Sensor based Irrigation System : A Review

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***Abstract*— The growing water demand has raised serious concern to the future of irrigated agriculture in many parts of the country. Therefore, the knowledge of crop water demand is an important practical consideration to improve the water use efficiency in irrigation practices. The traditional irrigation systems provide unnecessary irrigation to one part of a field while leading to a lack of irrigation in other parts. Changing environmental conditions and shortage of water have led to the need for a system which efficiently manages irrigation of fields. The aim of this paper is to review the need of soil moisture sensors in irrigation, sensor technology and their applications in different aspects of agriculture and in irrigation scheduling.**

Keywords— Agriculture; Irrigation; Soil moisture sensors

I. INTRODUCTION

Water plays a crucial role in photosynthesis and plant nutrition. Agriculture is the major user of fresh water, 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 [20]. One of the major problem in agriculture is non-optimal usage of water. It is 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 [20]. The problem of agricultural water management is today widely recognized as a major challenge that is often linked with development issues. Many freshwater resources have been degraded by agricultural activity, through over-exploitation, contamination with nutrients and salinisation [15]. Many studies have been carried out related to irrigation water requirements [9,14,18]. Irrigation is defined as the artificial application of water in agricultural land and it is considered as one of the most important constituents of agriculture. Scarcity of water in several areas instigates the need of proper use of water that is water should be provided to only those places where it is needed and in required quantity. Different methods of irrigation are in use like drip irrigation, sprinkler irrigation etc to cope up with the water wastage problem in traditional methods like flood irrigation and furrow irrigation [2]. The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation [1]. Irrigation water demand as well as crop water requirement can be estimated by combining the modified Penman–Monteith equation recommended by FAO and GIS technology [7,14]. According to Shen et al. [14], irrigation water demand is essential to the water resources allocation for the benefit of economy and natural ecosystems in the highly water deficit region. Determining the water requirements of crops is important for improved scheduling of irrigation [13]. Hence there is a need for a way to determine field conditions when water must be applied to the fields. This mechanism would reduce the workload of the farmer and help them to maintain proper soil conditions for improved and better crop production. Hence with the advance technology it is possible to design systems that eliminated the direct involvement of the farmer with respect to irrigation of their fields [5]. Therefore a new approach of collecting real time data from the field by using soil moisture sensor offers real potential for reliably monitoring soil water status in agriculture fields. The relatively low cost of the sensor nodes allows for installation of a dense population of soil moisture sensors that can adequately represent the inherent soil moisture variability present in any field [6,8,16,17]. The main objective of this paper is to review the need of sensors based technology for an automatic irrigation system which can be used for optimum use of water, saving money, electricity and time of the farmer.

II. METHODS OF IRRIGATION

Various irrigation methods have been developed over time to meet the irrigation needs of certain crops in specific areas. The four main methods of irrigation are surface, sub-surface, sprinkler and drip/micro irrigation as shown in Fig. 1.

