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Precision Irrigation:
Sensor Network Based Irrigation

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1. Introduction

Availability of water for agriculture is a global challenge for the upcoming years. This chapter aims at describing components of precision irrigation system and its potential in future farming practices. A case-study of deploying Wireless Sensor Network (WSN) monitoring soil moisture, estimating Evapotranspiration (ET) and driving drip irrigation for a large grape farm in India on pilot basis is described.

Agriculture plays a vital role in the economy of every nation be it developing or developed. Agriculture is the basis of livelihood for the population through the production of food and important raw materials. Moreover, agriculture continues to play an important role in providing large scale employment to people. Agricultural growth is considered necessary for development and for a country's transformation from a traditional to a modern economy. Therefore attention must be accorded to science and technology being used in the field for higher yield and growth in agriculture.

Agriculture system is a complex interaction of seed, soil, water, fertilizer and pesticides etc. Optimization of the resources is essential for sustainability of this complex system. Unscientific exploitation of agricultural resources to bridge the gap in supply/demand owing to the population growth is leading to resource degradation and subsequent decline in crop yields (Mondal and Tiwari, 2007). In addition, uncertainty of climatic conditions is also playing an important role in this complex system. This calls for optimal utilization of the resources for managing the controlled agricultural system (Whelan et al., 1997). Also agricultural systems are inherently characterized by spatial and temporal variability making yield maximization with minimal inputs a complex task. Thus the farming technologies followed in all parts of world need to be constantly updated to meet these challenges. Development of a range of new technologies in different parts of the world has brought agriculture to a whole new level of sophistication. In fact, modern agriculture has already undergone a sea-change from the ancient times. The concept of precision agriculture has been around for some time now. A new approach of collecting real time data from the environment could represent an important step towards high quality and sustainable agriculture. Precision agriculture is an agricultural system that can contribute to the sustainable agriculture concepts.

1.1 Precision Agriculture (PA)

The term "precision agriculture" is defined as the application of various technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production (Pierce and Nowak, 1999). Conventional agronomic practices always follow a standard management option for a large area irrespective of the variability occurring within and among the field. For decades now, the farmers have been applying fertilizers based on recommendations emanating from research and field trials under specific agro-climatic conditions (Ladha et al., 2000). Applications of agricultural inputs at uniform rates across the field without taking in-field variations of soil and crop properties into account, does not give desirable crop yield. Consideration of in-field variations in soil fertility and crop conditions and matching the agricultural inputs like seed, fertilizer, irrigation, insecticide, pesticide, etc. in order to optimize the input or maximizing the crop yield from a given quantum of input, is referred to as Precision Agriculture (PA). It is an information-based and technology-driven agricultural system, designed to improve the agricultural processes by precisely monitoring each step to ensure maximum agricultural production with minimized environmental impact. It involves the adjustment of sowing parameters, the modulation of fertilizers doses, site-specific application of water, pesticide and herbicides, etc (Adams et. al., 2000). Irrigating farms backed-up by estimated water-requirements is one of the essential components of precision agriculture to reduce water wastage. Given the limited water resources, optimizing irrigation efficiency is very essential.

1.2 Precision irrigation

Water plays a crucial role in photosynthesis and plant nutrition. The problem of agricultural water management is today widely recognized as a major challenge that is often linked with development issues. Agriculture consumes 70% of the fresh water i.e. 1,500 billion m^3 out of the 2,500 billion m^3 of water is being used each year (Goodwin and O'Connell 2008). It is also estimated that 40% of the fresh-water used for agriculture in developing countries is lost, either by evaporation, spills, or absorption by the deeper layers of the soil, beyond the reach of plants' roots (Panchard et. al., 2007). Post green-revolution era agriculture in India is facing a technological fatigue for two reasons viz a) high rates of ground-water depletion and b) soil salinity due to excessive irrigation in some pockets. Efficient water management is a major concern in many crop systems. More and more planners as well as farmer associations are becoming conscious about warder-audit and water utilization efficiency as the water resources is getting more and more scarce. Efforts of using micro-irrigation methods such as sprinkler and drip irrigation have been made in last three decades in many parts of the world. It has been reported that in year 2005, 1.15 million ha was under micro-irrigation (drip and sprinkler) in India (Modak, 2009). There is no ideal irrigation method available which may be suitable for all weather conditions, soil structure and variety of crops cultures. In the semi-arid areas of developing countries, marginal farmers and small farmers (with a land holding between 2 and 4 hectares) who cannot afford to pay for powered irrigation, heavily depend on the rainfall for their crops. It is observed that farmers have to bear huge financial loss because of wrong prediction of weather and incorrect irrigation method. In light of a real need to improve the efficiency of irrigation systems and prevent the misuse of water, the focus is to develop an intelligent irrigation scheduling system which will enable irrigation farmers to optimize the use of water and only irrigate where and when need for as long as needed.

Precision irrigation is worldwide a new concept in irrigation. Precision irrigation involves the accurate and precise application of water to meet the specific requirements of individual plants or management units and minimize adverse environmental impact. Commonly accepted definition of Precision irrigation is sustainable management of water resources which involves application of water to the crop at the right time, right amount, right place and right manner thereby helping to manage the field variability of water in turn increasing the crop productivity and water use efficiency along with reduction in energy cost on irrigation. It utilizes a systems approach to achieve 'differential irrigation' treatment of field variation (spatial and temporal) as opposed to the 'uniform irrigation' treatment that underlies traditional management systems.

