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Autonomous Irrigation Management in Decision Agriculture

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Chapter 12
Autonomous Irrigation Management in Decision Agriculture

Abstract In this chapter, the important application of autonomous irrigation management in the field decision agriculture is discussed. The di erent types of sensor-guided irrigation systems are presented that includes center pivot systems and drip irrigation systems. Their sensing and actuator components are with detailed focus on real-time decision making and integration to the cloud. This chapter also presents irrigation control systems which takes, as an input, soil moisture and temperature from IOUT and weather data from Internet and communicate with center pivot based irrigation systems. Moreover, the system architecture is explored where development of the nodes including sensing and actuators is presented. Finally, the chapter concludes with comprehensive discussion of adaptive control systems, software, and visualization system design.

12.1 Introduction

The application of uniform irrigation leads to under- or over-watering, if there is no information available on soil and crop conditions[4]. The variable-rate systems can be utilized to efficiently use water. Although saving water is the biggest driving factor behind switching, but other advantages includes: erosion prevention, reduced maintenance cost, avoiding fines for not using enough water, and limiting nutrient runo [25]. Using the current irrigation systems, Chemigation, without involving any human, uniformly applies chemicals that too without danger of exposure. Smart irrigation system is accepted as beneficial technology, however, its adoption can be delayed because of cost involved in replacing or modifying the current equipment. A balanced approach would be to use cheaper valves in place of expensive pressure control nozzles[4, 46].

There has been lot of investigations done towards the application of smart irrigation for delivering cheap decision-making solution in an e ort to improve its adoption rate[25, 26]. A challenge could the lack of interdisciplinary approach to fill the gap between machinery and agricultural requirements. A hardware-based system might be cumbersome and expensive to adopt for different crop and soil conditions, whereas a software-based solution can flexibly address this challenge.

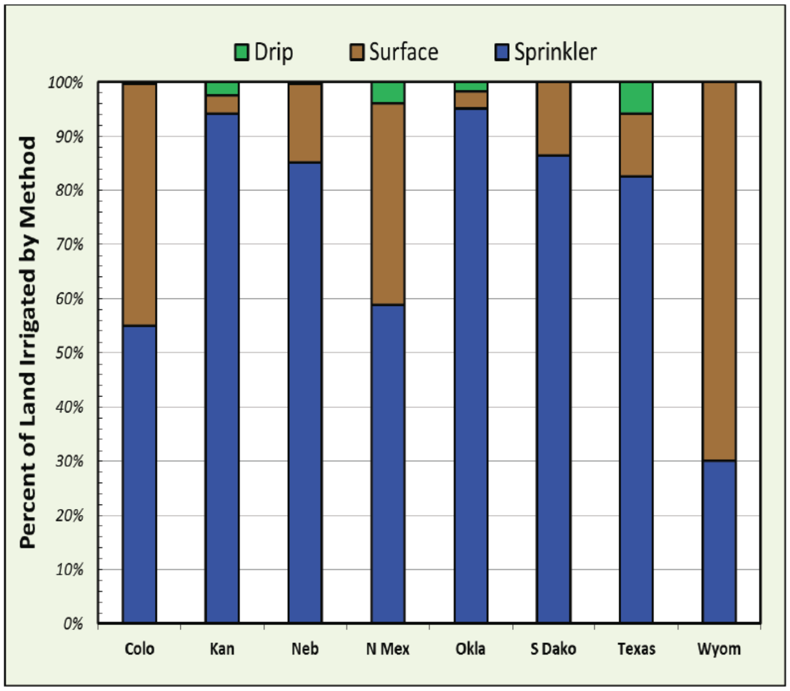


Fig. 12.1: Ratio of different sources (gravity, sprinkler, drip/trickle) used for land irrigation in Great Plains [15]

12.2 Types of Sensor-Guided Irrigation Systems

Many different types of techniques are used for autonomous irrigation systems (e.g., drip, surface, and sprinkler). The percentage of land irrigated by sprinkler, gravity and drip/trickle systems in the Great Plains is shown in Fig. 12.1. In this section, the different types of irrigation systems are discussed.

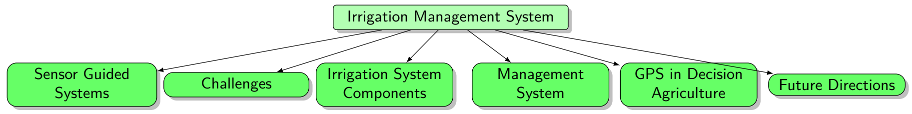


Fig. 12.2: Organization of the Chapter

12.2.1 Center Pivot System

The infrastructure is required for field management practices such as center pivot irrigation system. This system need a more advanced communication capabilities to be able to communicate and control the center pivot using IOUT soil moisture measurements. A list of required features in a center pivot system for autonomous irrigation is given below [65].

- The center pivot location/angle can be graphically viewed online
- The pivot can be remotely controlled online for speed, irrigation application rate, etc.
- Operational information and data can be viewed and stored
- Pivot point operating water pressure can be monitored
- Operating direction of the pivot can be changed
- AS/RS status can be monitored
- End gun operations, including the water application rates, can be controlled
- The system can be run “dry” or “wet”
- Text alerts can be sent if any operational or safety issues are encountered.

