IoT in Irrigation

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***Abstract*—Many countries in the world have very limited water resources, which has forced researchers to look for optimum utilisation of water resources. Bringing automation in the irrigation system has become popular in the modern era. This paper gives (a) a complete overview and guidelines for what key elements needed for IoT-based irrigation systems. (b) communication technologies, WSN (Wireless Sensor Network) and what hinders communications in different system architectures. (c) challenges and opportunities in current IoT-based irrigation designs for future research.**

Keywords—IoT, Sensors, Smart Irrigation, WSN, Internet of Underground Things （IoUT）

I. Introduction

A. Motivations

By statistics, by 2050 the world's population is going to increase by 33%, which means we will need more water to produce more crops to feed 9.9 billion people. Also, by statistics, up to 70% of all water withdrawals are for food production. Hence, how to manage water resources to find the best possible utilisation is in urgent need [1].

Climate change is also the topic of interest in all fields of life starting from social science and going to applied science. Global climate cycles and world food production systems are under threat due to the recent climate extreme events. These events include heat waves and change in the rainfall patterns [2]. Recently we have noticed a lot of weather extremes happening everywhere in the world. Some areas are having less rainfall, some areas are facing new record severe floods.

Climate change has severely impacted the agriculture industry, and one of the biggest factors behind it is rainfall. Furthermore, in many countries, water has limited resources and is not particularly cheap. How to water wisely has been one of the popular topics in the industry. An IoT-based smart irrigation system can be one of the achievable solutions.

B. Precision Irrigation

As we have known the main reasons behind watering wisely are limited water resources, rapid population growth and climate change, if we would like to define what IoT-based smart irrigation can achieve, Precision Irrigation is a good practicable concept. This concept was incepted in the 1980s [3]. Precision irrigation was introduced to minimise the environmental impact. This needs researchers to find the accurate and precise utilisation of water resources to meet the specific requirements of each type of plants or crops. "Widely accepted definition of precision irrigation is sustainable management of water resources which involves application of water to the crop at the right time and right amount, right place and right method" [4].

C. Concepts

To apply precision irrigation, we will look at what parameters are commonly monitored and what devices are usually chosen for trendy systems. Next, we will focus on what communication technologies to use to connect all the deployed nodes and how to collect data from them, and what hinder the communications in different connection architectures. Finally, we will also talk about some new forms of IoT-based irrigation systems that combine with robots and IoUT (Internet of Underground Things).

II. Monitored Parameters

There are many different parameters to monitor of the IoT irrigation systems to achieve precision irrigation. Everybody would choose different ones for the specific design. In this section, we are going to discuss what parameters are mostly mentioned in a survey which was conducted by the University of Haute Alsace in France. They investigated a total of 283 papers that were obtained from Google Scholar, IEEE Xplore, Scopus and the digital library of Sensors. The keywords they used to obtain these papers were "IoT irrigation", "IoT irrigation system", and "smart irrigation" [5].

A. Soil Monitoring

In this section, the result is concluded from a total of 106 papers that include at least one sensor for the soil in their research.

In Fig. 1, we can see apart from soil moisture some research also monitors "Soil temperature", "Soil pH" or "Soil nutrients". When the soil temperature is higher, the soil moisture tends to evaporate more quickly. As for soil pH and soil nutrients, pure water is not the only option to use in irrigation systems. Users can add chemicals or fertilizers in the water to modify the soil pH and the nutrient level.

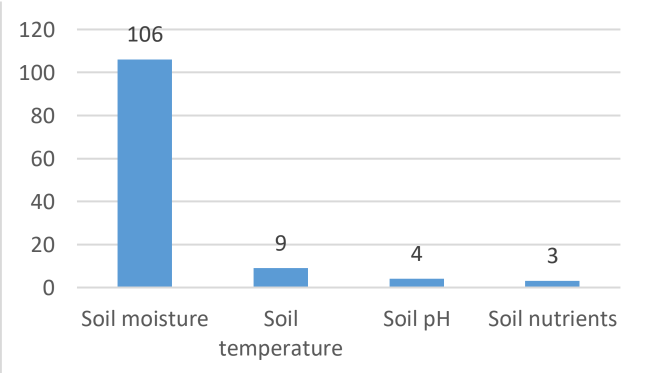

Fig. 1. Monitored soil parameters in all the evaluated papers [5].

In Fig. 2, we can see for the main parameter "Soil Moisture", what sensor models are people's favourite, if they did mention their sensor model among these 106 papers.