1.2.1 Benefits of precision irrigation

Precision irrigation has the potential to increase both the water use and economic efficiencies. It has been reported that precision irrigation (Drip and Sprinkler) can improve application efficiency of water up to the tune of 80-90% as against 40-45% in surface irrigation method (Dukes, 2004). Results from case studies of variable rate irrigation showed water savings in individual years ranging from zero to 50%. The potential economic benefit of precision irrigation lies in reducing the cost of inputs or increasing yield for the same inputs.

1.2.1.1 Water savings

The primary goal of precision irrigation is to apply an optimum amount of irrigation throughout fields. It is reported by many researchers as the most likely means of achieving significant water savings (Evans and Sadler, 2008). The site specific or variable rate irrigation is considered as a necessary or essential component of precision irrigation. Most researchers expect a reduction in water use on at least parts of fields, if not a reduction in the value aggregated over entire fields (Sadler *et al.* 2005). It has been reported that variable rate irrigation could save 10 to 15% of water used in conventional irrigation practice (Yule *et al.* 2008). Hedley and Yule (2009) suggested water savings of around 25% are possible through improvements in application efficiency obtained by spatially varied irrigation applications.

1.2.1.2 Yield and profit

The experimental studies were carried out by King *et al.* (2006) for measuring the yield of potatoes under spatially varied irrigation applications. It was reported that yields were better in two consecutive years over uniform irrigation management. Booker *et al.* (2006) analyzed yields and water use efficiency for spatially varied irrigation over four years for cotton. They concluded that cotton seems to be unpredictable to manage with spatially varied irrigation. This result is supported by the work of Bronson *et al.* (2006).

1.3 Components of precision irrigation system

a. Data acquisition

A Precision Irrigation system requires ability to identify and quantify the variability i.e. spatial and temporal variability that exist in soil and crop conditions within a field and between fields. Existing technology is available to measure the various components of the

soil-crop-atmosphere continuum many in real-time so as to provide precise and/or real-time control of irrigation applications.

b.   Interpretation

Data has to be collected, interpreted and analyzed at an appropriate scale and frequency. The inadequate development of decision support systems has been identified as a major bottle neck for the interpretation of real time data and adoption of precision agriculture (McBratney *et al.*, 2005).

c.   Control

The ability to optimize the inputs and adjust irrigation management at appropriate temporal and spatial scales is an essential component of a precision irrigation system. Applying differential depths of water over a field will be dependent on the irrigation system. Automatic controllers with real time data should provide the most reliable and accurate means of controlling irrigation applications.

1.4 Technology associated with precision irrigation

The advent of precision irrigation methods has played a major role in reducing the quantity of water required in agricultural and horticultural crops, but there is a need for new methods of automated and accurate irrigation scheduling and control. The early adopters found precision agriculture to be unprofitable and the instances in which it was implemented were few and far between. Further, the high initial investment in the form of electronic equipment for sensing and communication meant that only large farms could afford it. The technologies used are *Remote Sensing* (RS), *Global Positioning System* (GPS) and *Geographical Information System* (GIS) and *Wireless Sensor Network* (WSN).

The technology of GIS and GPS apart from being non-real-time, involved the use of expensive technologies like satellite sensing and also labor intensive. Over the last several years, the advancement in sensing and communication technologies has significantly brought down the cost of deployment and running of a feasible precision agriculture framework. However, a stand-alone sensor, due to its limited range, can only monitor a small portion of its environment but the use of several sensors working in a network seems particularly appropriate for precision agriculture. The technological development in Wireless Sensor Networks made it possible to monitor and control various parameters in agriculture. Also recent advances in sensor and wireless radio frequency (RF) technologies and their convergence with the Internet offer vast opportunities for application of sensor systems for agriculture. Emerging wireless technologies with low power needs and low data rate capabilities have been developed which perfectly suit precision agriculture (Wang et al., 2006). The sensing and communication can now be done on a real-time basis leading to better response times. The wireless sensors are cheap enough for wide spread deployment and offer robust communication through redundant propagation paths (Akyildiz & Xudong, 2005). The wireless sensor networks (WSNs) have become the most suitable technology to monitor the agricultural environment.

1.4.1 Wireless Sensor Network (WSN)

Wireless sensor networks (WSN) is a network of small sensing devices known as sensor nodes or motes, arranged in a distributed manner, which collaborate with each other to

gather, process and communicate over wireless channel about some physical phenomena. The sensor motes are typically low-cost, low-power, small devices equipped with limited sensing, data processing and wireless communication capabilities with power supply, which perfectly suites the PA/PI (Wang, 1998; Stafford, 2000). A wireless sensor is a self-powered computing unit usually containing a processing unit, a trans-receiver and both analog and digital interfaces, to which a variety of sensing units such as temperature, humidity etc. can be adapted (Fig 1.1). The sensor nodes communicate with each other in order to exchange and process the information collected by their sensing units. If nodes communicate only directly with each other or with a base station, the network is single-hop. In some cases, nodes can use other wireless sensors as relays, in which case the network is said to be multi-hop. In a data-collection model, sensors communicate with one or several base stations connected to a database and an application server that stores the data and performs extra data-processing. The result is available typically via a web-based interface.