In addition to the remote control and operation hardware and software, the center pivot nozzle sprinkler nozzles should support variable water application capabilities as well as support to enhance the uniformity of the water application. The variable rate center pivot and all of the hardware and software components as well as all agronomic and soil management practices and leads to an efficient design of autonomous irrigation system [34, 43].

12.2.2 Drip Irrigation System

Drip irrigation system (DIS) is a water system which uses low-pressure to water small lawns and gardens using di erent methods. It di ers from other irrigation methods in that it uses less amount of water to keep the roots moist instead of soaking it. The drip system can be hidden under the mulch with water spraying part above the mulch or kept above the soil or mulch with plants hiding it as their size increases with the growth. As discussed above it gives an advantage of using less water as compared to the other counterpart options such as UG sprinkler systems and lawn sprinklers. Moreover, a customized water can be applied using drip irrigation system by restricting watering in some area and allowing in others.

Following are some advantages of drip irrigation system:

1. Conserve water by preventing over-spraying, hence, reducing evaporation and environmental e ect.
2. It can directly connect to the hose spigot with having to do cuts in home water supplies.
3. It can be placed underground eliminating the need of trenches.
4. It provides customization for water spray control and container in which it can be placed.
5. It prevents over moistening which, otherwise, can cause fungal diseases.

Components of Drip Irrigation System

While creating a DIS yourself, make sure to buy all components from same manufacturer. *Soaker hoses* is a simplest DIS with small holes allowing water to come out. However, this cos-efficient solution uses more water than a normal DIS. Another alternative to create a DIS is using an entire system *kit* to create a customized DIS. KIT integrate the components to create DIS for specific applications e.g., for flower beds, vegetable gardens, landscape plants (shrubs and trees), and container plants. These kits can also be extended as per the need of the user. Various components of DIS are given below:

- *Backflow preventers* - Also known as anti-siphon devices, do not allow the DIS water to go back to water supply so that drinking water is be contaminated while system is switched o .
- *Pressure regulator* - Balances the pressure between the home water supply and DIS, otherwise, the water pressure of home supply is much greater than the water pressure at DIS.
- *Filters* - are used to prevent clogging in the tube caused by the debris.
- *Fittings* - are used to connect all the system components together.
- *Stakes* - are used to secure all the system components together.
- *Risers* - are used to bring the water emitters to the top, i.e., at the level of plants
- *Timers* - are used to prevent over watering be setting the time to automatically switch DIS on or o . It can also be controlled via smart phone or computers by connecting it with the home automation system.
- *Hole punches* are used to create the holes in the tube which is connecting emitters. *Plugs* can be used to stop holes punched by mistake.
  Emitters - Emitters are connected with the tubing system and it emits water through tubes. Its flow rate is given by gallons-per-hour (GPH) and it depends on the type of soil and plant being watered. every emitter has maximum water pressure mentioned in pounds per square inch (PSI).

12.3 Development Challenges

The challenges which were addressed while developing the system are [65]:

- **Deployment of a field network capable of measuring the soil moisture levels, temperature, and radio communication metrics.** The desired network must be low-maintenance, durable in all weather condition and do not a ect other farm activities.
- **Characterization of the underground/above-ground wireless channel to determine communication reliability.** Communication and channel characteristics are quantified by using di erent metrics,e .g., coverage distance, and received signal strength indicator [29, 65].
- **Back-end software development for data management and visualization.** WUSN networks produce glut of important data. All this data must be dynamically received and stored on a cloud application online (via GPRS/3G/4G link) and offline mode (locally). A cloud application can be used for monitoring, e.g., sensor nodes communication, and visualizing, e.g., real-time the power status, purposes. Furthermore, visualization can also be used to locate disconnected sensor nodes, for visualizing historical readings such as soil moisture readings, radio packets location, last reported pivot angle, timestamp and signal strength of packet received from each underground node [20, 71].
- **Usage of test software to interact with commercial irrigation solutions.** Some studies are done on irrigation systems controllers, however, most commercial deployments uses industrial solutions. These solution comes with a proprietary cloud-based control system with no facility of customized programs development using APIs. The control systems are programmed using a test software [24], [49, 51].

