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A Review On Iot Based Precision Irrigation Planning And Scheduling

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ABSTRACT

Global warming and climate change are warnings showcasing water crisis. At the same time ever growing population is ultimatum to the food security. In span of such times, world has to be made a sustainable habitat. It is only possible when each ounce of resources is being measured and used judiciously. Maximum responsibility is on farmers and researchers of the world. In times of advanced technologies, Internet of Things (IoT) has surfaced as a saviour. IoT based systems have been stated as success in monitoring and control mechanisms. Thus, this paper was intended to review the control strategies and monitoring systems based on IoT. The literature incorporates basic information as well as recent trends in the field of irrigation management based on IoT.

1. Introduction

Indian agriculture is backbone for developing world population and its demands. India is largest producer of few cereals and spices as well as milk in world. It is one of the largest producers of rice, wheat, sugarcane and few vegetables as well as fruits. Agriculture of this country does not afford to lag behind in use of technologies for production. It needs to increase the productivity of land where in major role is played by water resources. Innovations and application of new technologies to meet the need of agricultural growth especially in irrigation. Science in past decades have opened the scope for IoT (Internet of Things) based technologies, precisions farming, use of artificial intelligence and lot more. Use of such technologies in field of agricultural production for better management is known as "Smart Agriculture". IoT based technologies are used to monitor crop growth, detect diseases, monitor irrigation, spraying of pesticides, food grading etc. This system retrieves information from field using several sensors for temperature, moisture, light, colour, oxygen etc. cost of using several sensors and connected elements of technology makes it costly affair. Thus, to incur benefits of IoT based technology in agriculture first requisite is that it has to be cost effective.
There are several variables on which agricultural production depends like machineries, inputs and weather factors. Precision Agriculture (PA) is a method adopted to manage such variables to fit the needs of crop yield as well as farmer (Nowak, 1997). The main aim of PA is to increase the effectivity with which inputs are being used in production, reduce cost and wastes (Cisternas et al.2020). It uses space and time data to optimize the

requirement of inputs (Aubert et al., 2012). For example, PA can calculate the exact quantity of fertilizer required and location of application. Actually, PA uses Information Technology (IT) for collection of site-specific data to apply exact amount of input resources required (Rodriguez et al., 2017). The data obtained from IT helps to understand location specific need rather than taking average requirement of whole land under crop (Paxton et al., 2011). It leads to wastage of resources as well as the aim of crop management is left unfulfilled. Ease of optimisation is biggest advantage with PA. In spite of many pros, PA is still not under blanket application in India (Pathak et al., 2019; Higgins et al., 2017). The complexity of technology beyond common man understanding is one major hindrance as farmers do not find it a comfortable to invest upon something that they cannot handle themselves. Maximum youth leave agricultural or rural are for job to cities and farmers feel they must adopt technologies only which are under their control. Also, initial investment is quite on higher side for implementation of PA (Pathak et al., 2019, Orozco and Ramrez, 2016). Several researchers have suggested solutions to tackle the issue at hand for farmers but minimum degree for better understand of PA technologies and its application is a hindrance. In fact, there are certain limitations when it comes to combination of agricultural needs and IT solutions. Each agricultural land has its own unique characteristics which one IT solution or application may not be able to cater. Thus, an approach where phase by phase PA can be applied is better. This makes the process rigorous in itself for a beginner (Tripathi et al., 2013; Shannon et al., 2018).