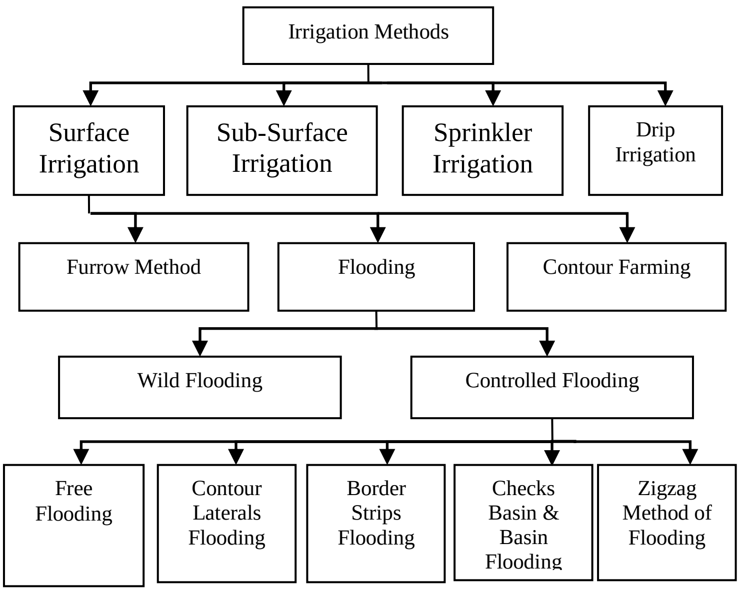

Fig. 1 : Methods of Irrigation

Water flows over the soil by gravity for surface irrigation. The surface irrigation method can further be divided into furrow, flooding and contour farming methods. According to the International Commission on Irrigation and Drainage, surface irrigation is used on about 85% of the 299 Mha of irrigated crop land in the world [28]. India and China each irrigate more than 60 Mha of crop land, accounting for almost half of the irrigated land in the world. Approximately 95% of the irrigated land is surface irrigated in India and China [29]. Surface irrigation is often considered less efficient than sprinkler irrigation or micro irrigation because soil conveys the water within surface irrigated fields.

Sub-surface irrigation is a minor irrigation method, where the water table is raised to or held near the plant root zone using ditches or subsurface drains to supply the water. Sub-surface irrigation is not often used in arid or semi-arid irrigated areas where irrigation is often needed to germinate crops. It is typically used in conjunction with subsurface drainage, or controlled drainage.

Sprinkler irrigation applies water to soil by sprinkling or spraying water droplets from fixed or moving systems. Sprinkler irrigation is often more efficient than surface irrigation because water application is more controlled. In hot and windy areas sprinkler irrigation can have significant water losses to evaporation and wind drift. Maintenance is also important for efficient sprinkler irrigation; worn nozzles and leaking pipe connections reduce application uniformity and system efficiency.

Drip irrigation applies frequent, small applications by dripping, bubbling or spraying, and usually only wets a portion of the soil surface in the field. Subsurface drip irrigation can significantly improve yield and water use efficiency compared to surface irrigation [3].

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 [20]. The selection of a irrigation method is depends on soil, water and climatic conditions as well as crop types, user knowledge and preference, capital and operating costs, and infrastructure availability

TABLE 1: Application Efficiencies for Irrigation Systems

Irrigation Method	Application efficiency
Surface irrigation	
a) Furrow	50-70 %
b) Level basin	60-80 %
c) Border	60-75 %
Sub irrigation	50-80 %
Sprinkler irrigation	60-85 %
Drip Irrigation	80-90 %

Source : Bjorneberg et al., [3]

There is no ideal irrigation method available which may be suitable for all weather conditions, soil structure, variety of crops cultures and gives 100% efficiency [20].

III. USE OF SENSORS IN IRRIGATION

For determining the soil moisture content (in volumetric and gravimetric forms), various techniques can be employed, which can be categorized into (i) classical and (ii) modern techniques for both the laboratory and in situ measurements. The classical soil moisture measurement techniques include thermo-gravimetric, calcium carbide neutron scattering, gypsum block and tensiometer methods. While the modern techniques utilize soil resistivity sensor, tensiometers, infrared moisture balance and dielectric techniques like Time Domain Reflectometry (TDR), Frequency Domain Reflectometry (FDR) capacitance technique, heat flux soil moisture sensors, micro-electro mechanical systems and optical techniques [4,12]. Estimation of water content based on sensor measurements provide real time, in situ measurements at a relatively affordable cost. Soil moisture sensors potentially provide the means to irrigate in accordance with the unique characteristics of a given crop in a given field. These sensors can be used as a ‘‘stand-alone’’ method, or their use can be combined with the FAO method, or they can be used to complement irrigation management based on experience [15]. A conceptual system layout of distributed in-field Wireless Sensor Network (WSN) is illustrated in Fig: 2. The system comprises over several components called ‘nodes’. The nodes are smart devices that are used to collect the application oriented data requirements. A sensor network performs three basic functions: (i) Sensing (ii) Communication and (iii) Computation by using hardware, software and algorithm. The nodes perform several roles. The distributed nodes that collect the information are called source node while the node that gathers the information from all source node is called the sink node or the gateway node. The sink node could have relatively high computing power. A source node also works as a routing node due to the requirement of multi hop routing. External memory is an optional module that could be needed in case of data storage requirement for local decision making. The in-field sensors monitor the field conditions of soil moisture, soil temperature, and air temperature. All in-field sensory data are wirelessly transmitted to the base station. The base station processes the in-field sensory data through a user-friendly decision making program and sends control commands to the irrigation control station [2].

