A REAL-TIME SMART SENSOR ARRAY FOR SCHEDULING IRRIGATION: COMMERCIALIZATION

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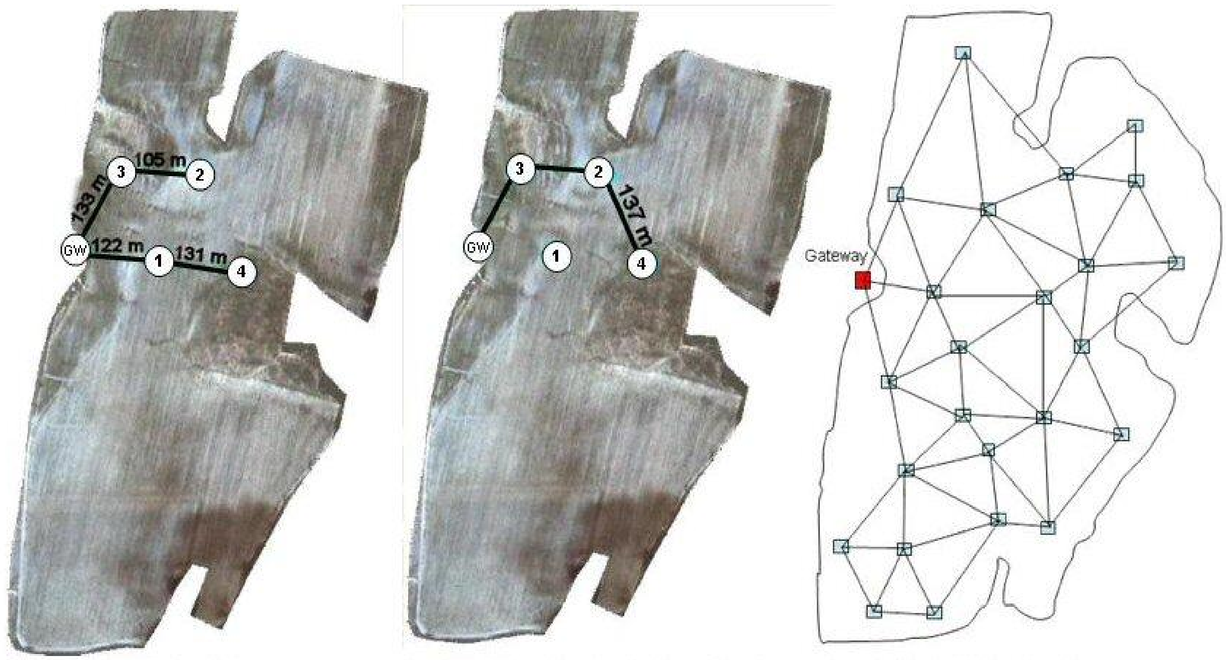
Introduction

In 2004 we first developed a real-time smart sensor array for measuring soil moisture and temperature. Further testing in 2005 and 2006 showed the system to be effective at providing real-time monitoring of soil moisture conditions. The sensor readings were used to schedule irrigation in several fields. Additionally, by observing sensor readings after irrigating, the sensor array provided a means of determining the effectiveness of an irrigation event in bringing soil moisture values to desired levels.

In our system, soil moisture values at each location, or node, in a field are transmitted wirelessly to a receiver and datalogger housed in an enclosure at the edge of a field. Each sensor node has the capability to read up to 3 Watermark® soil moisture sensors and up to 4 thermocouples. Radio Frequency Identification (RFID) tags were used as the transmitters for the sensor node. The RFID tags were chosen as the wireless component for their low-cost, reliability, and transmitting range. Although the RFID tags used have a transmitting range of up to 1/2 mile (line-of-sight), problems arise when the transmission path from a tag to the receiver is obstructed. Obstruction problems can be reduced by raising the tag(s) and/or installing the receiver on a tall mast. However, in undulating topography where hills, ridges, and depressions are located between a tag and the receiver, there may be no means of overcoming the obstructed transmission path. Other disadvantages of the RFID system are unidirectional transmitting and receiver costs. The RFID system is capable of only transmitting from the tag to the receiver. That is, the receiver does not have the capability to "talk to" the tags. Also, although the tags are relatively inexpensive the receiver is not. The Wherenet® RFID system we adapted for this project was designed for spatially tracking inventories. The receiver contains additional expensive circuitry not required in our application.

