A study on the significance of smart IoT sensors and Data science in Digital agriculture

Neenu Johnson
Division of Information Technology
School of Engineering, Cochin
University of Science and Technology
Kerala, India
neenujohnson86@gmail.com

Dr. Santosh Kumar M.B.
Division of Information Technology
School of Engineering, Cochin
University of Science and Technology
Kerala, India
santo_mb@cusat.ac.in

Dr. Dhannia T
Division of Applied Sciences and Humanities
School of Engineering, Cochin
University of Science and Technology
Kerala, India
dhanniat@gmail.com

***Abstract*—Agriculture is the backbone of the Indian economy. Environmental parameters such as temperature, humidity, rainfall, and so on are rapidly changing unpredictably. Internet-of-Things(IoT) and a wide range of agriculture sensors play a vital role to support farmers in enhancing their agricultural production despite the unpredictable behavior of natural parameters. Internet-of-Things(IoT) has a significant role in many smart applications that influences human life and sensors are inevitable in these systems. A high-volume of real-time data is generated from IoT sensor nodes deployed in farms at a faster rate. If this massive amount of data collected by IoT sensors need to be meaningful, it must be processed efficiently. This paper analyzes different types of sensors and IoT platforms used in smart farming. This paper also discusses the significance of data science in the agriculture sector and the various data processing methods applied over sensor data gathered for agricultural applications.**

Keywords—Internet-of-Things(IoT), Sensors, Data science, Blockchain, Smart farming, Digital agriculture

I. Introduction

According to the Food and Agriculture Organization(FAO) of the United Nations, the world's population will reach 9.1 billion by 2050. This points to the requirement for global agricultural production to rise by 70% between 2010 and 2050 [1]. The farming industry will become more significant than ever before in the next few decades. To meet the demand of the growing population, governments and agricultural industries are turning to the usage of IoT sensors and various data analytics methods to achieve greater agricultural production. Many environmental parameters such as temperature, humidity, rainfall and so on are rapidly changing. Human beings are responsible for this global climate change phenomenon as a consequence of which our farmers are struggling to sustain [2,3].

Agriculture sector in India is facing several challenges such as lower crop yield, high production cost, inefficient storage system for farm products, absence of effective agricultural extension services, and so on [4].Traditional farmers following their thumb rule are now unable to survive. Governments, researchers and industries are now holding their hands together to undertake novel projects and researches to support farmers as a result of which concepts such as 'smart farming', 'digital agriculture' and so on are coined under which tremendous researches and projects are being implemented. An instance of such a platform is Digi Agri, that supports smart farming using the convergence of technologies such as IoT, machine learning, and blockchain [5].

Smart farming methods which include the use of smart IoT sensors and their data processing for future prediction and storage are already becoming more commonplace among farmers. This paper aims to provide a review of the various IoT platforms and sensors used in the agriculture domain to support farmers. This paper also analyzes the different data processing methods applied over the sensor data generated from IoT devices in the farm and thus the role of data science in agriculture. This paper focuses on the significance of sensors, IoT and data science in agriculture to benefit those who seek to leverage the convergence of these technologies in the agriculture domain.

This paper is organized as follows: Section II highlights the significance of sensors used in various applications in agriculture. Section III presents existing IoT platforms and their implementation purpose. Section IV is a brief study of the significance of data science in smart farming and different methods applied for the analysis of agricultural data. This study concludes with the challenges that need to be addressed in IoT-based e-agriculture and a brief review of recent works that propose blockchain technology as a solution for security issues in IoT system.

II. ROLE OF SENSORS IN SMART FARMING

Crops require proper environmental conditions for optimal growth and health. Accurate measurement of these environmental parameters is important where the sensors play a major role [6]. Sensors, in general, can be classified based on various features such as its conversion methods, type of materials used, its sensing physical phenomenon, parameters it measures, and its application fields [7]. In this section, sensors that find applications in the field of the agriculture industry are described based on the parameters measured.