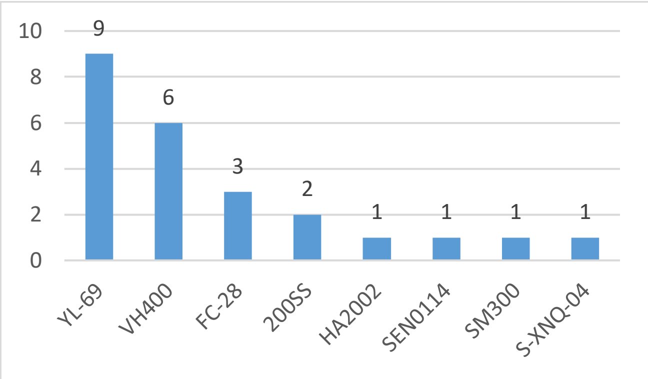

Fig. 2. Number of papers that used different models of soil moisture sensors [5].

The sensor most people would choose is the YL69, which has been used in 9 papers. The output voltageIt of the YL69 goes from 3.3 V to 5 V and the output values of the soil moisture reading goes from 0 to 300 for dry soil and 300 to 700 for moist soil. It is also low priced and is specifically designed for Arduino systems.

The second one most people would choose is the VH400. The output voltage of this sensor goes from 0 to 3 V and the output voltage is related to the volumetric water content in the soil. It is also low priced and can be implemented in Arduino systems. Plus it can detect the soil temperature as well.

Hence, if someone wants to build an IoT-based irrigation system with an Arduino board, these two sensors are good options to consider.

B. *Air Monitoring*

The second key factor in IoT-based irrigation systems is the air. Among 100 papers that include the air sensor readings, Fig. 3 illustrates the most monitored parameters, which is the "Air temperature", and the second top parameter most people monitor are "Air humidity", as with higher air temperature, the moisture in the soil evaporates more quickly. The other parameters are most likely involved when the performance of crops is in the equation.

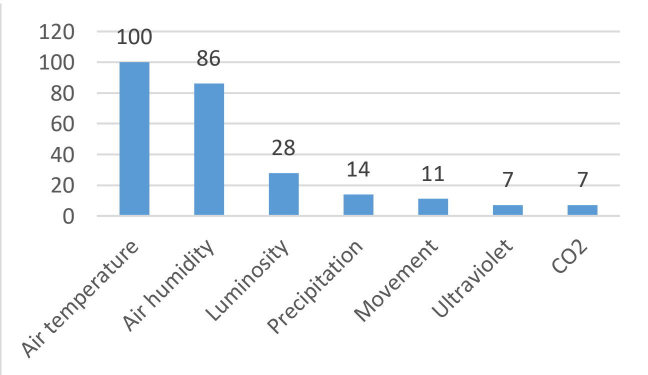

Fig. 3. Most Monitored air parameters [5].

As shown in Fig. 4, the DHT11, the DHT22 and the LM35 are the most popular air temperature sensors. All the sensors shown in Fig. 4 are low priced, where the DHT11 and DHT22 can monitor both air temperature and the air humidity readings, and the LM35 and the TMP-36 have broader temperature ranges. They are all good options.

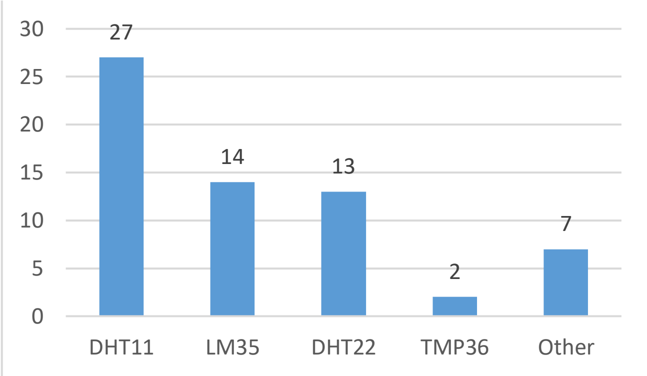

Fig. 4. Most utilised air temperature sensors [5].

Fig. 5 illustrates the air humidity sensors that were used in the papers. As mentioned before, the DHT11 and DHT22 sensors are more versatile, which makes them the most popular options. "Most systems that utilize these sensors do not choose a separate sensor for each parameter" [5]. I would recommend these two sensors too.