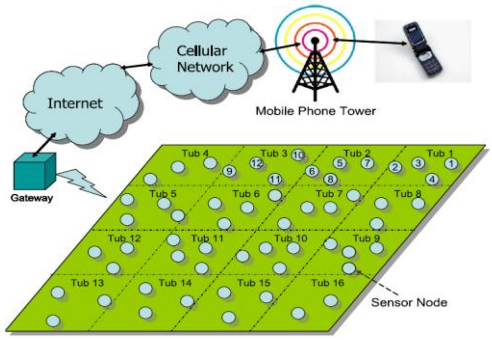

Fig. 2: Application of sensor network in field
Source: Sherine et al., [30]

In this system farmers can get the real time information (ex. soil moisture and crop growth) of their farmland by android app or through automatic SMS facility, for better crop management practices. Using this information the farmers could be advised that when and how much to irrigate. The sensors used in agriculture is given in Table 2.

TABLE : 2 Sensors Used in Agriculture Domain

		Soil						
S. no.	Sensors	Temperature	Moisture	Dielectric permittivity	Rain/ water flow	Water level	Conductivity	Salinity
1.	Hydra probe II soil sensor	✓	✓	✓	✓	✓	✓	✓
2.	Pogo portable soil sensor	✓	✓	✓	✓	—	✓	—
3	MP406 Soil moisture sensor	✓	✓	✓	—	—	—	—
4.	ECH2O soil moisture sensor	✓	✓	✓	—	✓	✓	—
5.	EC sensor (EC250)	✓	✓	—	✓	—	✓	✓
6.	ECRN-50 low-REC rain gauge	—	—	—	✓	—	—	—
7.	ECRN-100 high-REC rain gauge	—	—	—	✓	—	—	—
8.	Tipping buket rain gage	—	—	—	✓	—	—	—
9.	107-L temperature Sensor (Beta Therm 100K6A1B Thermistor)	✓	—	—	—	—	—	—

Source : Rehman et al., [2]

A. Field Application of Wireless Sensor Network (WSN)

Dias et al., [6] developed a new single probe heat pulse sensor (SPHP), which was comprised of only one element, a n-p-n junction bipolar transistor, worked as both heating and temperature sensing elements.

Xiao et al., [17] developed a wireless, integrated, frequency-domain soil moisture sensor for paddy field (WFDSS) applications in china. This soil sensor was able to measure soil moisture content and water depth at the same time and transmitted the collected data wirelessly to a remote data management center.

Shabadi et al., [25] developed an Android application which helps the farmer to ON/OFF the motor without his physical presence in the field.

Calamita et al., [23] evaluated the appropriateness of the multi-frequency sensor GEM-300 for the spatio-temporal retrieval of soil moisture at the hill slope scale in four sites located in the small mountainous catchment 32 km^2 in southern Italy. Six frequencies were chosen in the range between 7 and 20 kHz for the GEM-300. In order to assess in which conditions the GEM-300 sensor could be used for the retrieval of soil moisture variations during a complete hydrological year, a number of sites with different soil-landscape attributes were surveyed. Based on the results of the correlation analysis, a linear relationship between electrical
conductivity and soil moisture measurements was built with different degrees of explained variance (e.g., $R^2 = 0.46–0.69$) and confidence (e.g. RMSE = 3.2–7.8), with best results obtained in the wooded areas. Moreover, it has been demonstrated that the crop production decreases as the electrical conductivity of the irrigation water increases.

Lailhacar and Duke [19] used sensors from brands Acclima, Rain Bird, Irrometer, and Water Watcher that were buried at 7–10 cm depth, on plots with common bermuda grass. A calibrated ECH2O probe was also installed in every plot, at the same depth, to monitor volumetric soil water content continuously. When comparing the ECH2O readings with volumetric soil water content sensed by the soil moisture sensors, significant correlations were found for the three Acclima RS500 (AC) systems tested, and for two of the three systems of Irrometer Watermark 200SS/WEM (IM) and Rain Bird MS-100 (RB).

