Optimal Site-specific Configurations for Wireless In-field Sensor-based Irrigation

by

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Abstract:

The spatial variability of agricultural fields has been addressed widely over various research papers, while difficulty remains to optimize the site-specific field configuration. Because of the complexities and time constraints involved in real-time irrigation scheduling, integrated feedback of soil water and micrometeorological sensors distributed across a field is necessary for continuous update on decision support of irrigation systems. There is a demand to improve procedures so that the minimum number of in-field sensor systems would be placed with maximum impact to the decision support.

The performance of the wireless data collection is evaluated on the experimental plot prepared with conventional irrigation schedule. Each sensor station consists of sensors for leaf temperature and humidity, soil temperature and moisture, and rain gage. Optimized sensor distribution produces cost-effective system with increased computational speed, while frequent feedback of plant-based sensors and soil water sensors minimizes drift from actual conditions.

Keywords: precision agriculture, wireless network, irrigation, real-time, sensing.

INTRODUCTION

The rapid development of sensing, computing, and information technologies has introduced new concepts on the management and control of agricultural systems. Precision agriculture is a concurrent system utilizing many technologies for site-specific management: Global Positioning System (GPS) for site-specific mapping, Geographic Information System (GIS) for decision support, ground or remote sensing for biomass formation, harvest sensors for yield mapping, and information technology for on-farm database system. The benefit of precision agriculture will be achieved by the seamless integration of all these subsystems. Wireless radio frequency has been widely applied in consumer's electronics and provided opportunities to deploy wireless data communication in agricultural systems.

A wireless in-field sensing network is proposed for sensor-based irrigation system. The system consists of in-field sensing stations, a decision support engine, and an irrigation nozzle controller. The sensing stations monitor soil and plant status across the field and are tele-metered by 915 MHz spread spectrum radio. Decision support is made out of database of all on- and off-field information and sends an application map to the irrigation controller via ethernet bridge to operate individual nozzles.

The paper describes a framework of wireless in-field sensor network for automated irrigation system and evaluate optimal site-specific configuration for the wireless sensor network. Optimized sensor distribution can produce cost-effective system with increased computational speed, while frequent feedback of plant-based sensors and soil water sensors minimizes drift from actual condition.

WIRELESS NETWORK OF IN-FIELD SENSING STATIONS

A project was established to develop wireless network of in-field sensing stations for real-time irrigation decision support by Northern Plains Agricultural Research Laboratory at USDA-ARS on early 2004. The research presented in this paper is a part of project to evaluate optimal site-specific configuration for the in-field sensor network.

Motivation

The concept of the wireless in-field sensor network for automated irrigation system was derived from managing an irrigation system quickly, accurately, inexpensively, and globally. End-users such as farmers can quickly access for irrigation control by real-time monitoring and scheduling with hands-on technical support via online knowledgebase. The direct access to the field condition is accurately supported by in-field sensor network configured based on pre-sampled soil property maps, enabling site-specific application from localized database. Rapid development and popularity of wireless technology has been reduced cost and improved the range of data communication without interference using spread spectrum radio technology. The development of online interface allows the end-users to globally access their irrigation monitoring and controlling anywhere and anytime.

Deliverables

The wireless in-field sensor network systems enable end-users to remotely access to field condition via online monitoring. The development of knowledgebase can provide for farmers real-time actions suggested to site-/time-specific application on product-identified data. From the standpoint of developers, it takes an advantage of remote access to in-field sensor stations and enables real-time manageability. The online infrastructure can provide direct link between the end-users and developers and thus enable real-time electronic-support (E-support) from GIS-identified database through secured access.

The sensor network for automated irrigation system is a user-friendly system with the promise of a future-leading technology for a precision irrigation system. The system will provide efficient irrigation management for both end-users and developers, as it becomes accessible, displayable, communicable, and supportable.