12.4 Irrigation System Components

An advanced CP irrigation system can be used to study the long-term e ects of water stress and yield relationships, variable rate irrigation and fertigation, crop water and nutrient uptake, develop crop production functions, and other related issues. These study can be done under full and limited rainfed and irrigation settings [10, 11]. The Fig. 12.3 shows the overview of irrigation control system [20]. The GPS unit at the end tower in the center pivot can be used to control for various irrigation and other operational aspects in addition to these state-of-the-art features in control units of the center pivot. The characteristics of a typical center pivot, where 45% of land is under outer two spans while 2% is under first span ae shown in Fig. 12.4. The components of irrigation system are described in coming section:

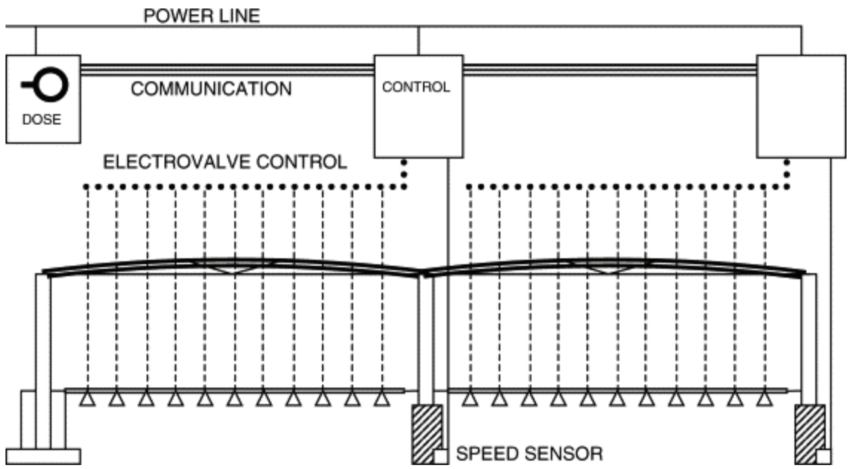
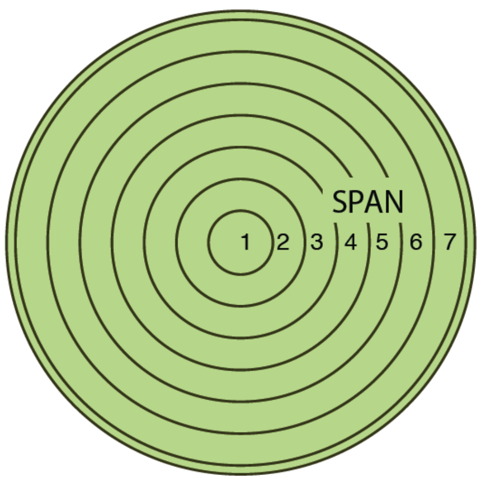


Fig. 12.3: The control system diagram

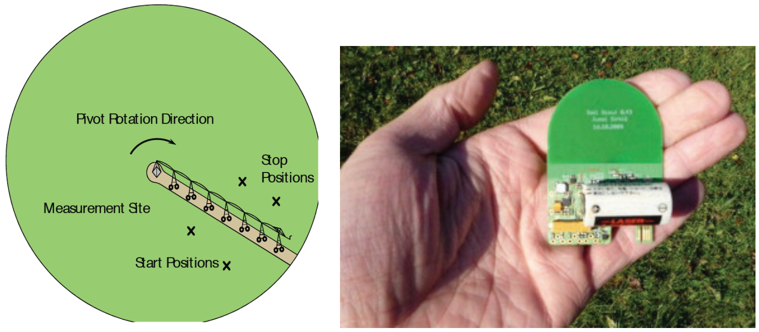


Span	End of Span, ft	Acres Within Span	Discharge from Span, gpm
1	180	2.3	14
2	360	7.0	42
3	540	11.7	71
4	720	16.4	99
5	900	21.0	127
6	1080	25.7	156
7	1260	30.4	184
OH	1310	9.3	56
Total		124	750

Fig. 12.4: A typical center pivot [15]

12.4.1 Sensing and Communication Nodes

Sensors are used to get the real information from the field. This information can be taken using in-situ sensors, i.e., inside the field, or using remote sensors. The real information of the field can be lost, if inaccurate equipment are used. Most sensing systems are used for sensing soil parameters, however, spectral imaging can also be used to detect plant stress[17, 53]. The sensed data, if not sent immediately to the cloud, can be stored locally for later retrieval. In the absence of direct link with the controller, an optional gateway is used.



(a) (b)

Fig. 12.5: (a) Underground node placement layout [15] (b) A prototype of an underground node, [61]

12.4.1.1 Subsurface Nodes

The subsurface node is an embedded cyber-physical hardware for sensing and communication between different low-powered low-frequencies sensors and radios. The subsurface nodes use underground antennas for communications [27, 62]. Soil sensors along with data loggers are also connected to these modes. The information from data logger act as the basis for calibration of soil sensors. The subsurface nodes can be buried at different depth in soil and should also support connections with soil sensors at different depths generally up to 4 feet [30, 46]. Accordingly, these observations can be used for better deployment of advanced irrigation systems. The subsurface node deployment should done considering the impact of crop growth and desnity should take into account the field terrain. Some of the nodes should be used in the field as a reference point for measurement calibrations and for comparison of sensor readings.

For irrigation applications, different types of subsurface nodes can be selected (e.g., off-the-shelf and customized) to speed up the development process and achieve communication between devices, respectively. These nodes and platform should includes efficient and high-speed processors, I/O ports, on-board flash storage, and serial ports. These are some of the important parameter to consider while subsurface node development because they are used to connect with the microcontrollers and GPS modules which communicate with underground nodes [25, 32, 37, 42]..