1.4.1.1 Wired vs. Wireless Network

Wireless sensor network have a big potential for representing the inherent soil variability present in fields with more accuracy than the current systems available. WSN can operate in a wide range of environments and provide advantages in cost, size, power, flexibility and distributed intelligence, compared to wired ones. The wireless sensors are cheap enough for wide spread deployment in the form of a mesh network and also it offers robust communication through redundant propagation paths (Roy et al., 2008).
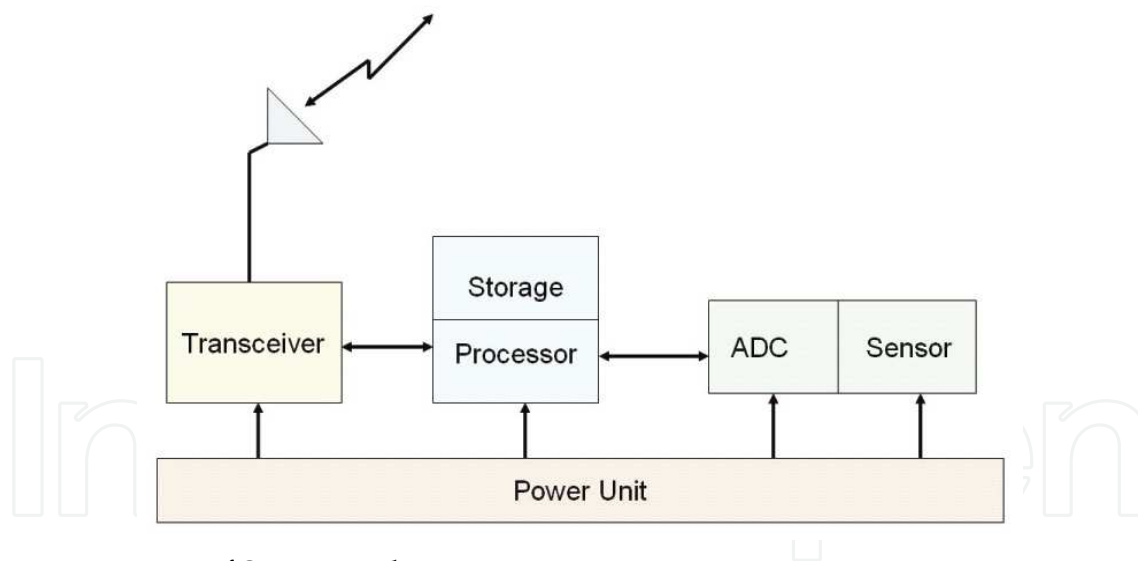

Fig. 1.1. Depiction of Sensor Node

The advantage for wireless sensor network over wired one is the feasibility of installation in places where cabling is impossible. Another obvious advantage of wireless transmission over wired one is the significant reduction in cost and simplification in wiring and harness (Akyildiz et al., 2002). It has been reported that adopting wireless technology would eliminate 20–80% of the typical wiring cost in industrial installations (Wang et al., 2006). However, wired networks are very reliable and stable communication systems for instruments and control. Since installation of WSN is easier than wired network, sensors can be more densely deployed to provide local detailed data necessary for precision agriculture.

Another advantage is their mobility i.e. sensors can be placed on rotating equipment, such as a shaft to measure critical agricultural and environmental parameters. Whenever physical conditions change rapidly over space and time, WSNs allow for real-time processing at a minimal cost. Their capacity to organize spontaneously in a network makes them easy to deploy, expand and maintain, as well as resilient to the failure of individual measurement points. Over the last few years, the advancement in sensing and communication technologies has significantly brought down the cost of deployment and running of a feasible precision agriculture using WSN (Wang, 1998).

Wireless sensor network (WSN), a potential technology found to be suitable for collecting real time data for different parameters pertaining to weather, crop and soil helps in developing solutions for majority of the agricultural processes related to irrigation and other agricultural processes. The development of wireless sensor applications in agriculture makes it possible to increase efficiency, productivity and profitability of farming operations.

2. Irrigation scheduling through evapo-transpiration

Irrigation scheduling defined by Jensen (1981) is as "a planning and decision-making activity" that the farm manager is involved in before and during most of the growing season for each crop that is grown." In other words it is a process through which water lost by the plant through the evapo-transpiration (ET) method is an excellent way to determine how much water to apply based on estimates of the amount of water lost from the crop. Water use efficiency can be achieved with the precisely scheduled irrigation plan. Such a plan on daily basis provides a means of irrigating with an exact amount of water at the targeted dry area to fulfill the needs of evapo-transpiration (ET).