Approaches and Design

The wireless in-field sensing-based irrigation system can be achieved by a seamless integration of sensing, control, and wireless data communication. In hardware review, wireless I/O system was selected because a wired system is expensive to install and maintain. In some cases, it is difficult or impossible to install wires. A wireless system takes advantages of dynamic mobility and cost-free relocation. There are many different wireless technologies available in the market. Most of recent wireless technologies follow a standard such as 802.11, Bluetooth, or Zigbee, which adopts spread spectrum technology. Three spectrum bands (902~928 MHz, 2.4~2.48 GHz, and 5.7~5.85 GHz) were allocated for license-free spread spectrum devices (Kulkarni, 2005). The choice of wireless standard depends on how to interface: distance, data rate, compatibility, interference, and security. Major two factors are distance and speed.

The wireless in-field sensor network requires large networks that can form autonomously and operate reliably without any operator intervention for long battery life extended by solar power. Network topology is determined by a number of nodes and coverage area. A simple wireless network topology called an ad-hoc network consists of a set of wireless stations that communicate directly on peer-to-peer level without an access point, as shown in Figure 1. An infrastructure network allows more flexible configuration by bridging the wireless and wired networks via access points (Meel, 1999).

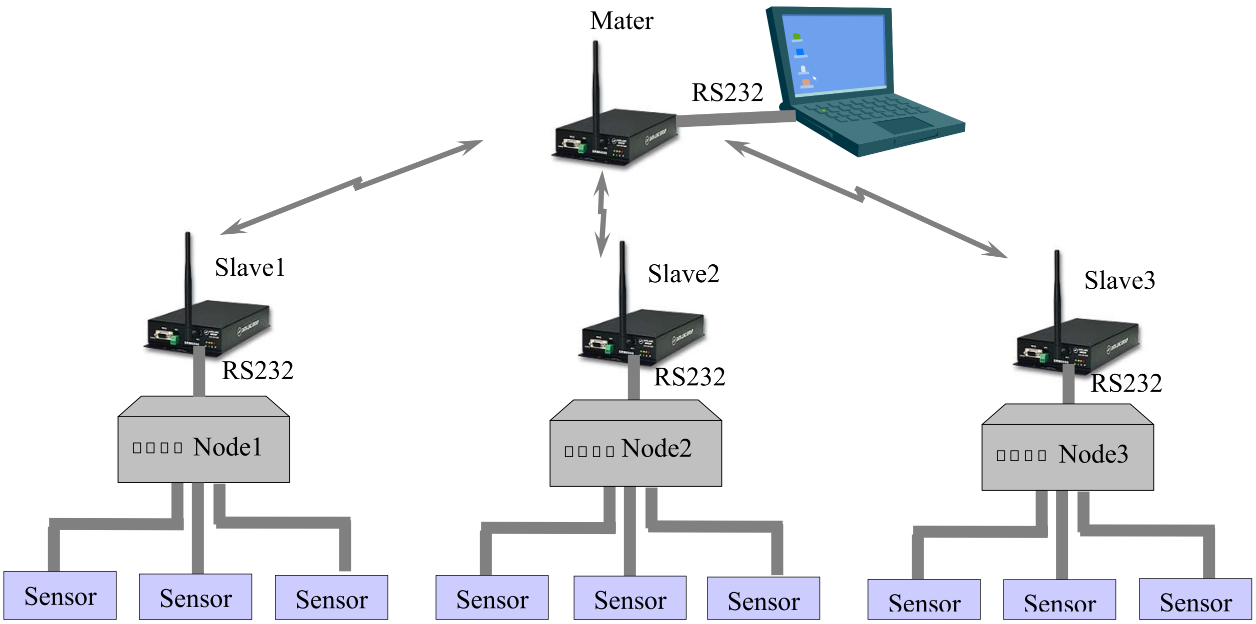

Figure 1 Ad-hoc network topology.

Data processing and management

The network infrastructure provides data communications from all available information sources. The development of microprocessors in the 1970's made it possible to realize many complex functions in a simple manner and enhanced the sensing and data processing in a unified framework. In-field information is acquired by data processing from raw data through filtering, transmitting, and fusion and sent to data management which performs decision-making, display, and diagnosis. The schematic diagram of data flow is shown in Figure 2.