Irrigation is critical part of agricultural production process as demand of fresh water is high and crop success depends largely on availability of water. Thus, an efficient method for water usage in agriculture is needed that meets the needs of water conservation as well as food requirement of growing population at the same time (Tsang and Jim, 2016). Rainfall dependent agriculture is a thing of past now. It has become erratic, unpredictable and unreliable. Excess supplies cause surface runoff and soil erosion. And scarce rainfalls cause drought. Thus, irrigation systems are used across world to decrease the dependability on rains and assure control over watering in crop cultivation (Oborkhale et al., 2015). Conventional irrigation does not consider measurement of location specific water need. Surface irrigation involves application of uniform supply of water. It leads to wastage of some areas and lesser feed than required at some areas on same land. Over irrigation and under irrigation on same land are major drawbacks of conventional irrigation (Kumar et al., 2017, Anusha et al., 2017; Lakhiar et al., 2018; Say et al., 2018). Pre- programmed irrigation controllers manufactured and programmed on the basis of previous years' data on climate, environment, soil health and plant characteristics provide the function of controlled water supply, but they lack real time demand (Lozoya et al., 2014). The dynamic environment needs irrigation system that can control the supply of water on real time basis to ensure proper water uptake by plant (Yusuke., 2018). To counter above dynamics of crop irrigation, application of PA using IT has huge scope. It may assure optimal use of water resource as well as support crop production (Shibusawa, 2001; Zacepins et al., 2002). PA takes into account data of spatial and temporal variations of soil, its structure, hydraulic properties, plant characteristics in response to excess or deficit water situation, weather characteristics etc using Internet of Things (IoT). These data help in achieving improved crop yield and less water-use (Bitella et al., 2014; Capraro et al., 2018; Zhang et al., 2002). Few authors although suggest against it (Cambra et al., 2018; Chami et al., 2019). IoT helps in data collection and application related to nutrient need of plant. PA using IoT can apply required nutrient rich water at the root of plant or at optimum distance from root. Processes like this help to maintain soil moisture, nutrient availability and eliminate run-off. Methods like these accomplish target of deep percolation and meeting crop water demand leading to crop yield improvement and increase in productivity (Daccache et al., 2015; Tropea, 2014; Smith et al., 2010). An efficient smart irrigation data acquisition using IoT, monitoring, control and decision support (Pham and Stack, 2018; Zamora-izquierdo et al., 2018).

Several researches and reviews have been done on topic of precision agriculture (Semananda et al., 2018 and Pierpaoli et al., 2013). In addition to that incorporation of IoT monitoring and data analytics have been also discussed by many Abhishek and Sanmeet, 2019; Dlodlo and Josephat, 2015; Elijah et al., 2018; Kamilaris et al., 2017; Martin et al., 2017; Wolfert et al., 2017; Munoth et al., 2016). Several forecasting models have also been developed and reviewed in past (Ding et al., 2018). Only a few have reviewed the strategies to monitor and control irrigation systems in combination for water-saving agriculture. Thus, this paper is intended to discuss advanced control and monitoring combination for irrigation management.

2. Irrigation Methods

For proper plant growth irrigation is inevitable at appropriate stages of growth and as per demand of crop. There are two methods of irrigation followed. Either traditional method or water conservation method. Traditional methods mean Surface irrigation wherein it can be further classified into furrow method, flooding method and manual watering method. Water conservation irrigation methods are subsurface (capillary irrigation), drip irrigation and sprinkler irrigation. Sprinkler irrigation is further classified into standalone sprinkler, centre pivot sprinkler and lateral more sprinkler. Irrigation water quantity depends on soil type and timing of irrigation depends on crop type. Irrigation methods affect the nutrient uptake by plants, infiltration rate, evaporation rate, water absorption pattern and deep percolation of soil. In surface irrigation method, there is no control over the quantity of water being applied to specific location of crop area although it used to be practiced throughout world (Yonts, 1994; Ghodake and Mulani, 2016). This method needed well levelled land for uniform application and to avoid runoff (Zhang et al., 2004). Surface methods like furrow or flooding methods cannot be used if intention is water conservation because they lead to uncontrolled irrigation volume and losses due to blanket evaporation (Gillies, 2017). They also have drawbacks like surface runoff, leaching and depleting soil nutrients thus affecting crop yield (Adamala et al., 2014). Using IoT and precision agriculture technologies surface irrigation can become a water saving method. Control and monitoring mechanisms can be installed to increase water use efficiency (Koech et al., 2010).