Because of these limitations with the Wherenet® RFID system, we have been evaluating alternative wireless systems for use with the sensor array. As the name implies, mesh networks create a wireless mesh network between the nodes. During 2006 we conducted a preliminary study using five Mica2 motes manufactured and sold by Crossbow® Technology Inc. The Mica2 motes are postage stamp-sized intelligent radio modules that are capable of acquiring, analyzing, and transmitting sensor data. Additionally, the motes act as repeaters to pass along data from other nodes to form a meshed network of motes. If any of the motes in a network stop transmitting or receiving or if signal pathways become blocked, the operating software will re-configure signal routes in order to maintain data acquisition from the mote network. To test this ability, we installed five motes in a cotton field as shown in Figure 1. The map on the left shows the original signal routing established by the mote system's software. The lines represent established signal paths that route data from the four motes installed in the field to the fifth mote acting as the gateway (GW). To mimic a failed mote, we turned off mote number 1. The middle map shows how the software automatically re-routed the signals between the remaining operational motes to maintain connectivity. Data from mote number 4 are now routed though motes 2 and 3 to reach the gateway. The schematic on the right in Figure 1 shows a hypothetical mesh network of motes based on sensor node locations installed at this site during 2006. Under our conditions, mote to mote transmission had an effective range of 350 to 450 ft. By using a series of motes, range can be extended indefinitely and topographical features become irrelevant. Because of this successful preliminary test, we proposed a more comprehensive evaluation during 2007. Clearly, mesh networks have a distinct advantage over the RFID technology because they overcome limitations of distance and topography that limit our current system. The objective of our 2007 study focused on integrating the mesh networks with the soil moisture and temperature measurement nodes we developed in our earlier work.



Initial routing of signals between motes. Routing of signals after turning off mote number 1. Hypothetical Mesh network.

Figure 1. Preliminary test of a mesh network conducted during 2006. The map on the left shows the original signal routing established by the mote system's software. The lines represent established signal paths that route data from the four motes installed in the field to the fifth mote acting as the gateway (GW). To mimic a failed mote, we turned off mote number 1. The middle map shows how the software automatically re-routed the signals between the remaining operational motes to maintain connectivity. Data from mote number 4 are now routed though motes 2 and 3 to reach the gateway. The schematic on the right shows a hypothetical mesh network of motes based on sensor node locations installed at this site during 2006.

Materials and Methods

For our 2007 study we used the same type of Mica2 motes used during the 2006 pilot study. These motes use transceivers operating at a radio frequency of 916 Megahertz (MHz) to provide the wireless component. The motes are manufactured and sold by Crossbow® Technology Inc. On board intelligent circuitry gives the motes the capability to acquire and analyze data in addition to transmitting the data wirelessly. Because the mote's radio circuitry includes a transceiver, the motes are capable of both transmitting and receiving wirelessly. This capability is used by the onboard operating system to allow the motes to act as repeaters – receiving and passing along transmissions from other motes. The transmission pathways, established mote-to-mote, create a mesh network. This is illustrated in Figure 1. If a pathway between motes becomes obstructed, the operating system will re-route the data through other motes. The wirelessly transmitted data from all motes in a network eventually reach a gateway where the data can then be uploaded to a data logger. The mote-to-mote communications and re-routing capabilities aid in overcoming obstructions and give the overall network great range.

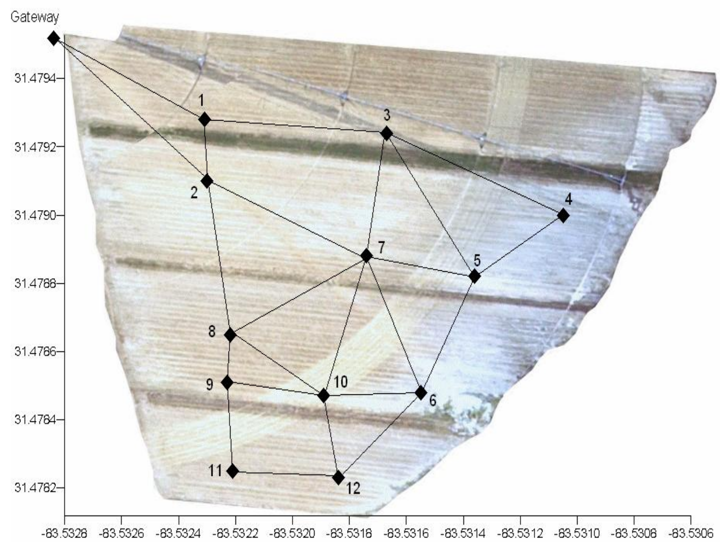


Figure 2. Mesh network established in the NESPAL field to evaluate the uses of motes for wireless transmission between sensor nodes.