2.1 Evapo-transpiration / crop water requirement (ET)

The combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapo-transpiration (ET). Evapo-transpiration is also known as water requirement of the crops. The water requirement can be supplied by stored soil water, precipitation, and irrigation. Irrigation is required when ET (crop water demand) exceeds the supply of water from soil water and precipitation. As ET varies with plant development stage and weather conditions, both the amount and timing of irrigation are important. The rate of ET is a function of four critical factors i.e. weather parameters, soil moisture, plant type and stage of development (Allen et $al.$, 1998). Different crops have different water-use requirements under the same weather conditions. The evapo-transpiration rate from a reference surface is called the reference crop ET and denoted as ET_0. The reference sureface is hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec m^{-1} and an albedo (reflectance of the crop-soil surface i.e. fraction of ground covered by vegetation) of 0.23, closely resembling the evapo-transpiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground" (Allen et al., 1989). The grass is specifically defined as the reference crop. The crop coefficients appropriate to the specific crops are used along with the values of reference ET for computing the actual ET at different growth stages of the crop. The modified Penman and Moneith model (shown in equation 2.1) was used to calculate the reference evapo-

transpiration. The calculation procedures of ET_o by means of the FAO Penman-Monteith equation (Eq. 2.1) are presented by Allen et al (1998).

$$ET_0 = \frac{0.408 \; \Delta(R_n - G) + \gamma\frac{900}{T + 273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

(2.1)

Where:

ET_o Reference evapo-transpiration [mm day^{-1}],

R_n Net radiation at the crop surface [MJ m^{-2} day^{-1}],

G   soil heat flux density [MJ m^{-2} day^{-1}],

T   Air temperature at 2 m height [°C],

U_2 Wind speed at 2 m height [m s^{-1}],

e_s Saturation vapour pressure [kPa],

e_a Actual vapour pressure [kPa],

$e_s - e_a$ Saturation vapour pressure deficit [kPa],

Δ   Slope of vapour pressure curve [kPa °C^{-1}],

γ   Psychrometric constant [kPa °C^{-1}].

2.1.1 Actual crop Evapo-transpiration (ET_c)

The crop evapo-transpiration differs distinctly from the reference evapo-transpiration (ET_o) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The Kc component of equation integrates the characteristics of the crop (e.g., crop height, fraction of net radiation absorbed at the land surface, canopy resistance, and evaporation from bare soil surface) into the ETc estimation equation, to account for the difference in transpiration between the actual crop and the reference grass. The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient (K_c). In the crop coefficient approach, crop evapo-transpiration is calculated by multiplying ET_o by K_c.

$$ET_c = K_c \text{ x } ET_o.$$

(2.2)

Where:

ET_c Crop evapo-transpiration [mm day^{-1}],

K_c Crop coefficient [dimensionless],

ET_o Reference crop evapo-transpiration [mm day^{-1}].

2.2 A case study on using Wireless Sensor Network (WSN) in estimating crop water requirement at Sula vineyard, Nashik, India

Grapes cultivation in India is limited due to high recurring cost of cultivation. There is significant variability in the quality of grapes over the years and also within the field. Assessing the yield and quality (both temporal and spatial) is a big challenge for wineries (Das et. al., 2010). Vine soil-water status constitutes one of the main driving factors which affect plant vegetative growth, yield and wine test and quality. Irrigation requirements are currently estimated from winter/summer season as well as berry forming stages. Providing the methods and tools for continuous measurement of soil and crop parameters to characterize the variability of soil water status will be of great help to the grape growers. A

wireless sensor network can facilitate creation of a real-time networked database. The real time information from the fields such as soil water content, temperature, and plant characteristics provided a good base for making decisions on irrigation i.e. (when and how much water to apply). The objective of our study was to relate irrigation requirement through evapo-transpiration. The section below describes the agricultural experiments conducted in the grape field which concentrated on monitoring different parameters relating to crop, soil and climate by deploying the wireless sensors network so as to establish a correlation between sensors output and agricultural requirement in terms of water management.