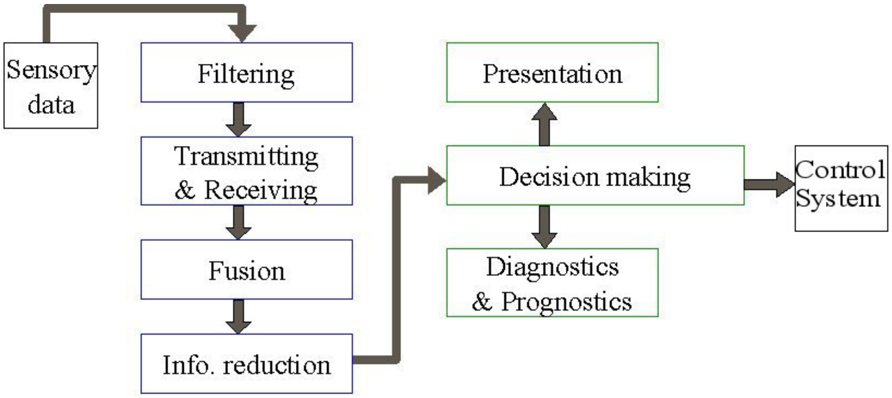

Figure 2 Schematic diagram of sensory data flow.

Data processing is a sequence of data flow from the raw sensory data to the refined data that is prepared for data management. A set of raw data are filtered to remove the noisy signals and transmitted in a suitable data format. Data fusion performs integration of low-level information provided by different kinds of sensors. The fusion of the collected data results in higher-level information that is more easily assessed by end users. Accordingly, the data fusion can provide efficiency in the decision-making process. Finally, data are screened to remove unrelated information and integrated. Refined data from the measurement system needs to be delivered to the management system. Information delivery in a timely fashion was emphasized by Harbers and Hoogenboom (2000) for their real-time database in application of dynamic web content.

Each sensory data have tolerances which relate directly to the original sensor modality and to the sensor-dependent algorithms. These tolerances may determine the overall accuracy of the system. The system will have benefits from the ability to compare the measurements of multiple sensor systems and thus provide a means of highly accurate tuning of the algorithms of all different sensor systems.

Decision making

The decision-making is a process of engineering information. A decision is made based on given information and knowledge. Integrated information system for the management in agriculture was discussed by Thiel *et al*. (2000) that used executive control center to combine the function of operative systems, decision support systems, executive information systems, and groupware systems. A correct decision is made when these two components are accurately obtained. In reality, however, the given information and knowledge often include uncertainties and also complexity arising from the dynamic nature of the underlying phenomena.

The flowchart of the dynamic decision-making process is illustrated in Figure 3. The collected information about the field condition is used to make a decision at each time frame. Field conditions are varying both independently and by the result of the previous decision. Thus, the decision is dynamically determined by the changing information from the time-variant environment just like an analogy to a medical decision making a proper treatment in time for a patient under his or her changing physical conditions over time. Similarly, decision-making in the agricultural system is to determine an optimal amount of irrigation or fertilizer with respect to various crop conditions over time and for different sites. The complexity of these problems is amplified, if information about the nature and the time of a certain situation are uncertain.

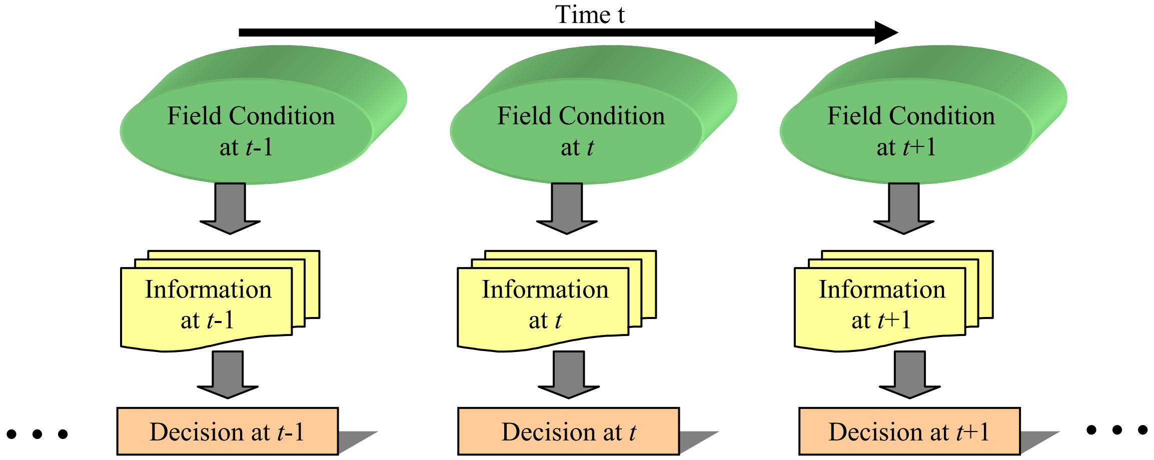

Figure 3 Flowchart of dynamic decision making process.