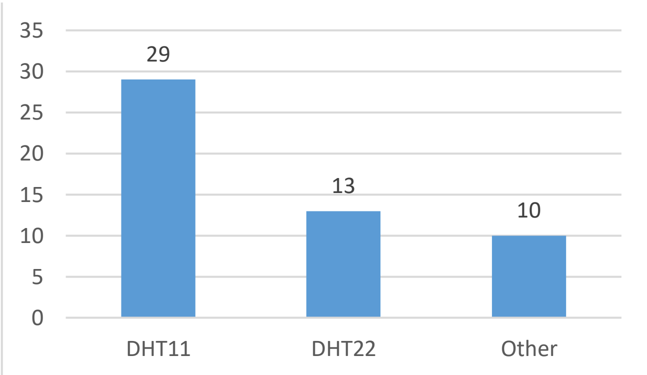

Fig. 5. Most utilised air humidity sensors [5].

C. *Weather Forecast*

There is something quite interesting to be seen here. Among all the papers I have read about IoT irrigation systems and all the tutorials I have watched, not many of them consider one of the key factors – weather forecast. From the survey shown in Fig. 6, among 89 papers from those reputable journals, only 15 papers of them use the weather forecast data and include this data in their systems.

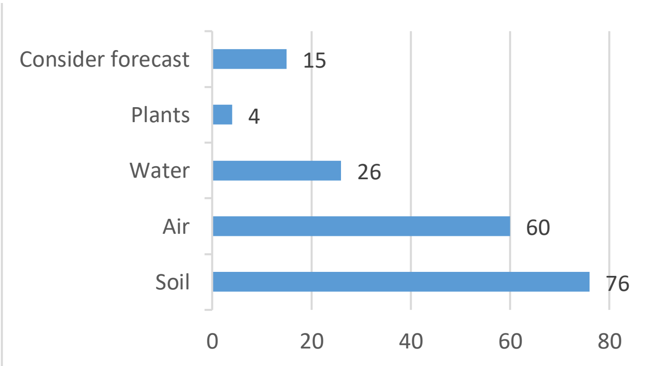

Fig. 6. Monitored environments in papers that propose an irrigation system [5].

It is very odd to make an IoT irrigation system without considering the weather forecast data. For example, the soil moisture sensor detects the soil is very dry, and the system recommends turning on the irrigation. But what if it is going to rain in the next hour or so? It does not meet the goal of the IoT irrigation systems at all, which is watering wisely. Unless it is specifically noted on the product that this IoT irrigation system is designed for indoor use only.

III. SENSOR NETWORK

A. *Arduino, Raspberry Pi or Others*

Fig. 7 illustrates the microcontrollers or the microprocessors that most people would choose for the implementation of IoT irrigation systems. As we can see, the Arduino UNO the most popular one, which was used in 34 papers. The Arduino Mega was also used in 6 papers. In addition, a total of 59 papers claimed to use an Arduino microcontroller as well, but they did not mention what model of Arduino boards they used.

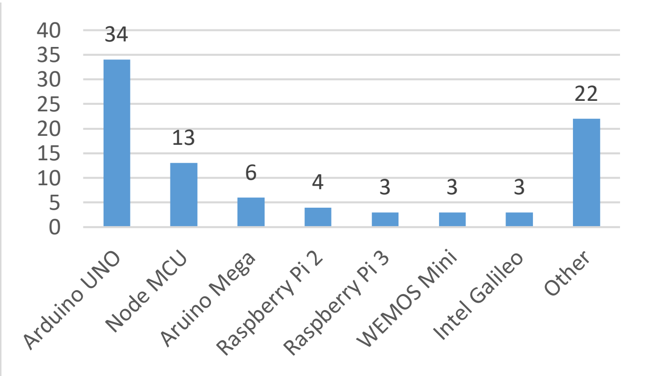

Fig. 7. Most utilised boards to implement IoT irrigation systems [5].

Both Arduino and Raspberry Pi have their own pros and cons. Even in this survey more people chose Arduino boards, as they are slightly cheaper, which is a favour for developing countries and smaller farms, as many farmers in those countries are in the low-income group. However, Raspberry Pi still has its own merit. Raspberry Pi has a much more powerful computing ability compared to Arduino systems, which allows the implementation of more demanding software and more complicated algorithms. We should use them according to the processing requirements of each task. Some research also chose less popular nodes, as they have their own particular requirements in their designs to address. Hence, the selection of the board would depend on what the systems are designed to achieve.