2.2.1 Experimental setup at Green House, IIT Bombay and vineyard at Nashik

Initial deployment of sensors with a wireless sensor network (WSN) in a greenhouse at IIT Bombay (6 X 9 m) provided a pilot scale crop monitoring environment. It was used for testing the ruggedness of WSN for crops grown under controlled conditions in a greenhouse, using sensors embedded in soil and surrounding which was later extended to a larger scale in an intensely cultivated commercial grape farm i.e. Sula vineyard at Nashik (India). Initially the WSN was tested in a greenhouse of 6 X 9 m in the laboratory at Indian Institute of Technology-Bombay (India). Okra plants were planted in nine plots (1.5 X 3 m), with four plants in a row, maintaining a distance between rows and plant of 50 and 30 cms respectively. WSN system deployed consisted of the battery-powered nodes equipped with sensors for continuously monitoring agricultural parameters consisting of air temperature, air relative humidity, soil temperature and soil water content. These parameters were periodically monitored and transmitted in a multi-hop to a centralized processing unit (see section 2.2.2). The measured and recorded values of parameters in real time over a period of 3 months permitted the calculation of evapotranspiration (ET) (Shah et al., 2009). Figure 2.1 shows the schematics of agricultural environment sensors deployed in the field while Fig 2.2 shows the sensors deployed in greenhouse, IIT Bombay.
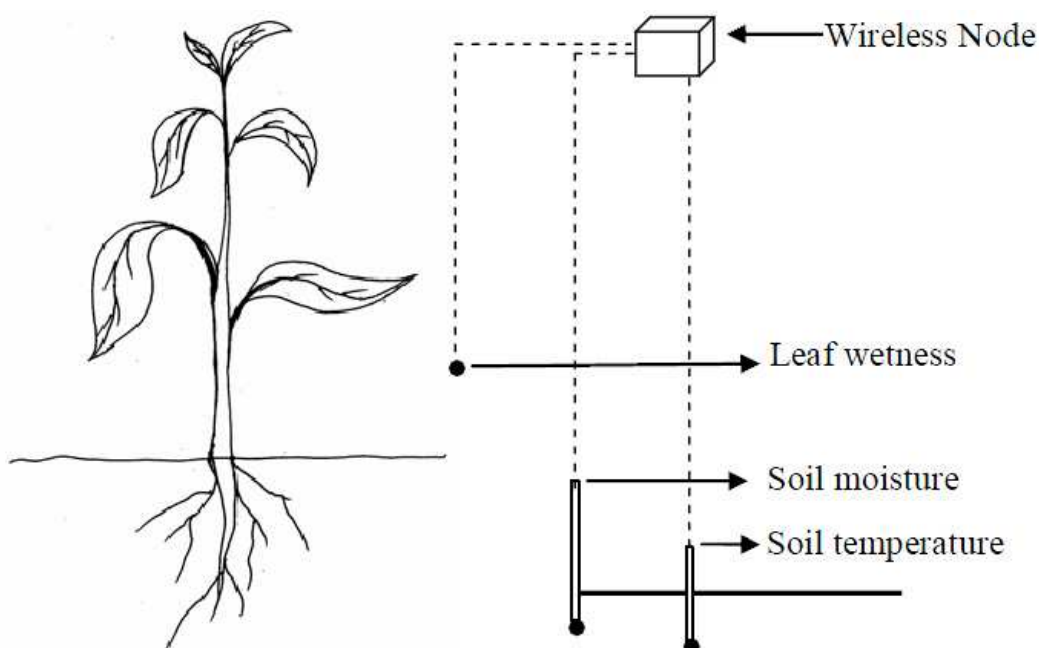

Fig. 2.1. Schematics of Agricultural Environmental Sensors deployed in the Field

Fig. 2.2. Deployment of Wireless sensor network (WSN) System

The WSN system tested at IIT- Lab facility was extended to Sula Vineyard, Nashik (India), for grape crop monitoring as shown in Figure 2.3. The sensors were deployed at a grid of 30 m by 30 m. Each node was able to transmit/receive packets to other nodes inside a well-defined transmission range of 30m. WSN system was focused on establishing feasibility of capturing and analyzing data and facilitated global data accessibility from a small number of wireless sensor pods.

Fig. 2.3. Wireless Sensor Network Deployment at Vineyard, Nashik, MH, India

2.2.2 Details of developed Wireless Sensor Network at IIT Bombay

The system designed, developed and deployed at IIT Bombay for its utility for in-field monitoring of grape crop performance, is being popularly known as AgriSens. (Das et. al.,

2010). It used a combination of wired and wireless sensors to collect sensory data such as soil pH, soil moisture, soil temperature, etc. Data collected by the sensors were wirelessly transferred in multi-hop manner to a base station node (about 700 m away from the mote) connected with embedded gateway for data logging and correlation. An embedded gateway base station performed elementary data aggregation and filtering algorithms and transmitted the sensory data to Agri-information server via GPRS, a long distance, high data-rate connectivity as illustrated in Fig 2.4. Here the data was processed and stored in a structured database to provide useful information to the farmers to take action such as, e.g., starting or stopping of the irrigation system. The server was situated at Signal Processing Artificial Neural Network lab, Department of Electrical Engineering IIT Bombay, India which is about 200 km away from the fields. The server also supported a real time updated web-interface giving details about the measured agri-parameters (Neelamegam et al., 2007). The closed loop self organizing WSN system used in the study comprised of the following:

- The battery powered nodes with embedded sensors for registering the air temperature and relative humidity were deployed at grid of 30 X 30 m.
- SHT1x is a single chip relative humidity and temperature sensor. The device includes a capacitive polymer sensing element for measuring relative humidity and temperature.
- Networked sensors that measure, and record into an electronics data base, several variables of interest such as soil moisture, soil temperature, pH, ambient relative humidity and ambient temperature. Such automated monitoring system also facilitates the crop experts with a large amount of raw data in electronic formats.
- Each node is able to transmit/receive packets to other nodes inside a well-defined transmission range varying between 30 to 1000 m. A single node can transmit the temperature and relative humidity every minute.
- In a wireless sensor network when the transmission range of a sensor node is not sufficient then it uses multi hop communication to reach the destination node or sink node. For example a node communicates data collected, to a nearby node which in turn transmits to another nearby node in the direction of the sink node. This data forwarding mechanism continues till the sink node is reached. Multi hop communication extends the transmission range of a sensor node and also prevents it from draining soon.
- Signal processing and data processing algorithms that extract useful information out of massive amounts of raw data which is then used to generate alerts that are used to alter sampling frequencies and activate actuators.
- Secure web portal that allows users at different location to access and share their agri-data.
- Solar cell Polycrystalline solar modules (6 V and 500 mA) were used for charging lead acid battery.

