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Wireless Sensor Networks and Actionable Modeling for Intelligent Irrigation

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Wireless Sensor Networks (WSNs) are emerging as an invaluable tool in agriculture. Current WSNs are good at reporting sensor data and many provide simple tools for viewing the data. The current approach assumes that growers are familiar with how the data should look and they are trained to use the data. This work extends the usage of WSNs to provide growers with actionable results based on the data. We are currently implementing plant physiological models for specialty crops into the CMU SensorWeb system. These models predict water usage, allowing growers to precisely control irrigation schedules. The sensor nodes used in this work also have onboard control functionality for automating crop irrigation based on the model's output. In this paper we present a framework for integrating models into WSNs and initial field results from this model driven approach.

Keywords. *sensorwebs, wireless monitoring, actionable models, WSN, irrigation, model, scheduling, real-time, internet, user interface, remote*

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Introduction

Wireless Sensor Networks (WSNs) are emerging as an invaluable tool in agriculture. The ability to monitor environmental parameters enables growers to save resources while improving crop yield and helps agriculture researchers study crops with high-fidelity, high-resolution data. In order for the data from the WSN to be useful the visualization tools must be easy to use, advanced real-time data products need to be accessible, and the data needs to be actionable. This work focuses on developing an easy to use interface and a framework for integrating models that allows the system to take data and produce an actionable result using onboard control functionality to control irrigation.

System Description

Our WSN system consists of nodes designed at Carnegie Mellon University (CMU) as well as nodes developed by Decagon Devices Inc. The CMU nodes (Figure 1) (Lea-Cox, J. D. 2008) are highly flexible nodes capable of reading from up to 11 sensors and serves as a testbed (Valada 2011) for testing new ideas and approaches. We are using two nodes developed by Decagon Devices Inc., an off the shelf EM50R wireless sensor node (Figure 2) (Decagon. 2011) and a modified EM50R that can control irrigation solenoids.



Figure 1: CMU node in a production greenhouse in Maryland



Figure 2: Decagon EM50R node. The new node with irrigation control ability looks similar (Decagon. 2011).

The second critical component of our system is the intelligent base station. Our intelligent base station has the software tools to configure the nodes, modify calibrations, view the data both spatially and temporally, assign models to process the data, and an irrigation controller. The base station is typically connected to the internet through a hard line connection (DSL/Cable) or a cellular modem to allow remote access to the data.

The base station uses a sqlite3 database to store all the data from the nodes and to make it available to the web based user interface. The user interface is written in Ruby on Rails to provide a seamless database experience.

The system is setup such that all data and functionality is available locally, however, since many nurseries and greenhouses have poor internet connectivity we also host a mirrored version of the interface on a high speed server at CMU. This allows for high reliability connections as well as faster data access time (Figure 3).

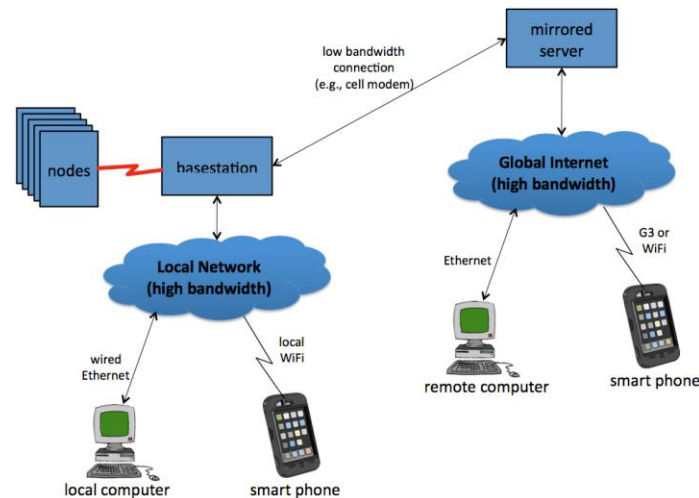


Figure 3: System configuration showing local and remote access options

Data Visualization

There are two primary ways to view the data, spatially and temporally. Spatial views (Figure 4) can be used to show various measurements on location as well as provide a quick view for spotting any problems. Our system also allows the user to choose which measurement is displayed spatially (each color is the average value from all similar sensors at that location). Temporal views can be used to see how the data changes over time (Figure 5). Some growers have reported switching from using temporal views to using the spatial views for daily monitoring since they can view the data faster.