B. *Communication Technologies*

In this section, we will talk about the key element for successful implementations, which is the communication technologies. It plays a very important role in IoT-based irrigation systems. As it can be seen in Fig. 8, the most used communication technology among 199 papers is WiFi. “The reason could be due to accessibility. The currently available low-cost devices for IoT usually support WiFi and, although its range can be considered short for the average expanse of a farm, small farms could be able to provide enough wireless coverage with several low-cost devices” [5].

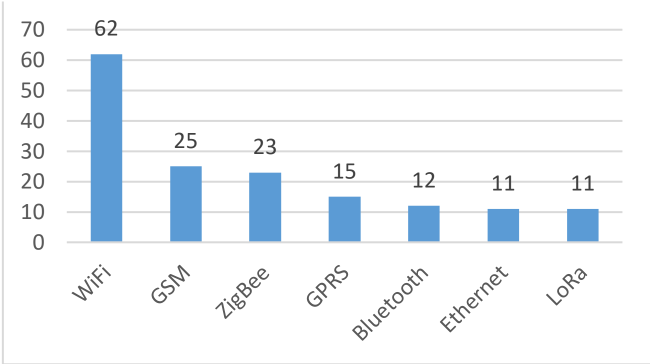

Fig. 8. Communication technologies employed to implement IoT irrigation systems [5].

Even so, a lot of current studies did not use only one single protocol but a combination of several communication technologies. Take Fig. 9 as an example, it is very common to connect the sensor nodes with wireless technology, then collect the data from the sensor nodes to the aggregation nodes, then use WiFi to send data from the aggregation nodes to the cloud platforms. This wireless technology can be categorized as WSN (Wireless Sensor Network).

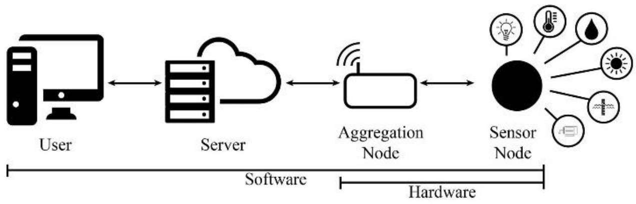

Fig. 9. Combination of several communication technologies [6].

C. *WSN*

Table I. illustrates a comparison among the 4 major wireless communication protocols. ZigBee and LoRa are two popular protocols for deploying WSN. Especially LoRa has a much wider range (20 times more than WiFi), much lower power consumption (at least 10 times lower than WiFi) and can be utilised with a large number of devices. All the above mentioned make LoRa stand out right when comparing it to other popular wireless communication protocols side by side.

TABLE I. MAJOR WIRELESS COMMUNICATION PROTOCOLS CHARACTERISTICS [6]

Feature	Wi-Fi	Bluetooth	ZigBee	LoRa
Data Rate [kbps]	11×10^3	1×10^3	250	110
Frequency [GHz]	2.4	2.4	2.4	0.868
Range [m]	1-100	10-100	10-100	2000
Nodes/Master	32	7	65540	15000
Power Consumption [mA]	100-350	1-35	1-10	1-10
Security	WPA/WPA2	128 bit	128 bit	128 bit

IV. SMART IRRIGATION SYSTEMS

All the elements mentioned before are for IoT-based irrigation systems, but they cannot quite be classified as smart systems yet, since a proposed smart IoT irrigation systems should be able to analyse soil moisture, air temperature and/or air humidity, combined with the weather forecast data even with the UV data in the near future, possibly plus geography data. The intelligence of these systems is based on a smart algorithm, which considers all the data as mentioned here [8]. Then the smart system should be able to dynamically predict the appropriate amount of water, and to make the correct decisions of the activation of irrigation systems without human interference and still keep the crops healthy. This kind of smart IoT irrigation system is the best solution for environmental sustainability.

However, fewer than 25% of the irrigation systems adopted by the US producers are science or machine learning based [7]. The rest of them are still rule-of-thumb based. They let users set thresholds for parameters to autonomously activate the irrigation systems, but the decisions based on personal experience could lead to over-watering or under-watering. Over-watering can cause root rot and kill the plants or crops, bring the users a huge water bill and raise environmental concerns.

That is why we need IoT-based smart irrigation systems. They can help people wisely manage the water utilisation with precision irrigation. To achieve even better results, some systems would also let users set the parameter for different types of crops, but those systems would require sensor readings on the crops, which would lead to a more complicated algorithm.

V. Challenges and opportunities

In the previous sections, we have talked about the key elements for implementing an IoT-based smart irrigation system. In this section, we are going to discuss what challenges and opportunities we may face for future research.

