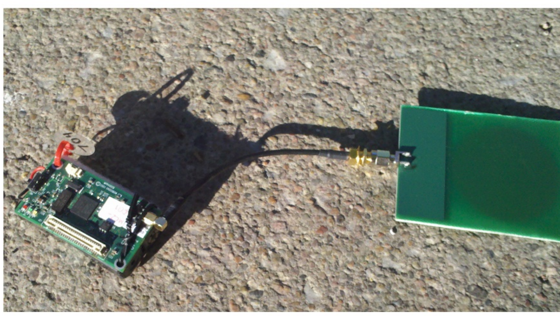
Conclusion

Being able to dynamically control a center pivot irrigation system allows for an underground wireless sensor network to actuate on the environment. The system presented here fits into the larger, autonomous irrigation project by implementing a wireless connection between TinyOS powered motes and a center pivot irrigation system with an SMS enabled controller. Though an actual sprinkler was not used to verify the work, several demonstrations were carried out showing the various communication challenges that exist, none of which showed issues with the cellular connection.

Appendix



a. Field - Underground nodes buried 15 m apart, 30 cm underground



b. Relay mote with planar antenna

c. Underground motes

d. Base Sation top and size views

Figure 5: Pictures from the final demonstration

References

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