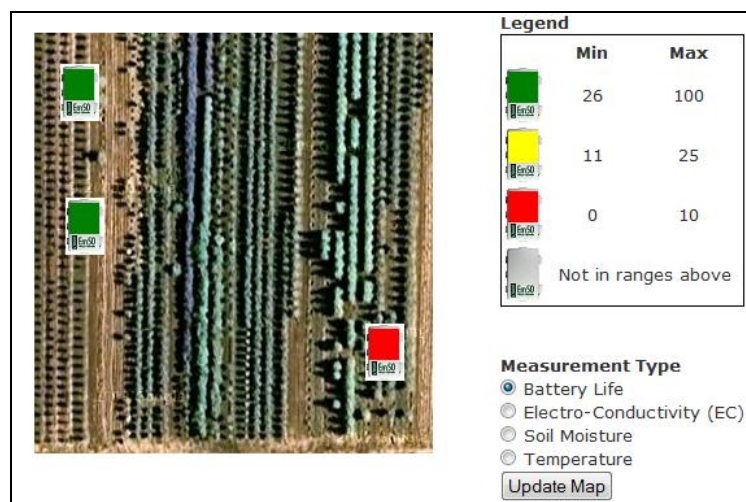


Figure 4: Spatial view with user configurable views and color ranges

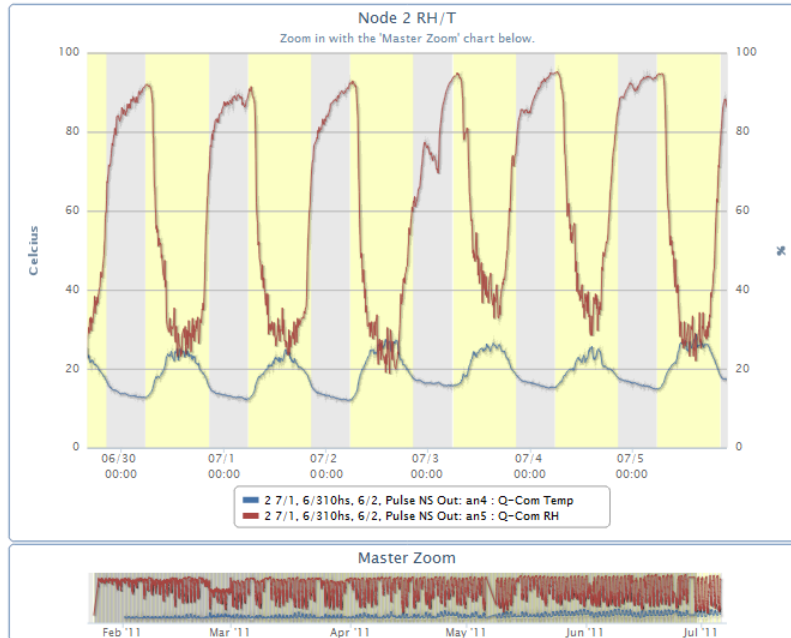


Figure 5: Temporal data. Visualization features such as color coded bars for daytime and nighttime hours help the user interpret the sensor readings

Model Integration

Almost all growers are concerned with water management. This can be for many reasons including water availability, runoff, and government regulations (Lea-Cox, J. D. 2009). In order to get the most out of available water and minimize waste, we use models to predict water requirements of a plant based on current and recent field measurements taken from sensors on the nodes (Bowden, J.D. 2005). Before using a model it needs to be installed by adding an entry to the main database that lists the model's name, how often to run the model, the input units, and the output units. Once installed this framework consists of 3 components (Figure 6).

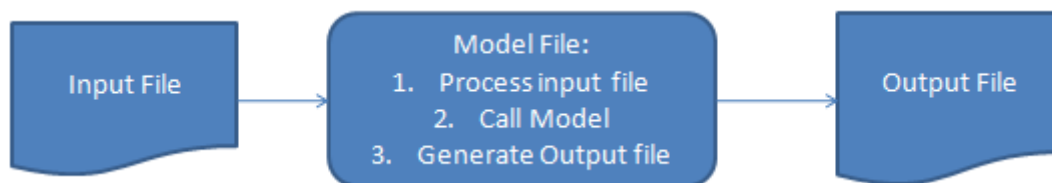


Figure 6: Flowchart of 3 step process for using the model framework

The input file (Figure 7) which contains the parameters necessary for the model to run is generated by the base station at a predefined interval specified by the user while creating the model instance. The second component is the model file, this script first processes the input file and then either performs the model's computations or calls the necessary program that is needed for the model and generates the output file. The output file (Figure 7) contains the processed result from the model and is in a form that the modeling infrastructure can understand. The base station then takes this output file, makes it viewable to the user, and applies the proper amount of water to the plants as computed by the model.

```

<model_input>
  <model_id>1</model_id>
  <model_name>petunia</model_name>
  <version>1.2</version>
  <flow_rate>2</flow_rate>
  <sample_rate>5</sample_rate>
  <last_run_time></last_run_time>
  <last_irrigation_time>1308824059</last_irrigation_time>
  <last_irrigation_volume>12</last_irrigation_volume>
  <units>time,umol/m2/s</units>
  <data>1308824159,600;1308824259,400;</data>
  <meta_data>1306721010</meta_data>
</model_input>

<model_output>
  <model_ID>1</model_id>
  <version>1.2</version>
  <model_name>petunia</model_name>
  <units>ml,time</units>
  <time>1309276672</time>
  <output_values>160.721,0.0212</output_values>
</model_output>

