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# WEB/SMART PHONE BASED CONTROL & FEEDBACK SYSTEMS FOR IRRIGATION SYSTEMS

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## ABSTRACT

The role of the internet and mobile devices in the control and feedback of irrigation systems is reviewed. This role is placed in the larger context of four distinct components required for irrigation management, including 1. The Control Panel; 2. Remote Control; 3. Soil, Plant, and Weather (SPW) sensors and feedback; and 4. Analytics. Numerous products and software are now commercially available that include one or more of these components, and these can be built into a custom system that can be changed and expanded according to management needs. Ongoing research and development is making advances in all four component areas, but the most rapid advances and growth in commercial products are anticipated for sensors and analytics.

## INTRODUCTION

> *"Within a few years a simple and inexpensive device, readily carried about, will enable one to receive on land or sea the principal news, to hear a speech, a lecture, a song or play of a musical instrument, conveyed from any other region of the globe. The invention will also meet the crying need for cheap transmission to great distances, more especially over the oceans. The small working capacity of the cables and the excessive cost of messages are now fatal impediments in the dissemination of intelligence which can only be removed by transmission without wires"* (Tesla, 1905).

The confluence and availability of several technological developments in the past decade has ushered in what many consider to be a new era in irrigation management. The control and feedback of irrigation systems is now practical and profitable using the internet (web) and mobile electronic devices (most commonly in the form of smart phones). The efficient operation and management of any engineered system or process requires some level of remote control and feedback; this has been recognized in Western civilization since the dawn of the Industrial Age, and by technically innovative civilizations for millennia prior (Hughes, 1989). The return on investment of control and feedback components is generally commensurate with the size and complexity of the system being managed, provided the components themselves are not too costly and do not have excessive learning curves (Kutter et al., 2011). Since web-based applications and mobile devices now mostly meet these criteria, remote control and feedback of agricultural irrigation systems are being increasingly adopted, resulting in reduced management time and other resource expenditures, such as transportation to and from field sites (Car et al., 2012).

Wireless control and feedback for irrigation systems have been commercially available at least since the 1980s (Duke et al., 1990). These usually used radio telemetry (RT), and later, cellular service as it became available. However, these were usually dedicated systems, meaning that they were isolated and not very versatile or expandable. Some systems had limited range that was inadequate for most agricultural operations, except for those on relatively small areas. Sensors required for feedback were impractical because they were hard-wired, costly, and had limited accuracy and service life due to harsh operating environments. Computers and dedicated processors used to transform data into usable and meaningful formats had severe limitations in speed and capacity (Phene et al., 1990).

The growth of the internet, speed of data transmission, and capacity of personal computers during the 1990s resulted in new possibilities for remote control and feedback of virtually any industrial or agricultural system. However, practical day-to-day management of agricultural irrigation systems would also require affordable wireless communication and a mobile user interface (Kranz et al., 2012). High-speed rural internet, adequate rural cellular coverage, WIFI, and small and lightweight mobile devices became more widely available and dependable during the first decade of the 21$^{st}$ century. Continued integrated circuit miniaturization, continued software development, and continued scientific research and development of irrigation and crop water productivity are additional prerequisites, but web and smart phones are now becoming essential tools for irrigation management (Car et al., 2012; Hu and Hillyer, 2018).

The objectives of this report are: 1. Organize the various components used in irrigation management into four logical categories, which should help elucidate the roles of the web and smart phones; 2. Review several web- and smart phone-ready products and systems offered by center pivot and third party manufacturers; and 3. Discuss ongoing research and future developments in remote monitoring and control. Although the focus will be mainly in the context of center pivots, many aspects also apply to lateral move systems and microirrigation (e.g., subsurface drip irrigation). The scope of this report is not limited to precision agriculture or precision irrigation; these topics have been well-addressed elsewhere (e.g., Evett et al., 2017). However, we argue that adoption of the various components described herein will strongly influence the level of precision that is achievable in irrigation systems and their management.