During 2007, we substituted motes for the RFID tags in our smart senor nodes and installed the system in the NESPAL field for a season-long evaluation. The NESPAL field is 6 acres in size and located on the University of Georgia's Tifton Campus. Researchers performing a pest-related co-study in the field, planted the field in plots consisting of cotton, peanuts, and soybeans. Figure 2 shows the layout and mesh network established by the motes in the field. The photo in Figure 3 shows a node's circuit boards pulled part-way out of its enclosure. The green circuit board is the mote. The mote attaches to the sensor acquisition board through a 51-pin connector. The node circuitry is powered by two alkaline AA batteries mounted on the back side of the sensor acquisition board. Each node antenna was made from a 3.25 inch length of 14 gauge solid wire. The 3.25 inch length is specific to the mote’s 916 MHz transmit/receive frequency.

Results

Initially, the mesh network worked as expected, with each node reporting the soil moisture values. However, as the plant canopies grew taller, the motes’ transmission range decreased. This was most likely caused by a portion of the signal bouncing off

Figure 3. A sensor node's circuit board pulled part-way out of its PVC enclosure. The green circuit board is the mote. The node circuitry is powered by two alkaline AA batteries mounted to the back side of the sensor acquisition board.

the foliage and arriving at the receiving mote out-of-phase with the main component of the radio energy. This out-of-phase portion acts to attenuate the main rf beam. As the crop grew taller, the motes' transmitting and receiving ranges, which have a line-of-sight distance up to 400 feet over level, non-cropped ground, were reduced to a range of less than 120 feet.

One attempt to increase the motes' transmit range was to construct higher gain, collinear antennas. These are constructed by soldering together multiple 3.25 inch antenna sections. As the number of sections increases, gain, and ultimately range, increases. Initial tests of 4-section collinear antennas on non-cropped ground showed an increase of range of as much as 30%. However, when the collinear antennas were placed in the crop foliage, their range was no better than the original antennas.

To overcome this issue, the original antennas were inserted into the top of an 8 foot, 0.25 inch

Figure 4. To overcome the range issue, the original mote antennas were enclosed in an 8 foot, 0.25 inch diameter hollow, flexible, fiberglass rod. The rods were mounted to a PVC pipe used as a supporting stake with a spring used for conventional CB antennas. The pipe also supported the PVC enclosure housing the node circuitry including the Mica2 motes.

diameter hollow, flexible, fiberglass rod. The antenna was connected to the mote via an electrical cable that ran through the fiberglass rod. This placed the antenna above the plant canopy. The rods were mounted to the PVC enclosure protecting the electronics with a spring used for conventional CB antennas (Figure 4). The flexible rods and spring allowed field equipment, such as sprayers, to bend the rods and pass over the sensors without damaging them throughout the growing season. This solved the range issue but did make the node slightly more cumbersome to transport during installation. An unexpected benefit of this extended antenna was that it made the location of the sensor nodes easily visible and ensured that they would not be accidentally damaged during normal field operations.

A more serious problem may be that three of the 12 motes failed during the growing season. We were not able to determine the specific reason for the mote failures. After extensive discussions with the manufacturer, we concluded that the design of the motes may not have been robust enough to survive a full season in the field under the high heat, high humidity conditions experienced in southern Georgia.

We have recommended design modifications to the manufacturer which are now being implemented. A new design will be available for the 2008 growing season which should ensure that the motes will have a long, multi-season, life. The positive outcome of these failures was that we were able to document that the mesh network reestablished itself and the motes were able to re-route signals when the pathway between two motes failed.

Conclusions

Wireless mesh networks, formed by Mica2 motes, showed promise as an alternative to RFID tags for accessing soil moisture information from remote locations in an agricultural field. The motes were able to re-route signals when the pathway between two motes failed. Raising the antenna above the crop canopy allows the transmit/receive range of the motes to be maintained as the crop matures. We have held discussions with two different companies interested in commercializing the mesh network approach. The first is a small start-up agricultural electronics company based in Miller Co., Georgia. The second is a larger, well established agricultural electronics company based in Nebraska who has strong ties to national pivot manufacturers. There are no firm agreements at this time however we are optimistic that with the involvement of the Agricultural Innovation Center, progress will be made soon.

Acknowledgements

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