Subsurface and drip irrigation methods have been reported to show better water-saving and crop yield as compared to surface irrigation (Nalliah and Sri Ranjan, 2010; Li et al., 2018; Ohaba et al., 2015; Shukri Bin Zainal Abidin et al., 2014; Shukri Bin Zainal Abidin et al., 2012). Subsurface irrigation involving capillary mediums like wicks, mats, ebbs, porous ceramics help in gradual flow of water from source to directly the root zone of plant, evidently saving water losses due to evaporation and taking up water only till saturation (Semananda et al., 2018; Cai et al., 2017; Wesonga et al., 2014). It basically works on principle of negative pressure. Several other studies have also reported subsurface irrigation is better at water saving (Kamal et al., 2019; Ferrarezi et al., 2016; Kinoshita et al., 2010; Masuda, 2008). A major disadvantage that has come to notice is accumulation of salt due to upward movement of water in capillary thus increasing the problem of salinity which can be handled through leaching (Fujimaki et al., 2018). This creates a scope for installation of monitoring and control system in capillary subsurface irrigation method to keep salinity in check.

In drip irrigation method narrow tubes are used to supply water to the soil near plant roots (Brouwer et al., 1990a). Water loss due to evaporation, wind or surface runoff are avoided efficiently through drip irrigation (Pramanik et al., 2016; Bhalage et al., 2015; Rekha et al., 2015). Drip irrigation method is used to provide nutrient rich precise amount of water supply which helps to reduce leaching too (Elasbah et al., 2019). However, to make drip irrigation a success, several calculations are required for distribution wetting patterns, distance between drippers etc. (Bajpai and Kaushal, 2020; Hou et al., 2015). Major disadvantage with drip irrigation system is the setup cost for pipes, emitters, trickles etc. (Bralts and Edward, 1987). Also, it is a high maintenance system as the emitters need regular cleaning to avoid blockages and distribution pipes have to be regularly monitored for any leakage or breakage (Ravina et al., 1992).

Another mostly used method is sprinkler irrigation. It functions by sprinkling water using spray head and creating a pattern of precipitation on the plant. It uses extensive piping system and thus covers large area (Evans et al., 2012a; Evans and King, 2012). Major disadvantage with this method is the high operating cost due to accessories like sprinkler head, high pressure pumps and electricity. One more limitation is it cannot be used in places where wind speed is high as it leads to water losses due to wind drift and evaporation (Xingye et al., 2018; Zhao et al., 2009). Similar to drip irrigation system, sprinkler method has high maintenance cost and requirements. Sprinkler and connection pipes require regular monitoring for any breakage or leakage. Thus, in sprinkler and drip irrigation both systems, regular real time monitoring and controlling techniques are required to make sure the water distribution uniformity is not disturbed.

2.1IoT based precision irrigation

To develop a precision irrigation system, huge amount of data is required so as to predict the real time status of crop characteristics, soil and weather conditions. IoT helps in collection of such data using sensors, actuators and internet (IT). These data when accumulated and run through appropriate software help in monitoring and controlling the entire irrigation process (Ferrandez-Pastor et al., 2018). Some wireless sensors like WSN (sensor nodes) can be used at large scale for sensing, computing and transmitting information regarding each parameter (Hamouda, 2017). IoT has seen widespread implementation in precision irrigation through sensors, cameras. Unmanned Aerial Vehicles (UAV), drones and satellites for data acquisition. For relaying or transmission purposes, cloud services are used too (Karim et al., 2017; Dubravko Culibrk et al., 2014. Cloud services use data received from sensors to analyse them and help in decision making and visualization (Rajeswari et al., 2017). The algorithms for monitoring and control are placed on cloud using smartphone applications or particular devices (Jayaraman et al., 2016; Pongnumkul et al., 2015). Thus, it becomes considerably easier for farmers and enhance the effectiveness of IoT based monitoring system for supply of irrigation water (Andrew et al., 2018; Kushwaha et al., 2015; Uddin et al., 2017). Figure below shows a flow diagram depicting working of an IoT based monitoring system. Wireless communicators like GPS, 3G, 4G, Wi-Fi, Bluetooth etc are used. Several low power wide area (LWPA) technologies are also used like LoRa, LTE Cat-NB1, Sigfox etc. (Li et al., 2017; Ramesh and Rangan et al., 2017, Lin et al., 2017). Some important parameters that are measured or sensed for design of precision irrigation system are soil moisture content, salinity, pH, soil water absorption capacity, greenhouse canopy light, air temperature, humidity, evapotranspiration, vegetation indices (NDVI, EVI), leaf area index (LAI), crop water stress, stomatal conductance, sap flow, stem water content etc.