## COMPONENTS OF IRRIGATION MANAGEMENT

Numerous tools and components have been developed for irrigation management (Table 1). These can be built as a custom system and changed and expanded according to management needs (Figure 1). Most components are commercially available and are being adopted, and a few are nearing commercialization. We have organized these components into four broad categories, which roughly correspond to their function and chronological development. These include: 1.The Control Panel; 2. Remote Control; 3. Soil, Plant, and Weather (SPW) feedback; and 4. Analytics.

### 1. Control Panel

The traditional control panel site is usually at the pivot point or one end of the lateral move. Its primary function is to CONTROL, MONITOR (i.e., feedback and alerts), and RECORD all variables of interest of the irrigation system. The control panel has evolved from a box containing analog switches and gauges (which may control and monitor but not record) to digital touch screens. The complete system of hardware and software used to control, monitor, and record any process or system, including irrigation, is termed Supervisory Control and Data Acquisition (SCADA). One such

system was developed and patented for variable rate irrigation (VRI) by Evett et al. (2014), termed the Irrigation Scheduling Supervisory Control and Data Acquisition (ISSCADA). Most SCADA systems, including ISSCADA, also include at least one component of remote control, SPW feedback, and analytics.

## 2. Remote Control

The consolidation of irrigated areas under a single management entity has increased the need for remote control, where the complete SCADA system can be accessed off-site. Many irrigation systems are at remote, often difficult-to-access locations (especially following precipitation), and lack telephone land lines. Therefore, remote control often requires wireless communication (e.g., cellular, satellite, RT, WIFI), which can be linked to a mobile device directly or via the internet. Remote control software (i.e., "apps") can reside and execute virtually anywhere in the system, such as in the component firmware, on the web, and in the mobile device (Bartlett et al., 2015).

## 3. Soil, Plant, and Weather (SPW) Feedback

Soil, plant, and weather (SPW) feedback is by sensors deployed in the field; this is distinct from feedback related to the irrigation system itself (compare variables listed in the 1st and 3rd categories in Table 1). Many SPW sensors were developed before the 1960s, and have been used in both research and commercial production since, although their use has been limited by cost, accuracy, harsh field environments, and the need for wireless data transmission (Phene et al., 1990). Automated data acquisition was developed and increasingly adopted in the 1970s and 1980s. The first automated agricultural weather stations used land telephone lines to transmit data. This was followed by cellular and then internet service (Elliot et al., 2000). Wireless interfaces were developed for existing and new field sensors with the advent of several wireless protocols, such as the Zigbee standard (O'Shaughnessy et al., 2011; 2013). Numerous wireless sensors are now available that can be accessed directly in the field by a mobile device via Bluetooth or WIFI, or accessed through commercially available SCADA systems offered by center pivot or third party manufacturers (see later section). These have greatly enhanced sensor ease-of-use and adoption.

## 4. Analytics

Analytics are concerned with reports, forecasts, and decision support tools for irrigation management. Analytics can be a major component of a SCADA system, and similar to remote control apps, can reside and execute anywhere in the system (e.g., firmware, web, or mobile device). However, analytics are a step beyond merely acquiring data, where they include additional calculations to synthesize data into meaningful reports, and forecast future conditions using crop and weather modeling. These feed into decision support tools (e.g., variable rate irrigation prescriptions, or VRI Rx) and irrigation system automation (O'Shaughnessy et al., 2015; 2016). For instance, weather data and canopy temperature measurements can be used to map crop water stress, which can be used to trigger irrigation events (O'Shaughnessy et al., 2013). The role of analytics will become more crucial as SCADA systems acquire increasingly voluminous amounts of data, and we find ourselves "drowning in information but starved for knowledge" (Naisbitt, 1982). At the same time, practical field experience is still relevant and will guide successful adoption of analytical approaches (Cahn, 2017).