2.2.2.1 AgriSens irrigation system

In India, sprinkler and drip irrigation systems are becoming popular irrigation systems. Drip irrigation saves considerable amount of water and hence preferred. As grapevines are arranged in uniform row pattern, drip irrigation is an easy way to control water. Automation can fulfill water requirements of fairly large number of grapevines with single valve. The same pipeline can be used for providing required nutrients also. Grapes are seasonal in India, and they are being planted in month of December to March, which is not a rainy season. Thus, alternate water source has to be used making external source of water essential for grapevines

(Shah et. al., 2009). In vineyard there are different types of grapevines which requires different amount of soil moisture (Burrell et al., 2004). Also, it is very difficult to manually control the irrigation required for particular type of grapevine. WSN based irrigation automation can tackle the problem and also help to save considerable amount of water. The moisture contents of the soil decide the actuator activation. If the threshold level of the soil moisture goes down below a certain level, the valve gets open. This threshold level has to be decided based on climate, topography and type of plant, etc, at the Agri-Information server (Desai et al., 2008). The WSN System, was designed to aid end users and researchers to analyze real time sensor data and assist in decision making for various applications. It was a web based application that could be accessed ubiquitously by the users thus providing a convenient and nimble tool. Since it was integrated with google map, it could provide location-based data. Moreover, this enabled the information to be displayed in a visually readable format.
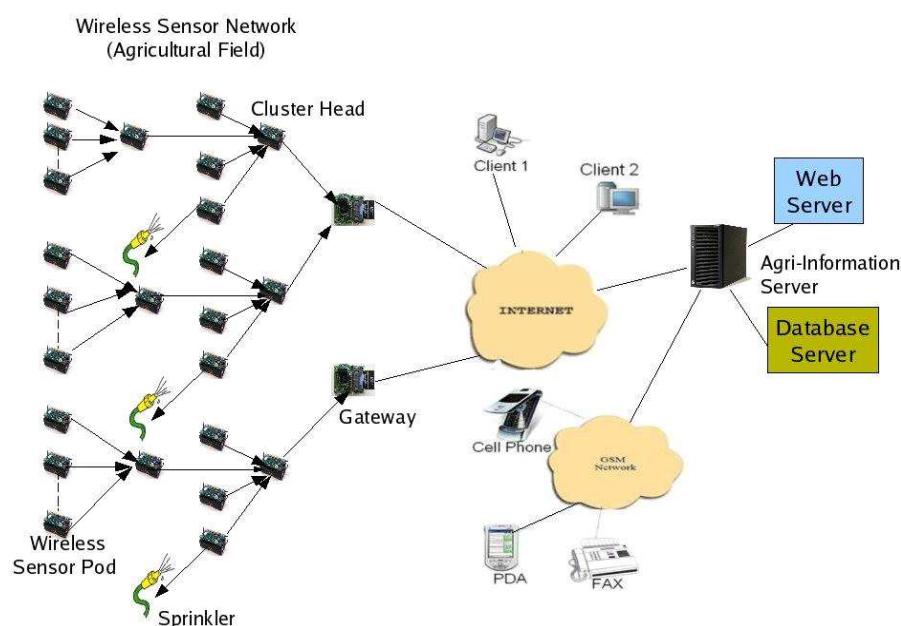
Fig. 2.4. Different Components of Systems Developed at IIT Bombay

2.2.2.2 Sensors suite

Following sensors were deployed based on the feedback received from Sula Vineyard (http://www.sulawines.com) in addition to air temperature and air humidity sensor.

a.   Soil moisture sensor

Measuring and monitoring soil moisture helps determining when to irrigate, how much water to apply. The sensor used is ECH2O probe by Decagon as shown in Fig. 2.5 (a). It is a capacitance probe that measures dielectric permeability of medium. In soil, dielectric permeability is related to soil moisture content. Soil moisture was calibrated in terms of volumetric soil moisture content.

b.   Soil temperature sensor

The soil temperature shown in Fig 2.5 (b) from Decagon, has a resolution of 0.1∘C. It is enclosed in a low thermal conductivity plastic assembly design to shield the sensor from sunlight and at the same time maximizes convective air movement around the thermistor.
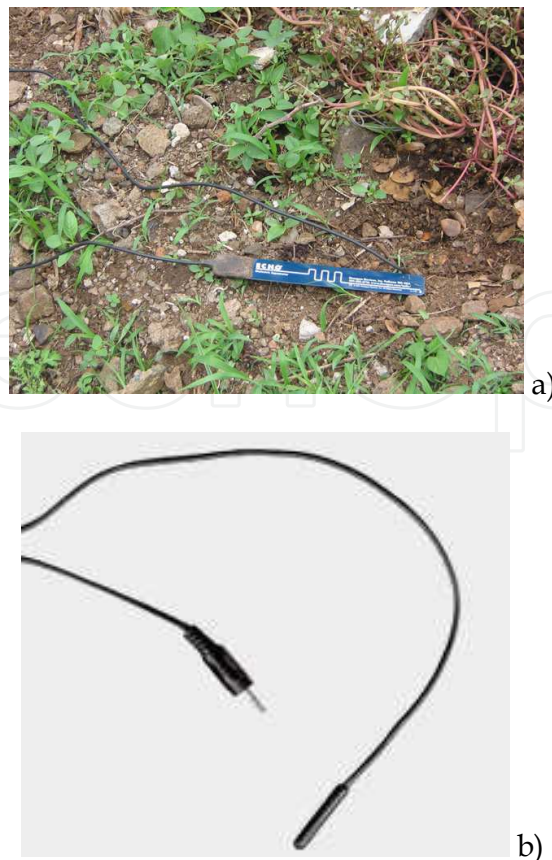
a)

b)