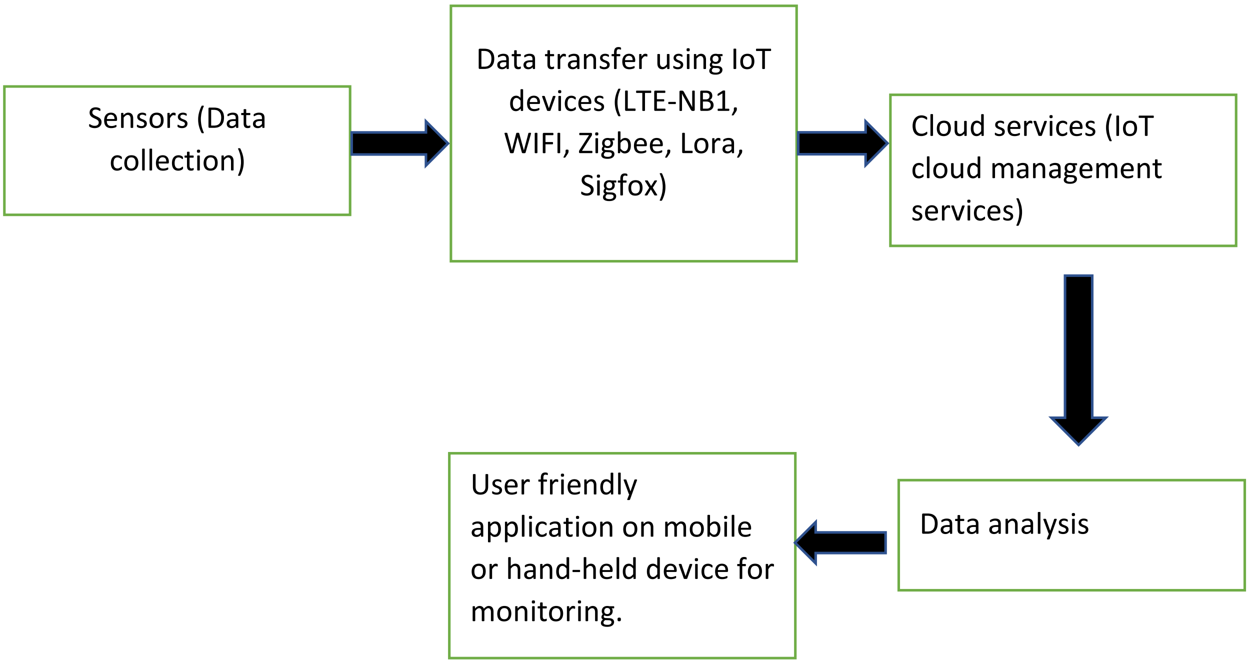

Figure 1: IoT based monitoring system

3. IoT based soil monitoring

Soil moisture affects the soil as well as plant dynamics. Thus, it is a crucial parameter to be monitored to keep drought or flood under check. Soil moisture data can help farmer in irrigation scheduling as well. IoT based Raspberry Pi and Arduino prototype boards are used to monitor soil moisture in precision irrigation technologies. They are interfaced with real time sensors of soil moisture. It gives information on crop water use and help in deciding next irrigation schedule (Rao and Sridhar, 2018; Anusha et al., 2017; Chate and Rana, 2016).