## COMMERCIALLY AVAILABLE COMPONENTS

The five major US center pivot / lateral move manufacturers and several third party manufacturers offer hardware and software products that span several component categories, and are web and smart phone ready (Table 2). The products are built around a SCADA system that includes a control panel, remote control, interfaces to SPW sensors (usually third party sensors), and some analytics. Many products are modular and expandable in terms of the number of irrigation systems that can be handled and the number of components or features that can be added. Some products are interchangeable across center pivot manufacturers. Many require an annual subscription or license fee for firmware and software updates, technical support, maintenance, etc., although some products offer a one-time fee. Presently, most of the analytics are limited to irrigation history reports, irrigation prescriptions (i.e., VRI Rx), and evapotranspiration history and forecasts to approximately one week. Ongoing research and development is rapidly making advances in SPW sensors and analytics, as described in the next section.

## ONGOING AND FUTURE DEVELOPMENTS

Control panel and remote control components are well-established as core components of SCADA systems. Numerous products that embody SCADA and that are linked by the internet and mobile devices are commercially available and gaining acceptance, but are constantly evolving in concert with industry-standard communication protocols, along with the expanding capabilities of SPW feedback and analytics. Rapid advances and market demands in these areas are resulting in many new products and software under development and being introduced.

Sensors that measure soil temperature, electrical conductivity, and report volumetric soil water content are now available as a single encapsulated unit (Schwartz et al., 2016). Also available are wireless infrared thermometers that measure crop canopy temperature; measurements are accessible by smart phone and the internet (O'Shaughnessy et al., 2011; Colaizzi et al., 2018). Drones have been well-established in mapping crop reflectance and temperature (Berni et al., 2009; Yemoto and Zhang, 2018), and sensors are being developed to more efficiently distinguish between soil and vegetation ground coverage and temperatures (O'Shaughnessy et al., 2018).

Analytic components are presently under development, where sensor measurements are combined with weather data and irrigation events recorded by a SCADA system to produce maps of crop water stress (Bellvert et al., 2014; Gago et al., 2015; O'Shaughnessy et al., 2012; Osroosh et al., 2015), crop evapotranspiration (Colaizzi et al., 2017; Xia et al., 2016), soil water depletion (Evett et al., 2015), crop growth and development (Webber et al. 2017), and final crop yield (Wang et al., 2017). When available on mobile devices in real time, these sensors and analytics will help producers make better irrigation management decisions, with the overarching goal of increasing net returns.

## CONCLUSION

Web-based applications and mobile hand-held devices (e.g., tablets or smart phones) are now routinely used in the control and feedback of irrigation systems. The mobile device may well be used more often than the traditional control panel throughout the growing season, provided coverage of wireless communication and internet speed and capacity are adequate. The control panel, remote control SPW feedback, and analytics are four distinct components of managing an irrigation system, and numerous products are now commercially available that integrate these

components. Research and development in all four components are ongoing, but growth in SPW feedback and analytics has been rapid, and new types of field maps that are instantly viewable on mobile devices will become commercially available, as Nikola Tesla had envisioned in 1905.