To provide soil moisture calibration data to the IOUT, the soil moisture sensors, temperature sensors, and electrical conductivity sensors can be installed in the center location of different grids (see Fig. 12.4) that can be created in the center pivot field in a spatial and temporal domains that measure soil moisture, soil temperature, and electrical conductivity on an hourly basis throughout the growing year. External batteries are the power source of subsurface node that can be complemented by intelligent uninterrupted power supply (UPS) [19] to control the power management and also to report the status of power. A step-down voltage converter can be utilized to meet the 5V power requirement of nodes [29, 53]. Furthermore, during daytime, power can be provided by solar panels that can also recharged lithium-ion polymer batteries for night usage when solar energy is not available [65].

In addition to system upgrades, a prototype enclosure (Fig. 12.5) is required to make the nodes fully underground, where connectors can be used for software updates along with bratty connections for easy above-ground access. The enclosure can host these connectors under ground, with easy access through a structure close to the surface. Accordingly, these new enclosure should be tested during the harvesting period for accuracy and durability.

Due to high signal attenuation in the soil, the low operation frequency and low power transceivers are preferred in underground communication such as WizziMote developed by WizziLab [64]. WizziMote combines a Texas Instruments CC430F513 16-bit ultra-low-power microcontroller unit with a four analog to digital input/output pins, a CC1101 low-power sub-1GHz RF transceiver, eight configurable GPIOs, and female SMA antenna connector. the microcontroller unit comes with a flash memory of 32 KB, and a 12-bit analog to digital converter (ADC). It consumes, at its maximum capacity, 3.2 mA, however, it has various power saving feature which, if enabled, can be tailored down the consumption to 1.0 micro Ampere. WizzMote works with 433 MHz applications and reports the transceiver sensitivity of -116 dBm at 0.6 kBaud with a 1% packet error rate, at this frequency [26, 35], [65].

The protection of subsurface nodes is an important issue. The waterproof subsurface nodes are very important for efficient underground operation [23, 41] and can be achieved by using waterproof enclosures. These enclosures come with a automatic equalization valve that helps to balance the internal pressure and avoid water condensation [65]. It should also provide ease of access through a soil structure close to the surface. This enclosure should also be able to handle the weight of the farm machinery that used in harvesting season for collecting crop [33, 33]. The electronic equipment can protected by the PVC enclosures but it has the risks of being damaged by the leaks in connectors.

12.4.1.2 OTA Nodes

The OTA nodes are design to study and validate the impact of irrigation system in the real-time. Therefore, data is collected using opposite facing directional antennas before and after the completion of irrigation. The improved communications in CP helps in studying changes in soil moisture. Similarly, customized solution are developed by updating on-board models for irrigation systems, in real-time, to reach soil moisture level [40, 44]. A modem [21] is used to send data from OTA node to server using a wireless mobile communication network. A USB dongle can operate at di erent cellular bands depending upon the availability;lty of with services from telecom service providers. A voltage data logger based can be used to register the battery voltage over time in order to record data for battery replacement needs. The duty cycling in underground nodes is important to conserve energy. This can be achieved by disabling ports. Moreover, the power can be disconnected and restored