A. Model Uncertainty

Model uncertainty is the biggest obstacle in developing IoT-based smart irrigation systems. Many people think one model can be applied directly to all other different sites, which is usually not correct. When we apply the model we find to a new site, a lot of specific on-site data are not the same, such as field characteristics, soil types or management practices, which leads to a failure in the simulations if these inputs are not available. For example, how long the soil retains moisture and how much moisture the soil retains can vary greatly according to different types of soil. Besides, if some of the site generated model parameters are unknown or using default values. This will lead to big uncertainties. “To possibly resolve this issue, we need to calibrate the process-based models at each individual field. The challenge thus is how to get the required field-level measurements for the calibration at each individual field” [7].

The future research for this challenge can be using data model fusion methods to integrate multiple data sources instead of individual data sources to produce more accurate and useful information for those specific on-site parameters.

B. Power

In some places where people apply IoT irrigation systems, the systems might not be able to access the power grid, or in some agricultural countries, like some cities in India can only receive power on a constrained time period a day. As [9, p. 8] mentioned that “low power wireless sensor stands as an opportunity in implementing the applications of internet of things with specific reference to the agricultural sector.” Some authors also decided not to monitor the parameters in real-time in order to lower down energy consumption, like taking a measure every 10 seconds rather than real-time to save power [10]. For those reasons, we definitely need alternative methods or materials to power up devices or reduce the power consumption.

The possible solution to address this issue is to incorporate the systems with solar power functionality, as in agricultural fields, it is usually too far to access the power grid. Furthermore, solar power makes the systems more environment friendly as well [11]. Besides, the use of solar power also decreases the power bills, which is a promising idea for low-income farmers.

C. Robots

Another innovative idea of IoT irrigation is the use of robots. The GPS based smart robots can be a great option when farmers want to water crops in some specific areas as the robots can travel to the desired location which may not be easily accessible for humans [13]. Furthermore, as those robots are equipped with sensors, they can also collect data from those remote areas and decide if they need to irrigate the crops straight away based on the accurate on-site real time data. In addition, they can achieve other tasks, like weeding, scaring birds or animals off, keeping vigilance for fields, etc., which are an all-rounded option to achieve multitaskers [12].

It is really a fascinating idea. However, there are still a lot of challenges that need to be addressed. Even if the authors want to power the robots with solar energy. It is hard to say how long the power can last for the robots to run. Also, the range of the distance to remote control the robots is another challenge too.

D. IoUT

As mentioned in the previous section, robots can be used to scare birds and animals off, because all the IoT irrigation nodes deployed in the field can be compromised by all kinds of physical attacks. Therefore, another new concept has also been brought up - The Internet of Underground Things (IoUT). “It consists of deploying both underground and above ground IoT devices that communicate among themselves with underground-underground, underground-above ground, and above ground-above ground communication” [14].

IoUT irrigation systems cannot only reduce the amount of physical damage on devices, but also make the device deployment easier without hindering the work of farmers and farm machines. Nevertheless, there is still a big challenge on IoUT irrigation systems, since there are a lot of factors underground that can affect the device communication performance. For example, it is a big challenge for WiFi, as it is not designed for underground communications. The WiFi communications can only reach a few centimetres in the ground. As [15, p. 1] mentioned “the ultimate potential of IoUT for high data rate communication depends on the underground channel characteristics, which is not well modelled.” The soil type, soil moisture and the burial distance from the ground can all affect the communications, which would lead to signal loss, RFI (Radio Frequency Interference) or RMS (Root Mean Square) delay spread [16]. As such, another wireless communication technology has been brought into the equation – Wireless UG (Under Ground) communications. The technology conducts part of the communications through the soil by burying the radios in the ground [1].

If the communication technology can be improved by UG communications or any other better methods, it is possible that all the data can be collected real time from underground devices through the soil combined with all the other data from the above ground field, then be sent to the cloud for analysis to achieve real time decision making.

VI. CONCLUSION

The possible consequences of global climate change have made people pay more attention to smart water management systems. Plus, because of the recent speedy development in IoT and WSN technologies, the precision irrigation and the management can be possibly realised by the smart IoT-based irrigation systems. In this paper, we have provided an overview of current applications of the systems. We have also identified the challenges and opportunities in improving the systems. Furthermore, the current new concepts in different forms of IoT irrigation systems have been discussed as well. All of the above have provided a basic foundation for possible future research work.

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