Fig. 2.5. a) Soil Moisture Sensor, b) Soil Temperature Sensor

3. Lessons from the case-study on AgriSens project

3.1 Estimation of Evapo-transpiration (ET) rates for crop okra and grapes

ET is the loss of water from the crop through combined process of soil evaporation and crop transpiration as explained in section 2.1. As discussed earlier, the rate of ET is a function of three critical factors i.e. weather parameters, soil moisture, and nature and stage of growth of the crop. Estimation of ET, to establish the irrigation scheduling using mathematical approach has long been seen as an appealing technique due to simplicity of method when compared with on-site measurements (Allen et al., 1998). ET was estimated using the modified Penman and Moneith model (shown in equation 2.1) to calculate the reference ET and then multiplied with crop coefficient (available in literature) to get the actual crop ET at different growth stages of the crop. The ET for okra was found to vary between 0.1 to 4.0 mm/day, with highest water demand of about 4.0 mm/day during the month of October - December 2007 as shown in Fig 2.7. This is explained by dry climate experienced in Mumbai during month of October to December.

The calculated values of ET for sula vineyard, Nashik were plotted against measured values of soil moisture in Fig. 3.1. Figure 3.1 indicates that soil moisture is influencing the ET loss. This is in agreement with the effect explained by Hatfield and Prueger (2008) and Brown (2000). The rates of ET decreased substantially with decrease in soil moisture content measured over about the top 30 cm depth. Knowing the ideal soil moisture content for crops and given soil texture we can compute the ET and hence irrigation requirement. The
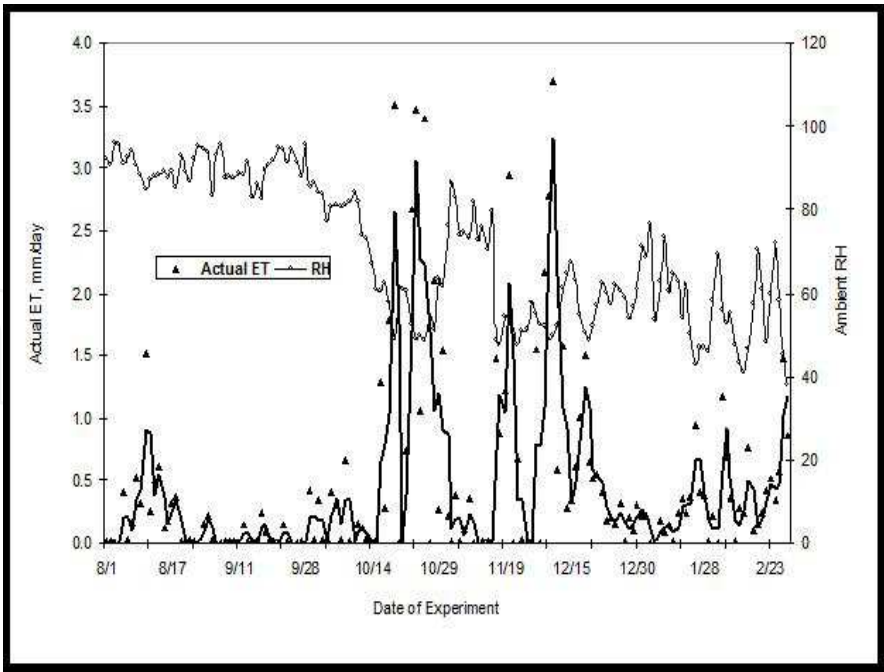
Fig. 3.1. Variation of Evapo-transpiration (ET in mm/day) and Ambient Relative Humidity (RH %) in the Greenhouse, IIT Bombay
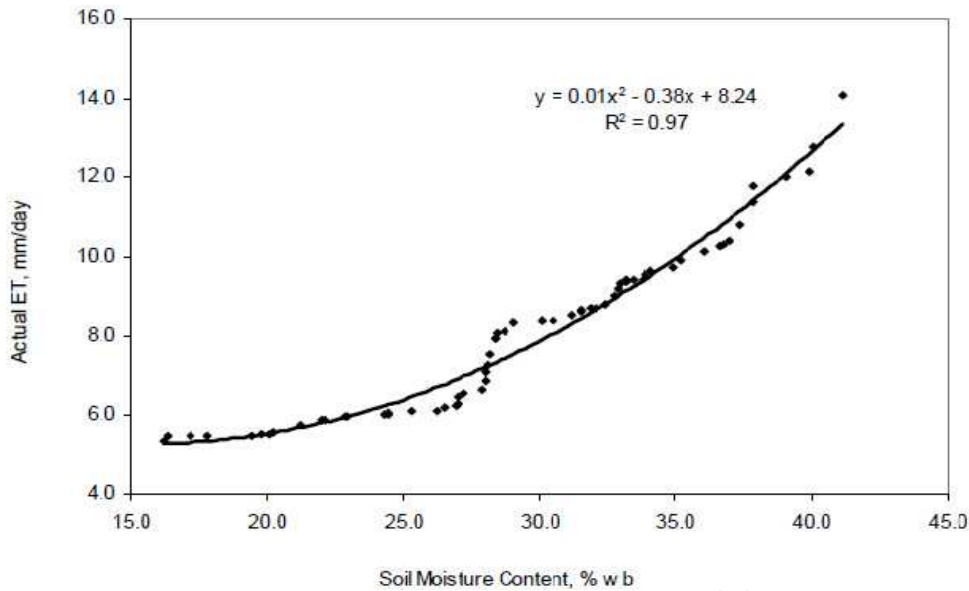