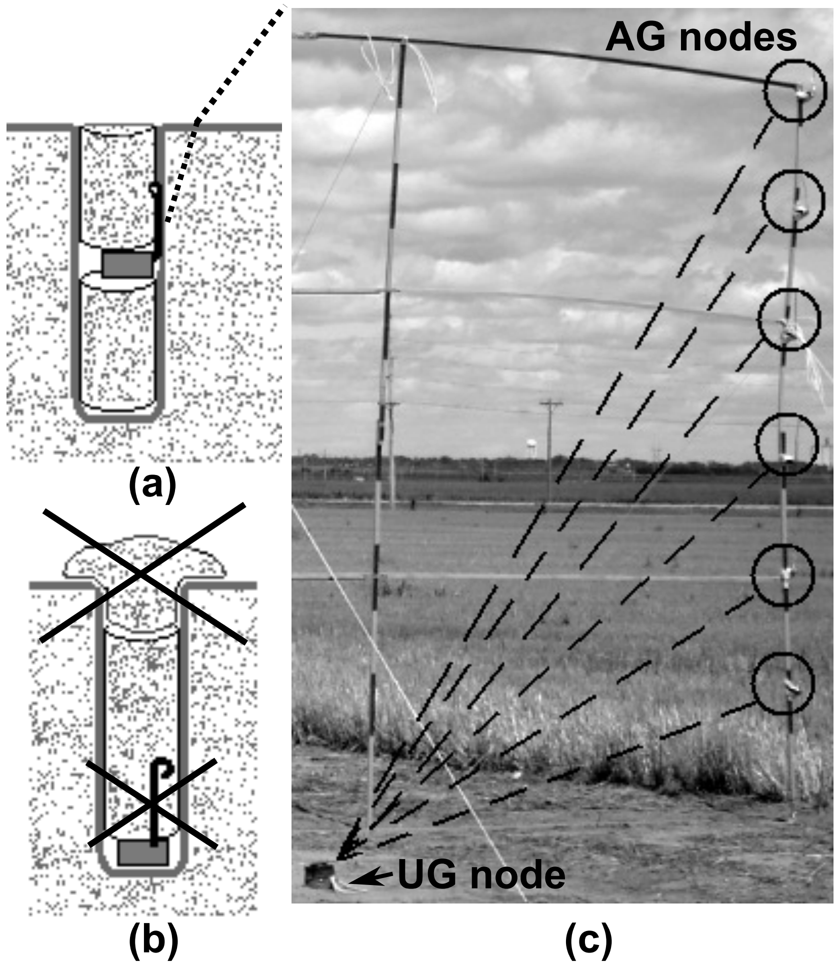


Fig. 12.6: Experiments for AG2UG and UG2AG communication: (a) Antenna placed in non-obstructed direction of AG device, (b) UG2UG experimental aspects which cannot be used for AG experiments, and (c) AG nodes grid [57]

after some optimal duration to duty cycle the device in the absence of pivot rotation. The communication between devices can allow transmitting the additional data together, which can be implemented in the control. In addition, modifications to the voltage regulation circuit for sampling allows placing a regulator between the battery and embedded system, which can solve the problems arising due to the fluctuations in the reference voltage.

Many GPS modules are available with ability to track multitude of satellites on di erent channels [2]. These are used for localization in this system. The module selected should be equipped with high sensitivity receiver, built-in data-logger, radio frequency connector for an external active antenna, and internal patch antenna for efficient power performance. Moreover, the high performance antenna with thread mount and waterproof capabilities are desirable [9].

The aboveground nodes are also used in the system for retrieving sensing data, monitoring the power consumption and battery capacity. This nodes enables the power management thread to gather power consumption information from the battery charging board. This component also enhances the system performance through design of a watchdog system, and provides the better control of the power system. Moreover, the antennas can be deployed with a better polarization angle in the deployments to enhance connectivity [48, 55]. The Fig. 12.6 shows the above ground components. The multi-element directional antennas [58] can be employed for OTA nodes with support for a wide-range of operational frequency in MHz and GHz bands. The antennas should support high power and gain with a front to back ratio greater than 20 dB. Generally, the lightweight antennas are preferable for these applications.

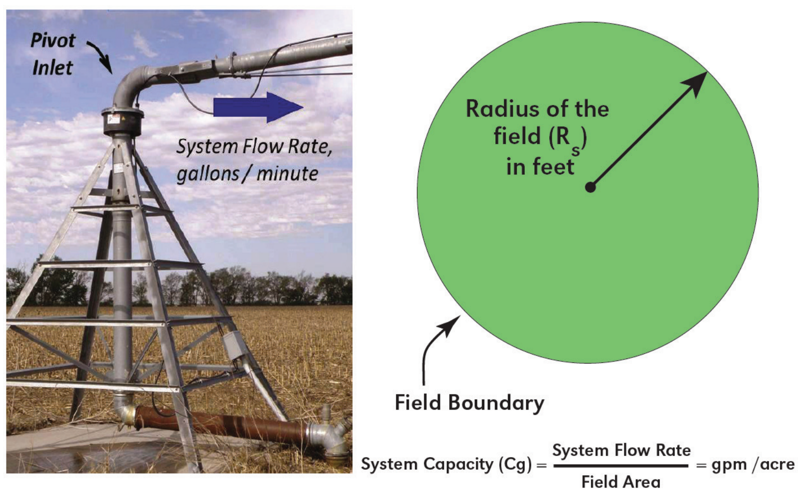


Fig. 12.7: Definition of system capacity for a field [15]

12.4.2 Software, Flow Rate, and System Capacity

12.4.2.1 Software System

The software are needed in terms of both functionality and to control state-of-the-art system architectures. The individual pieces of software that needed to be maintained separately can run on a single platform. Accordingly, a visualization system can be developed to display information in real time. The database can be hosted in a server with more resources ensuring that multiple connection requests can be handled properly. As a part of the system system, an adaptive control system can developed to support wireless underground sensor-aided irrigation control.

12.4.2.2 System Capacity

In addition to the software system components, a real-time capacity and flow rate system based on the this framework can be developed. A definition pf the system capacity is provided in Fig. 12.7. Accordingly, soil moisture, location of the center pivot, and wireless communication quality information can be displayed in real-time as data is received. A group of underground nodes can provide individual sensor status that is very useful to detect shorted or disconnected sensors. A gauge can be utilized to display the OTA battery voltage. Similarity, a map of the underground nodes can show the location of the irrigation pivot and the trail of the recent radio packages received by each subsurface node.

12.4.3 Data Collection

The data collection from the field is important in all seasons particularly in the growing season and winter season. Its significance becomes even higher during farming operations that include cultivation, spraying, planting, determining the amount of irrigation and fertilizer applications, irrigation and fertigation management, harvesting, herbicide, insecticide, pesticide, and fungicide applications, and other soil and plant management practices [28, 41, 50, 65]. This section discusses the message exchange among UG nodes, the AG nodes, and the server.