Information must be provided for flexible and efficient access. Visual display is useful information presentation. Descriptive information associated with processed sensory data can be represented to enable an end-user to easily access and efficiently manage the information. A communication protocol for a distributed nozzle control system may use a network bus such as Controller Area Network (CAN) which enables a huge reduction in wiring complexity with high speed, high reliability, and low cost for distributed real time control applications (Ekiz *et al*., 1996). The CAN system can provide direct feedback to the information collection and used to check the current status of each nozzle pressure. CAN bus application of distributed control to closed environments in agriculture was addressed by Alves-Serodio *et al*. (1998).

Conceptual system layout

A conceptual layout of wireless network of in-field sensing stations for real-time irrigation decision support system is illustrated in Figure 4. The wireless sensing stations monitor the in-field plant condition such as air temperature, relative humidity, soil temperature, soil moisture, and rain gage and transmit data into a base receiver connected into an office computer. A decision making is accomplished based on information given by in-field sensing stations and weather station and send outputs to an irrigation controller. The data processing and management are implemented by a computer that is bridged to internet database with secured access.

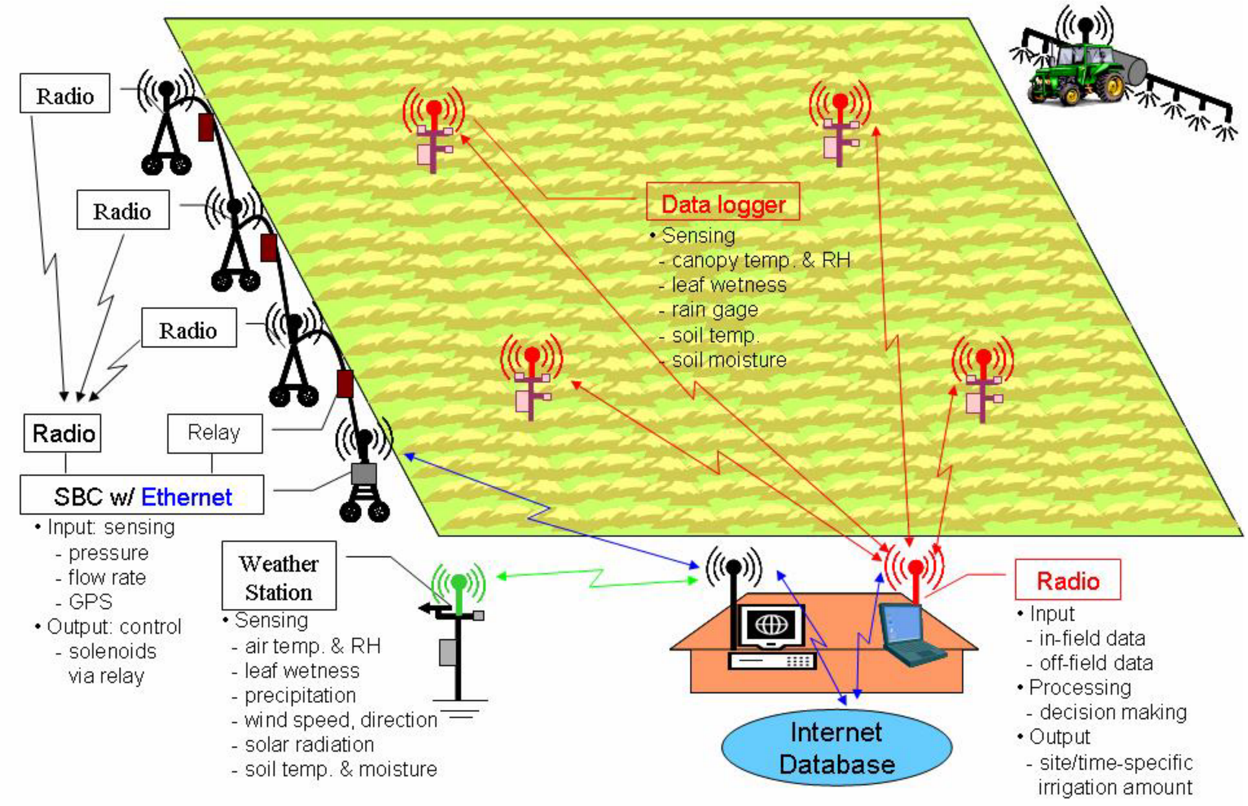

Figure 4 Conceptual layout of wireless network of in-field sensing stations for the real-time irrigation decision support system.

SITE-SPECIFIC FIELD CONFIGURATION

Agricultural fields are not homogeneous and varying across the field. The field variability continues over the time and site, affected by natural environmental impacts and human's agricultural inputs such as seeds, irrigation, fertilizers, and pesticides. The variability results in yield varying across the field. One of the major factors of field variability is the change in soil properties.

Spatial field variability

The field variability has to be taken into consideration to configure in-field sensor network. The spatial variability of agricultural fields has been studied to optimize the site-specific field configuration for wireless in-field sensor-based irrigation. The study of the field variability can provide procedure such that the minimum number of in-field sensor stations would be placed with maximum impact to the field information.