Fig. 3.2. Variation of ET as a Function of Soil Moisture Content, Sula Vineyard, Nashik for the Months of March to May 2008

water requirement through a cycle of 110 days of grape cultivation in the field ranges between 500 to 1200 mm (www.ikisan.com) and the values computed through the sensed parameters in this work ranged from 550-1500 mm. The values of ET for grapes were found to be varying between 5 to 14 mm/day for the months of March till May, 2008. The ET values in grape fields are found to be three times higher than those found in the test bed for okra at IIT Bombay. The field ET for grape crop was computed for the summer months i.e. March to May. The higher ET values for grapevine is further explained by both higher wind

velocities in open field and the higher crop coefficients for grapes (0.75) which is almost 1.7 times higher than for okra crop (0.45). The variation in ET values between 5 to 14 mm/day is primarily due to change in soil moisture as the variation in weather data was small.

4. Conclusions

In the past 50 years, world agriculture has experienced enormous changes. Industrialized countries have created a modernized agricultural system with high productivity and advanced technology. Post green-revolution era agriculture in India is facing a technological fatigue for two reasons; a) high rates of ground-water depletion and b) Soil salinity due to excessive irrigation in some pockets. Rapid socio-economic changes in some developing countries are creating new opportunities for application of precision agriculture (PA).

The field deployment case study discussed in the chapter has demonstrated the utility in estimation/saving water use. Weather data monitoring in the shednet house test bed facility at IIT Bombay helped find the ET values for okra ranging between 0.1 to 4 mm/day. The actual ET for grapes in Nashik vineyard, India was found to be varying between 5 to 14 mm/day as the soil moisture varied between 15 to 40 %. While the ET computations were carried out based on data from one season, data for 3- 4 seasons is required for any package of recommended practices as guidelines for entrepreneurs. We believe that WSN supported agriculture management will be particularly useful for larger farms because of its flexibility, more number of sampling points, ease in operation compared to wired sensors- network system. The wide scale appeal of sustainable practices in agriculture and the newer developments in providing low cost/robust sensor based systems are likely to provide the necessary fillip in future agriculture world-wide. Currently the WSN system has high probability of economic viability for high value crops. Despite the widespread promotion and adoption of precision agriculture, the concept of precision irrigation or irrigation as a component of precision agricultural systems is still in its infancy. Some more case studies similar to the one described for other crop-agriculture systems will go a long way in building faith in sensor based irrigation towards both saving precious water as well as soil-degradation due to excessive surface flood irrigation. It also remains to be seen through the field trials that precision irrigation can provide substantially greater benefits than traditional irrigation scheduling. The advances in wireless sensor networks have made some practical deployment possible for various agricultural operations on demonstration scale, which until a few years ago was considered extremely costly or labor intensive. Precision irrigation system with robust components such as, sensing agricultural parameters, identification of sensing location and data gathering, transferring data from crop field to control station for decision making and actuation and control decision based on sensed data will find application in future agriculture. Thus the great potential of integrating the precision farming with WSN to interpolate over a large area for spatial decision making need to be tapped for making agriculture attractive in future.

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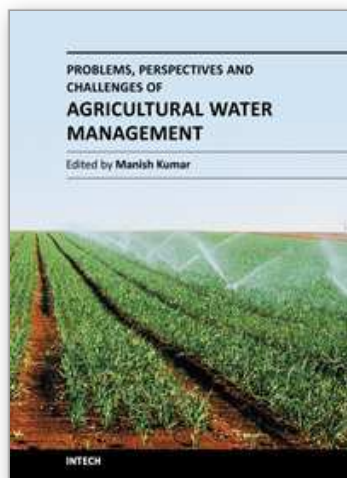
Problems, Perspectives and Challenges of Agricultural Water Management

Edited by Dr. Manish Kumar

Food security emerged as an issue in the first decade of the 21st Century, questioning the sustainability of the human race, which is inevitably related directly to the agricultural water management that has multifaceted dimensions and requires interdisciplinary expertise in order to be dealt with. The purpose of this book is to bring together and integrate the subject matter that deals with the equity, profitability and irrigation water pricing; modelling, monitoring and assessment techniques; sustainable irrigation development and management, and strategies for irrigation water supply and conservation in a single text. The book is divided into four sections and is intended to be a comprehensive reference for students, professionals and researchers working on various aspects of agricultural water management. The book seeks its impact from the diverse nature of content revealing situations from different continents (Australia, USA, Asia, Europe and Africa). Various case studies have been discussed in the chapters to present a general scenario of the problem, perspective and challenges of irrigation water use.

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