To enable an out-of-the-box operation, WizziLab provides a Software Development Kit (SDK). This SDk comes with a sample code and environmental installation procedures. A quick 433MHz solution can be developed using the wireless communication module of SDK, however, no modification can be made to it as it comes as a library. This limits the development of advanced programs for WizziMote because of a bug which, upon hardware interrupt, disable the radio [38, 47]. SDK handles the radio operation and development is done by application, which is the payload of the packets transmitted. The system mainly can use di erent packet for communications. The AG node sends a packet to request soil moisture from UG nodes. For soil moisture data collection, di erent sampling period of soil moisture can be used. UG nodes store these readings with timestamp in in device's flash memory. Accordingly, the AG node use a cellular link to connect and query the status irrigation system from the cloud [39].

Table 12.1: Di erent panels of center pivot control [13]

	Reinke	T-L	Valmont	Zimmatic
Monitors				
Position in field and travel direction	Y	Y	Y	Y
Speed of travel	Y	Y	Y	Y
Wet or dry operation	Y	Y	Y	Y
Pipeline pressure	Y	Y	Y	Y
Pump status	Y	Y	Y	Y
Auxiliary components[1]	Y (7)	Y (2)	Y (6)	Y (3)
Stop-in-slot and auto restart	Y	Y	Y	Y
Wind speed	Y	N	Y	Y
Controls				
Start and Stop	Y	Y	Y	Y
Speed of travel	Y	Y	Y	Y
Auto restart and auto reverse	Y	Y	Y	Y
End gun	Y	Y	Y	Y
High and Low pressure shutdown	Y	Y	Y	Y
High and Low voltage shutdown	N/Y	N/Y	Y/Y	N/Y
System stall shutdown	Y	Y	Y	Y
Auxiliary components	Y(7)	Y(2)	Y(6)	Y(3)
System guidance	Y	Y	Y	Y
Maximum control points per circle	3600	180	72	180
Sprinkler application zones	2	3	30	NL
Remote Communications				
Cell phone	Y	Y	Y	Y
Radio	Y	Y	Y	Y
Computer	Y	Y	Y	Y
Subscription required	Y	Y	Y	Y
Data Collection and Reports				
Soil water content	Y	Y	Y	N
Precipitation per season	Y	Y	Y	Y
Application date and depth	Y	Y	Y	Y
Irrigation events per season	Y	Y	Y	N
Chemical application rate	N	N	N	Y
Chemical application per season	N	N	N	Y
System position by date	Y	Y	Y	Y

12.5 Management System

The Table 12.1 shows the monitoring, control, communication, and data reporting capabilities of center pivot control panels for irrigation and water management research infrastructures. The loud-based and mobile applications are used in many commercial irrigation system for control and monitoring of the system [59]. The programming of irrigation system is done by using a very simple panel having couple of buttons. These buttons are enough to implement all options such as increasing/decreasing of value, and accept/cancel an action. The cloud-based applications adds more flexibility for the manipulation of irrigation system, e.g., scheduling events to occur at certain time. on such event may include start/stop the CP at certain time to synchronize the real-time clock. the cloud system provides interactive graphical interface with all command options appearing on single screen.

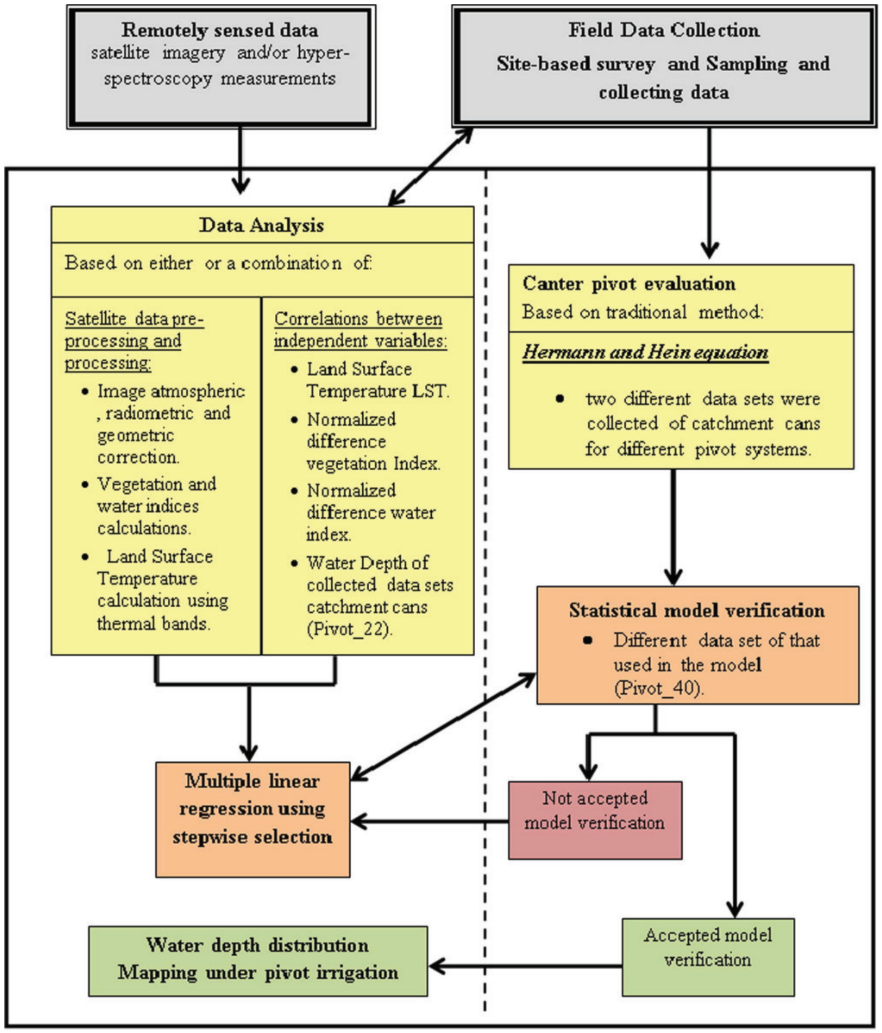
Moreover, the IOUT can collect the soil information from the system using a mobile sink. The sink can be attached on the top of the controller tower where two opposite-facing antennas for receiving data from the nodes at di erent distances can be employed using solar panel as a energy source. Accordingly, the subsurface devices installed in the field can measure soil moisture and temperature from di erent types of soil sensors buried at di erent depths. The nodes can employ batteries as a power source. The sink nodes then collects the spatio-temporal information form the subsurface nodes and sends it over to cloud using OTA communication which further interact with the CP controller to automate irrigation control [24, 46, 48, 55]. A data analysis flow chart is shown in Fig. 12.8.