Time domain reflectometry (TDR) based sensors have been reported to be considerably accurate form of sensors. They consist of two parallel rods inserted into soil at a depth at which moisture content is to be measured. The rate at which electromagnetic pulse radiated to and from soil is measured as it is directly related to soil moisture content. Since high sampling rate is required for better signal reflection from soil, it becomes high cost involving sensor. Capacitance based sensors are also real time sensors, they are practical to use and lest costly too (Shigeta et al., 2018). It works on the principle of volumetric moisture content (VMC). Bitella et al. (2014) proposed a soil water content sensor at different depths. It consisted of dielectric probe interfaced with Arduino Uno microcontroller the transmitted the data registered to internet using wi-fi. Work of same IoT based sensing was reported by other researchers who used Node MCU (Chieochan et al., 2017; Kumar et al., 2017). Cloud based (IoT based) monitoring and data analysis was done using Arduino as a controller was reported by researchers. (Jha et al., 2017; Salvi et al., 2017; yashaswini et al., 2017). Above IoT based data collection and analysing helped the studies to predict crop water use and strategize future irrigation scheduling. An automatic water supply was developed using wireless networks. These wireless networks were made to use GSM and infrared (Hebbar and Golla, 2017). A Pic controller was used in above study to switch the pump on or off using relay driver. This relay driver received signal only after a certain moisture level was achieved. This moisture level sensor was capacitance based that consisted of two electrodes measuring the resistance in soil. In another experiment, a sensor layout network technology was used to soil moisture. This was then integrated with an android application (Isik et al.,2017). Soil moisture sensors measured moisture/humidity at the root zone of crop and communicated the data to android application in mobile. This mobile phone then became the control unit to open or close electro valves. These valves controlled the amount and timing of water to be supplied in drip pipe.

In a citrus cultivation study conducted by Zhang et al. (2017) soil nutrient was monitored using IoT based detector. Moisture content of soil, air temperature, humidity and soil temperatures were also recorded using SHT17 digital sensor connected with JN5139 system control node through wireless connection of Zigbee. The information collected after sensing were used as input in a decision support system (DSS) for decision making. Fandika et al. 2019 conducted a study on "chameleon". Chameleon was name given to soil and nutrient sensing technology. This technology used colour coding for several indications like low, medium, high levels of soil moisture and nutrient levels. Farmers in Malawi got benefitted through this technology as it was better version of user-friendly technologies. It helped them in water management and knowing nutrient deficit status of their crop cover. In an experiment conducted by Joly et al. (2017), soil nitrogen was monitored using silicon chip. An ion-sensitive field effect transistor (ISFET) microsensor was used for sensing pH of soil and nitrogen content. Huskonen and Oksanen, (2018) used drone on cameras to do soil mapping to identity management zones. The images collected by aerial surveillance contained information regarding soil moisture and nutrient level in each zone. It helped in further irrigation scheduling. Prasad et al. (2016) in their study measured oxidation-reduction potential, salinity, potential hydrogen and salinity using different sensors. This many information gave great idea about health status and planning irrigation schedule.

4. IoT based weather variables' monitoring

Air temperature, solar radiation and wind speed are major weather variable that help to predict evapotranspiration and water loss rates. IoT based weather stations help us in giving information on above parameters as well as few sensors like Lysimeter, Light dependent resistor (LDR), SHT 11, DHT 22 sensor, handheld infrared thermometer etc. do the job too.

WSN method has been reported by several researchers for precision weather monitoring (Bauer and Aschenbruck, 2018; Keswani et al., 2018; Difallah et al., 2018; Hamouda, 2017; Mohanraj et al., 2017; Saraf and Gawali, 2017; Viani et al., 2017; Patil and Desai, 2013). It has been found suitable for large cropping area. It acquired data on real time basis and analysed them. This acted as control for activation of control switch.

An IoT based monitoring device to measure humidity, air temperature, solar radiation, windspeed and soil moisture content was used by Wasson et al. (2017). Data was transferred on real time basis using wireless communication and internet-based devices. Another study was done to measure soil moisture, soil temperature and leaf wetness using same method (Shahzadi et al., 2016).

5. IoT based plant characteristics' monitoring

Optical sensors have been found to be great aid in sensing data regarding plant/crop health or soil characteristics. Plant health directly indicate water deficit, pest attack or nutrient deficiency. Optical sensors can either mounted on drones, sprinklers or fixed near plant (Bogue, 2017; Nutini et al., 2017).

In a tea plantation study, Jia et al. (2019) developed a system of sensors, gateway node and wireless communication device. Crops and soil images taken using camera on drone were analysed to find soil moisture content. The study reported that this sensed information helped in water conservation and nutrient management. Leaf area index (LAI) was measured and monitored using sensors and wireless network. It helped in irrigation scheduling and improving crop performance (Bauer and Aschenbruck, 2018). Similar were the findings with Harun et al. (2019). They used sensed information for activating pulse width modulated (PWM) actuator in connection with IoT deployed device. It helped in establishing photosynthesis rate and water–use efficiency.