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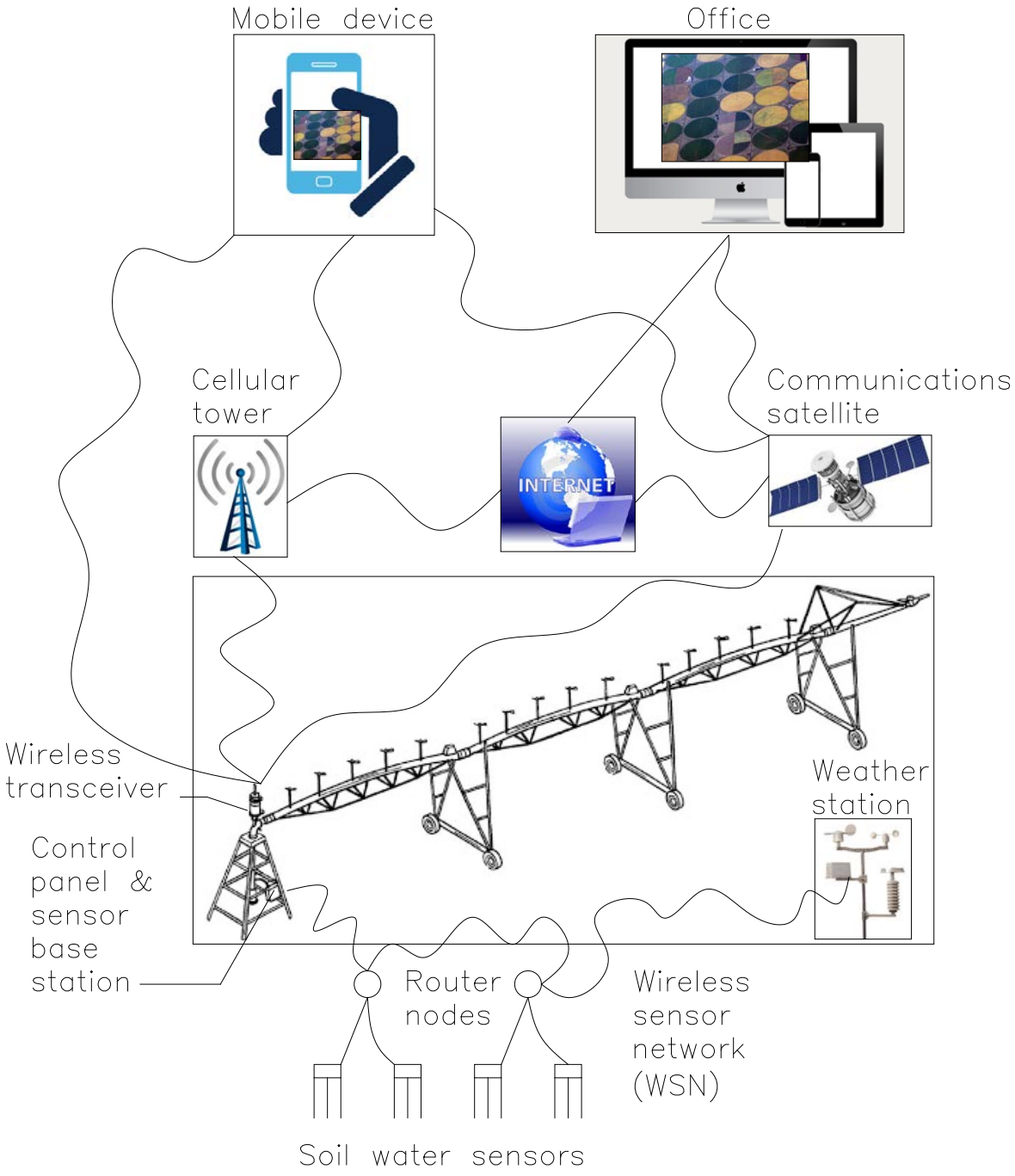


Figure 1. Wireless and web-based remote control and management of a center pivot.

Table 1. Conceptual categories of components used in irrigation management.

| Component | | Description and examples |
|---|---|---|
| 1. | Control panel | On-site user interface, usually the control panel, to CONTROL, MONITOR, and RECORD a stand-alone irrigation system<br>Embodies Supervisory Control And Data Acquisition (SCADA)<br>Control includes on/off, direction, speed, flow (e.g., variable frequency drive [VFD]), prescription (Rx, uniform or variable rate irrigation [VRI]), fertigation, chemigation<br>Monitoring should include everything controlled, and should also include position/location (GPS), pressure, water levels, cable integrity (e.g., theft detection)<br>Recording establishes a permanent record of all variables that were controlled and monitored |
| 2. | Remote control | Suite of hardware and software for off-site control, monitoring, and recording<br>Off-site can be near as field edge, or anywhere in the world<br>Unlimited number of irrigation systems and devices<br>Includes wireless data transmitting and receiving nodes, data conveyance (e.g., WIFI, radio telemetry, cellular, satellite, internet), user interfaces (anything with a screen, stationary or mobile), user-defined alerts |
| 3. | SPW Feedback | Soil, plant, and weather (SPW) feedback<br>Weather station (incoming solar irradiance, wind speed and direction, air temperature, relative humidity, subsoil temperature)<br>Precipitation (multiple points)<br>Soil water (e.g., time-domain reflectometry [TDR], capacitance, tensiometer, granular matrix)<br>Plant temperature (e.g., infrared thermometers [IRTs], drones, some satellites)<br>Plant leaf wetness |
| 4. | Analytics | Reports, forecasts, irrigation recommendations, decision support<br>Rx for uniform or VRI<br>Irrigation history<br>Soil water depletion<br>Crop water stress<br>Other biotic or abiotic stress<br>Crop evapotranspiration (ETc)<br>Reference evapotranspiration (ETo)<br>Crop growth and development<br>Final crop yield |