Soil property has a major impact on crop yield (Farahani, 2004). Among the many factors of field variability, soil electrical conductivity (EC) and compaction were used to map the field variability, because they are most widely used to characterize agricultural fields (Farahani, 2004 and Drummond *et al*., 2000). The EC measures the amount of salt in the soil as well as other soil properties and thus can relate to soil properties of sand, clay, and organic matter. Mapping soil EC and compaction may not identify yield variability, but provides a useful field characteristic for optimal site-specific configuration of the field variation.

A soil profiler (Veris 3000, Veris Technologies, Salina, KS) was used to map soil compaction and EC on an experimental field. The profiler is an automated system equipped with a penetrometer and soil EC probe (Fig. 5). The probe is vertically pushed into ground by a hydraulic power generated by self-contained 5.5 hp engine and measures pressure in MPa and EC in milliSiemens per meter (mS/m) at the probe tip sensed by its load sensor (Veris Technologies, 2002). The data are logged every 2 cm interval up to 92 cm in depth with geo-referenced points using DGPS (Trimble Ag132).

Figure 5 Soil profiler (Veris 3000) to measure soil EC and compaction.

Mapping spatial field variation

An experiment was conducted on a 1.4 ha field at Nesson Valley research farm located 23 miles east of Williston, North Dakota on April 14, 2005. The profiler measured soil compaction and EC at the probe tip sensed by its load sensor and associated with geo-referenced locations. A total of 134 data were collected with average 7.6 m sampling interval.

Geostatistical analysis was performed with GIS software (ArcGIS ver. 9.1, ESRI, Redlands, CA). Kriging model was used to interpolate both soil EC and compaction data and created spatial maps with five classifications by a quantile method. Figures 6 and 7 illustrate the spatial variation map of soil EC and compaction, respectively, at 30 cm soil depth. Both figures show field variations with a different trend. The soil EC in most of east area is uniform, while more variations were found in west area with highest EC in northern west area (Fig. 6).