```

Figure 7: Sample model input and output files for a petunia model (van Iersel. 2010)

Irrigation Control

Our approach to irrigation control is to let growers create a schedule for when water needs to be applied and then interrupt the schedule as needed to save water. This system provides growers with four operating modes. The first is a schedule based controller that is similar to what is common in the industry. There are then two different options for overriding this schedule to decrease the irrigation time in order to reduce water use, a local setpoint controller and a global controller. The schedule+local setpoint controller enables the node to make local control decisions based on sensors attached to the node. While the schedule+global controller allows the grower to use data from any node in the network, calculated data or models to control the irrigation and determine if the schedule should be interrupted. The fourth mode is a manual override mode that allows the grower to water for a given number of minutes (Figure 8).

The screenshot shows a web-based irrigation control interface. At the top, there's a dropdown menu for 'Select Node' with 'Snap Dragon Bed 1' selected. Below this, the 'Relay Mode' is set to 'Global setpoint control' (indicated by a blue dot). The 'Global Source' is 'Averaging Tool' and 'Global Sub-Source' is 'Port/Output 1'. The 'Low Setpoint' is 20 and 'High Setpoint' is 30. The 'Pulse Type' is 'MicroPulse' with a link to 'Edit pulse types here'. A 'Set Schedule Here:' section features a timeline from 6am to 6pm with several blue bars representing irrigation events. Below the timeline, a red text message states 'Maximum water usage per day is 1.44 gallons'. At the bottom, there's a section for manual commands: 'Send manual command to node Snap Dragon Bed 1 to turn on irrigation for [] minutes.' followed by a 'Send Manual Command Now' button. A note below reads '(note: It may take a few minutes for the command to take affect)'. There is also an 'Update Controller' button.

Figure 8: Part of the irrigation interface that allows for easily setting a schedule and defining irrigation events

Our system gives the grower the ability to control how water gets applied to the plant with various user settable irrigation parameters. The user can choose between a mode where water will be applied slowly with small delays in between to allow the water to reach the subsurface sensors or a mode in which the water will be applied continuously for a specified period of time

This approach enables the irrigation controller to perform exceptionally well in different growing environments.

Security Considerations

Creating an internet accessible irrigation controller creates a heightened need for security. In order to secure this system we introduced an additional layer of security that requires all irrigation controller changes be initiated from the local network or from a list of approved IP addresses. This helps ensure that only computers in trusted domains have access. The next step in securing the system requires user authentication so that both the user and the network is approved. There are three levels of control. In the *Data View Only* group, the users can only view the data but cannot modify any control configurations. This level is good for collaborators and field employees who need to see current and past data. In the *Control Authority* group, the users have the ability to view data as well as control the irrigation settings for the nodes. Users in the *Administrator* group have all the abilities of the Control Authority group but can also create and modify user accounts and privileges.

Future Work

There are still many areas where additional research and development are needed to fully benefit from WSNs. From a technological point of view we need tools that can handle large amounts of data, since many current systems slow down tremendously when working with large data sets. We also need to do a thorough user interface study on how growers actually use these interfaces and determine what features are still needed. From a plant science point of view we need to incorporate more models that have actionable outputs. There are many models today that can be adapted to run regularly and to provide actionable results with relative ease. We also need to verify the validity of these models. We are making rapid progress in solving these problems. We are developing tools to scale data as required to improve speeds and are also working with scientists and growers to actively integrate their models into this framework. This will let users select a plant model almost effort- free and begin to evaluate the model performance and reduce their water consumption.

Conclusion

The ability to get high resolution data, interpret it, and create an actionable conclusion is a critical ability for a WSN. Our work presented in this paper demonstrating an approach to integrating scientific plant models into a WSN system and providing the ability to automatically control irrigation based on actionable models. We believe that this approach is highly flexible and meets the needs of nursery and greenhouse applications moving into the future.

For more information on this project please visit <http://www.smartfarms.net> to learn how to save water, increase efficiency and to reduce environmental impacts.

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