Blonquist et al., [4] concluded that when a sprinkler system was used with the Acclima Digital Time Domain Transmission Soil Moisture Sensor for irrigation control and scheduling, 16% less water was applied compare to evapotranspiration estimates from a weather station and 53% less water was applied using a fixed irrigation rate of 50mm per week (7.14mm/day), Thus the potential water savings with the soil moisture sensor system is not only important to water conservation, but can save irrigators an estimated US$ 5.00-100.00 per month based on average water prices in the US and a 1000 m^2 irrigated turfgrass plot.
Vellidis et al., [16] used the array of watermark wireless smart sensor for measuring soil moisture and soil temperature. The system had a large number of sensors which were installed in a cotton field, located in the University of Georgia’s Tifton Campus. The sensors transmitted collected data wirelessly to a centrally located receiver. To evaluate the performance of the smart sensor array, two different irrigation scheduling strategies were adopted. In the western left half of the field, irrigation was scheduled using a traditional assessment of the crop (plant wilting, rainfall, and weather forecast) by a staff member with many years of experience growing cotton. In the eastern half of the field, irrigation was scheduled using the smart sensor array. Two or three sensor nodes were installed to characterize soil moisture conditions within the zone. Each smart sensor node consisted

of three Watermark® soil moisture sensors installed within the row at depths of 0.2, 0.4, and 0.6 m. The result shows that the smart sensor array was able to successfully monitor soil water tension as measured by the Watermark® sensors. On the west side of the cotton field, irrigation was triggered based on traditional assessment of the crop (no sensors). This irrigation scheduling strategy resulted in much higher soil water tensions at 0.4 and 0.6m depth than any observed in the eastern half of the field. In some instances, measured tension was more than double the trigger points established for the smart sensor scheduling protocol. It is also evident that the amount of irrigation water applied only served to momentarily reduce soil water tension below 0.2m depth.

Bartlett et al., [24] have created an online evapotranspiration-based irrigation scheduling tool called Water Irrigation Scheduling for Efficient Application (WISE) that uses the soil water balance method and data queries from Colorado Agricultural Meteorological Network (CoAgMet) and Northern Colorado Water Conservation District (NCWCD) weather stations. To expedite and mobilize required user interaction with the software interface, a smartphone app has been developed that allows users to quickly view their soil moisture deficit, weather measurements, and the ability to input applied irrigation amounts into WISE.

Montoya et al., [26] and Kuchekar et al., [27] have proposed advanced water deployment system. In this system combined action of wireless sensor network & embedded system was used in the irrigation. The temperature, humidity & soil moisture were measured by wireless sensor network and GSM service was used to inform the user about the exact field condition.

IV. BENIFITES OF SENSORS BASED IRRIGATION

The primary goal of this system is to apply an optimum amount of irrigation throughout the fields. Sensor based irrigation has the potential to increase both the water use and economic efficiencies. The potential economic benefit of this irrigation system lies in reducing the cost of inputs or increasing yield for the same inputs. The traditional farm-land irrigation techniques require manual intervention. With the automated technology of irrigation the human intervention can be minimized [21]. The benefits of this technology can be seen as follows :

A. Water savings

It is reported by many researchers that this system is the most likely means of achieving significant water savings [20]. It has been reported that the use of sensors with drip and sprinkler irrigation system can improve application efficiency of water up to 80-90% as against 40-45% in surface irrigation method [22]. Blonquist et al., [4] concluded that 16% of water could be saved in this irrigation practice.

B. Yield and profit

It is reported that proper timing of irrigation is an important factor for production while delaying irrigation can result in losses of between US$ 62/ha and US$ 300/ha [16]. The experimental studies were carried out by Sherine et al., [30] for measuring the yield of potatoes in Egypt using the wireless sensor network technology. It was reported that yields were increased and a loss of 2 billion pounds were recovered in a year.

This technology can be used to improve water use efficiency in semi-arid region like Rajasthan. Groundwater is the principal source of irrigation in Rajasthan state, which is declining by about 1 m per year. Currently, the irrigation practices utilized in this state is mostly old furrow system which provides unnecessary irrigation to one part of a field while leading to a lack of irrigation in other parts. Due to these reasons water use efficiencies are low, and water application is not optimized. Farmers irrigate their fields based on their traditional knowledge without taking into account soil moisture level in the field, soil type, crop water requirement and weather forecasting. If farmers of this region will use this sensor based technology then they could be advised about irrigation scheduling in their field and could increase their water use efficiency and yield, it would go a long way in meeting the food security requirement of this state as well as our country.

V. CONCLUSIONS

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 non-optimal use 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. Whenever there is a change in temperature and humidity of the surroundings these sensors senses the change in temperature and humidity and gives an interrupt signal to irrigate. These sensor 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.

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