High- resolution cameras mounted on UAV were used in few studies to monitor the entire area under irrigation (Aleotti et al., 2018; Uddin et al., 2017). They reported that multispectral images captured were used to calculate normalized difference vegetation index (NDVI) map. Which in turn helped in clear mapping and planning of irrigation schedules. This study also brought focus on scopes of wireless sensing and analysing methods for forecasting models. Lozoya et al. (2016) conducted study in four experimental layouts of green pepper vegetation. Each vegetation area was monitored using VMC sensor, hunter flow sensor and camera. Irrigation valve was connected through actuator nodes that received information from sensors. IoT based weather station was also used for evapotranspiration readings.

To achieve high crop yield, better water uses efficiency and optimisation of nutrients, irrigation water application should be scheduled and monitored using control feature in IoT based precision system (Boman et al., 2015; Marinescu et al., 2017). There are two types of control technique used on irrigation system, open loop and closed loop.

Irrigation decisions are manually taken by the operator or farmer after receiving signals from mechanical and electromechanical timers on precision system. The volume of water to be applied is also decided by the

operator. Open loop system does not exactly function as precise system because the knowledge and perception of responses from sensors of operator play major role in decision making (Zazuta et al., 2008). Open loop control on precision irrigation system is more common among farmers because of user friendly nature (Agency, 2017). It has preset action list as per irrigation timers. Basically, volume of water to be applied and timing of watering are set by the operator. The operator here does not have to read or analyse the crop responses. Thus, it makes open loop system simple to operate for peasants. The crop variable parameters and weather variable parameters are not included or any feedback loop is also not set, thus easy to use (Harper, 2017). In a report it was stated that open control approach in sprinkler and drip irrigation system for a horticultural crop was designed where in real time clock was connected with Arduino board which was further connected to an actuator for pump operating water supply (Sudarmaji et al., 2019). In another study, open loop time-based precision irrigation system showed 18% leaching and lesser LAI as compared to closed loop approach (Montesano et al., 2016). Open loop precision irrigation is not dynamic thus requires regular resetting according to changes in the environment (Patil and Desai, 2013). Basically, open loop approach systems are irrigation timers and nothing more than that.
This systems function on feedback loop. Here the measured parameter is compared with a pre-set condition and to maintain the intended condition. Decision making is done for duration and volume of water supply. Klein et al. (2018) reported that closed loop approach makes the system fully automatic for irrigation scheduling as per crop's requirement. The control system is completely into the hands of system for time and frequency of water supply (Patil and Desai, 2013). The decision of irrigation time, place and volume are made based on the feedback received after sensing of soil, plant and weather parameters (soil moisture, air temperature, humidity, solar radiation, NDVI etc) (Deng et al., 2018; Adeyemi et al., 2017)

6. Future for farmers

Many companies have come up with smart watering system for precision irrigation and conservation of water. It also aims to reduce human labour in irrigation. The limitation is high cost; thus, farmers do not afford it or think of even buying the technology. Since these technologies are already built, they are difficult to be tuned as per requirements of each farmer. Thus, farmers can take the advantage of IoT based technologies or applications which may be user friendly and well attuned to their needs. A real time monitoring, data sensing and intelligent precision irrigation system may increase the water use efficiency, water saving considerably, as well as take care of the food security.

Conclusion

This review was done keeping in mind the gap between evolution of technology but need of farmers at large. An awareness about climate change did bring about considerable changes in the way farmers and researchers are approaching agricultural operations. Similarly, an awareness and knowledge of this IoT based operable irrigation scheduling will take the resource conservation to next level. Every farmer and researcher play an important role in keeping the earth and its resources sustainable. Thus, precision irrigation using IoT should be used by each one. This review has given a glimpse of recent trends in precision irrigation use and advancement. IT industries are further striving to make IoT based systems more user friendly and increase accuracy. The globe is reaching a point where agricultural production may become a mobile operated accurate system which may help in water crisis and resources overuse.

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