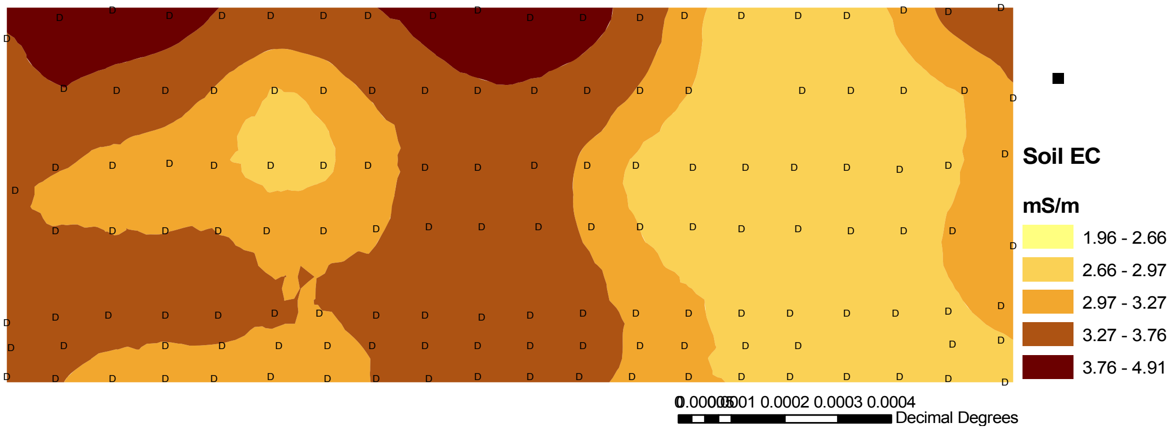

Figure 6 Spatial mapping of soil EC at 30 cm subsurface with a profiler (Veris 3000).

A spatial map of the soil compaction at 30 cm subsurface was created based on pressure reading sensed at a probe tip and displayed in figure 7. Although a few variations were found along the field edges, most of area remained uniform with the compaction of about 2 MPa. Highest compaction was located at northern east area of the field. The small scale of variation from 1.04 to 3.44 MPa indicated uniformity of the field.

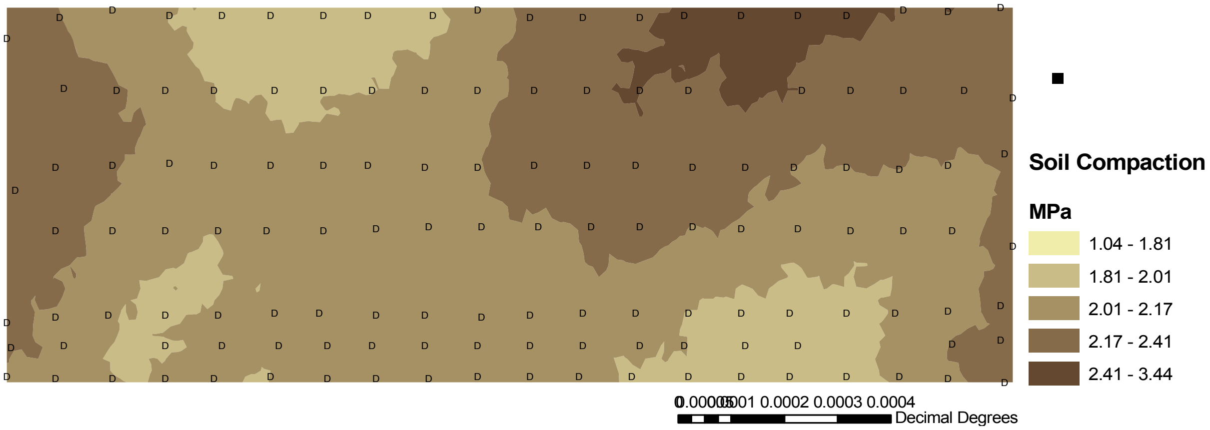

Figure 7 Spatial mapping of soil compaction at 30 cm subsurface with a profiler (Veris 3000).

CONCLUSIONS AND FUTURE WORKS

A wireless in-field sensor network for automated irrigation system was presented. The research was motivated to manage an irrigation system quickly, accurately, and inexpensively. Spread spectrum wireless technology was selected for its dynamic mobility and cost-free maintenance. Data processing and management were described from raw data to decision making through information flow.

The spatial field variability was studied on an experimental field to optimize the site-specific field configuration. Soil EC and compaction were sampled to map the field variability and geo-statistically analyzed to create spatial field variation maps. The soil compaction map resulted in minimal variation, whereas the soil EC map showed direct source to optimize network topology for site-specific field configuration,

The system framework was constructed and details on hardware interface and software will be investigated and developed. Future works include development of knowledgebase for decision making and integration of the sensor network with an irrigation controller.

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