12.5.1 Control and Actuation Nodes

Studies such as [7, 28][3][18][14], uses actuator as a micro-controller attached to an on/o valve. This valve is used to control the water flow of an irrigation system and is similar to a drip [22], [5], [56], and [14]. The works [3, 39, 42, 52] provide a comprehensive design of an actuator interacting with whole system using a communication protocol. The water flow is regulated by the solenoid valves and power to valve is manipulated by latching circuit which takes signals from micro-controller I/O pins. This latching circuit makes the system power efficient by applying short pulses instead of using continuous signals to control the system. The pressure available to a sprinkler along pivot lateral is shown in Fig.12.9.

12.5.2 Commercial and Cloud Nodes

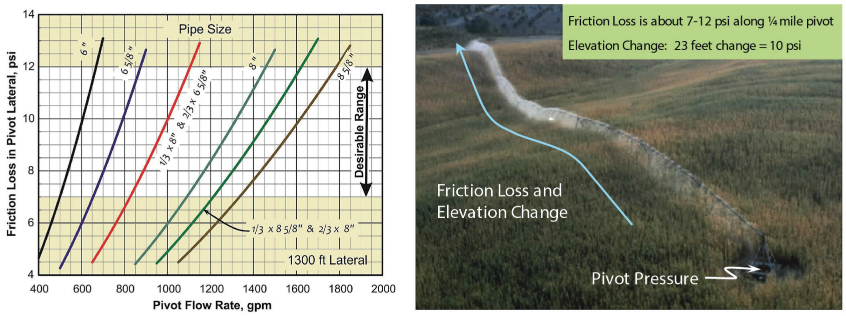
As in the case of actuator, controllers are also application-specific and multiple parameters must be considered while designing controllers. There can be in-situ, remote or cloud-based controller; standalone or shared with other task; hardware could be a cost-efficient micro-controller or an expensive full-fledged computer system. An in-situ controller can also act as gateway which makes irrigation decision after receiving and processing information. These works [14, 33] suggest a use of real-time operating systems so that execution of all instructions can be ensured.



(a)

Fig. 12.8: Data analysis flow chart [6]

In [56], a WSN is implemented for application of peach trees monitoring and achieves 72% reduced water consumption. The controller takes decision based on weather and precipitation probability data taken from cloud. If any of the three deployed sensors values goes below the lower threshold, the system starts watering the tree. Due to deep deployment, the upper threshold overshot which, otherwise, would have added significant value to savings. In [14], authors have used hydrological model to determine exact amount of water to apply.The value for average correlation coefficient of the model estimation and field measurements is 0.9331. For both studies,



(a) (b)

Fig. 12.9: (a) Pressure loss because of pipe friction due to flow of water [15] (b) Sprinkler pressure dependent upon pressure loss occurring due to friction, varying elevation fields, and pivot inlet pressure

a valve was used as an actuator to control the water flow from irrigation system. [8, 40] recommends to consult farmers for marking threshold values for the irrigation system. In addition to soil moisture value, they also measured soil temperature and started the irrigation every time the threshold of soil moisture and temperature was crossed.

There are no commercial controllers with specific features. This fact motivated [7, 37] towards designing a Wi-Fi re-programmable precision irrigation control system. It is powered by solar radiations and uses the threshold approach as given in [34, 56]. The commercial irrigation system mostly comes with a proprietary control and modification can end up in losing warranty or service term. however, they come with a cloud-based or graphical interface controls and can be extended by writing macro-like scripts for inclusion of data from other sources. Major applications of microcontroller agriculture is to sense crop and soil properties. It reduces the role of humans by using by remotely collecting the data using wireless transceivers. The system can be customized to one's need by using di erent communication technologies such as Bluetooth, ZigBee and Wi-Fi and too without loosing long range and power-efficiency. However, it would difficult to combine solutions from di erent vendors because there is no standard protocol [1, 38].