Table 2. Examples of commercially available hardware and software components for irrigation management (continued on next page) [1,2].

| Center pivot manufacturer | Component or subcomponent | Product name | Third party add-on or service | Notes |
|---|---|---|---|---|
| Lindsay ™ | Control panel | Pivot Control, Basic, Vision, Boss | | FIELDNET ® ready, cellular and radio telemetry links |
| | Remote control | FIELDNET ® | | |
| | SPW Feedback | GROWSMART ™ | | Sensor management software module. |
| | Analytics | FIELDNET Advisor ™ | | Suite of DSS modules: Irrigation Advisor ™, Crop Advisor ™, Weather Advisor ™, VRI Advisor ™ |
| Pierce | Control panel | EvoTouch ™ | | WIFI, web-enabled, magnetic compass instead of GPS |
| | Remote control | PivotLink ™ | | Control panel adapter, can upgrade existing panels |
| | Analytics | FieldView ™ | | Software platform for SCADA |
| Reinke | Control panel | RPM (Reinke Precision Management) | | Basic, Standard, and Advanced versions |
| | SCADA | Navigator ™ Series GPS | | |
| | Remote control | RC10 | | Remote management device (essentially a smart phone); ReinCloud ™ ready; cellular and satellite links |
| | SPW Feedback, SCADA | RS300 | | Field station node for irrigation SCADA, weather, soil water sensors; ReinCloud ™ ready; cellular, radio telemetry, satellite links |
| | Remote control, SCADA, Analytics | ReinCloud ™ | | Comprehensive web-based SCADA, can monitor third party SPW feedback sensors |
| | Analytics, weather forecast | | Weather Underground | |
| | Analytics, VRI Rx | Precision Irrigation Management | CropMetrics ™ or Reinke | Requires field elevation, soil properties (water holding capacity, electrical conductivity), can optimize soil water sensor locations. |

[1] This list is not exhaustive and is subject to change rapidly. Compiled 1/2018.

[2] USDA and its affiliates assume no liability for the use of any product mentioned.

Table 2 (continued). Examples of commercially available hardware and software components for irrigation management [1,2].

| Center pivot manufacturer | Component or subcomponent | Product name | Third party add-on or service | Notes |
|---|---|---|---|---|
| T-L | Control panel | PPC III (Precision Point Control III) | | |
| | Remote control | Precision Link | | Links PPC III panels with AgSense |
| | Remote control, SCADA, Analytics | | AgSense ® | Comprehensive web-based SCADA, can monitor third party SPW feedback sensors |
| | Analytics, VRI Rx | Precision Irrigation Management | CropMetrics ™ | Requires field elevation, soil properties (water holding capacity, electrical conductivity), can optimize soil water sensor locations. |
| Valley® | Control panel | ICON ® | | Can be accessed from edge of field using WIFI only, without cellular or internet service |
| | Remote control, SCADA | BaseStation3 ™ | | Web-based interface; includes Irrigation Exchange® (data sharing software). |
| | Remote control, SCADA | ICON Link | AgSense ® | Links ICON panels with AgSense |
| | Remote control, SCADA, Analytics, VRI Rx | CommanderVP ® | AgSense ® | Designed for pre-ICON panels |
| All | Remote control, SCADA, Analytics | Field Commander ® | AgSense ® | Comprehensive SCADA and VRI Rx platform. |
| All | Remote control, SCADA, SPW Feedback | Crop Link ® | AgSense ® | Controls and monitors other devices, such as pumps, flow meters, tank monitors, motors, SPW sensors, including fertigation and chemigation. |
| All | SPW feedback, Analytics | Aqua Trac | AgSense ® | Monitors and records soil water sensors. |

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