The di erence between the prototype and commercial irrigation control system is that the former can be customized for water flow control [22, 24, 34]. There is very limited space of customizing control in commercial systems and due to warranty restrictions internal circuitry cannot be manipulated. The commercial systems comes with the support of cloud-based interface and/or mobile applications for sending operational commands and visualizing status of the field. Fig. 12.10 shows the system architecture.

The cloud-based controllers has their own limitations which must be addressed in order to implement a reliable system. A reliable network is the key to reliability of the

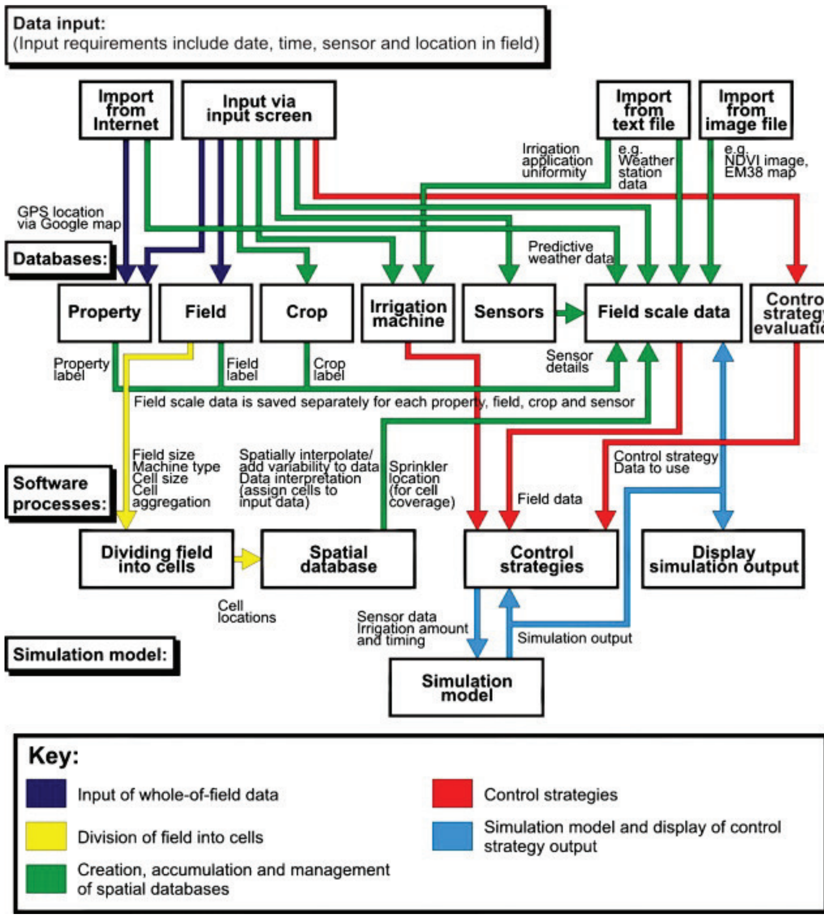


Fig. 12.10: The variable rate irrigation [16]

system because it provides access to Internet. Loading time of the web-page depend upon the load on the network. A re-designed website may warrants rendering of replay commands sand redesigning of control interface. It is also important to mention here that using web-page also brings its own challenges, e.g., time out between the commands can add extra time in execution an action. A modular approach can be followed while designing the adaptive control system to e ectively address these limitations with major changes to the system.

12.6 Global Positioning System in Decision Agriculture

The decision irrigation relies on accurate location information to control the irrigation system. However relying solely on GPS information can lead to significant errors in precision irrigation applications. While higher-end GPS devices may decrease the errors to some extent, GPS errors should be considered in system design due to the wireless nature of the GPS system and cost considerations. Due to the inherent errors and delays in pivot angle and GPS measurements, a multi-modal design with other sources for system localization should be developed to solve this problem. Alternatives include using image detection to determine the field location.

12.7 Future Research Directions

The fresh water is important resource and it be preserved in significant amount if a center pivot irrigation system automatically soil condition. However, decision from such system are likely to have an adverse e ect on crop yield which requires a long-term commitment in order to study in detail. The controller advanced should used to receive information from UG node, buried in the field, and accordingly set the irrigation rate, However, there is still need of improvements.

Accordingly, such systems should be capable of self-calibrating. To that end, remote soil sensing technologies should be used for the sensors adjustment close to the surface. GPS systems are very important part of control system and GPS interferometric reflectometry is a perfectly viable method. The center pivot movements can be used to calibrate the UG nodes in the vicinity of irrigation system path on the go. The current systems are incapable of employing more sensors and adding software components that reduces the efficiency of embedded system in terms of low power consumption. Therefore, there are potential areas in which underground nodes can be improved.

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