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A. Temperature sensors

1) Soil temperature sensor

Soil temperature is a significant factor, especially in precision agriculture, as it closely controls the physical, chemical and microbiological processes that happen in soil. This parameter can also influence other important crop growth factors such as germination, blooming, photosynthesis, the water potential of the soil, respiration, decomposition, soil translocation, and nitrogen mineralization [8]. Soil temperature is an important soil factor that influences root growth [9]. According to the World Meteorological Organization(WMO), the temperature is defined as a physical quantity characterizing the mean random motion of molecules in a physical body [10]. These factors point to the significance of using the soil temperature sensors for accurate measurement of soil temperature. Some of the agriculture sensors which are used to measure soil temperature are ECH2O soil moisture sensor, Hydra probe II soil sensor, MP406 soil moisture sensor, EC sensor (EC250), Pogo portable soil sensor [11].

2) Plant temperature sensor

The accurate measurement of plant temperature is a key factor in achieving optimum production and quality. This parameter has a significant impact on crop yield prediction, as it is an indicator of plant stomatal conductance. Infrared images are greatly used as it can provide the temperature measurement of individual leaves [12]. LT-1M (leaf temperature sensor) is specifically designed for monitoring the absolute temperature of leaves. LT-1M unit includes two leaf temperature sensors and a two-channel dc powered signal conditioner [13].

3) Air temperature sensor

The air temperature of an agricultural area is an important factor, as it influences the rate of evaporation, precipitation patterns and types, relative humidity, wind speed, and direction [14]. This parameter can also influence the physiological, chemical, and biological processes in plants such as photosynthesis [15]. 107-L Temperature sensor [16] is an accurate probe that measures temperatures of air, soil, and water. Kyosuke Yamamoto et al. [17] conducted experiments to improve the measurement accuracy of air temperature sensors such as SHT-71 under the influence of environmental parameters. The experiment used machine-learning methods in which results showed that solar radiation strongly influences the measurement of air temperature.

B. Humidity sensor

The humidity sensors detect changes that alter electrical currents or temperature in the air and thus measures moisture and air temperature. Imbalances in humidity and temperature can adversely affect the regulations of moisture and gas exchanges during photosynthesis in plants. Thus the fact that a combination of high relative humidity and high temperature can be deadly for crops, points to the significance of accurate measurement of these parameters. CI-340 handheld photosynthesis [11] is a portable sensor that can measure air humidity, photosynthesis, respiration, transpiration, stomatal conductance, and internal CO_2 [18]. Syed Akhtar Imam et al. [19] has provided a detailed description of various humidity sensors relevant to precision agriculture applications.

C. Soil moisture sensor

The soil moisture sensors determine actual water content in the soil, which is a key variable in deciding the irrigation schedule [20]. MP406 moisture sensor measures the volumetric moisture content of the soil, which can take the continuous measurement over time. This sensor also measures soil water potential through soil moisture meter and soil characteristic curve [21]. Paulo Sergio de Paula Herrmann et al.[22] conducted experiments to develop a non-invasive method to measure soil moisture in which the effect of temperature in measurement is also discussed.

D. Soil pH sensor

Soil pH value, which is a measure of hydronium ion(H+), affects the physical, biological and chemical properties and thus the plant growth [23]. Soil pH value strongly influences the availability of nutrients and the presence of microorganisms in the soil. As each plant requires a particular range of pH to optimize its growth, accurate measurement of this parameter is crucial [24]. SX-620 pH meter is used in the experiment conducted to study the effect of simulated acid rain on soil pH of three different soil types under observation [25]. Suvamoy Bhattacharyya et al. [26] designed a robotic hand-type mechanism for effective irrigation and balanced fertilization in which soil pH sensors and soil moisture sensors are used as main sensors in an automated way. Vaibhav Bhatnagar et al. [27] proposed a soil health monitoring system that can monitor soil pH, soil moisture, and soil temperature using an android smartphone.

E. Nanobiosensors

The nanobiosensors have immense potential in the agriculture sector, which is a modified form of biosensors. This sensor can accurately sense a wide variety of fertilizers, pesticides, and soil quality. Nanobiosensors can be used to detect nutrient content, plant stress, and soil diseases [28]. Akbar Hossain et al. [29] highlighted the potential use of nanobiosensors for a sustainable crop production system.

F. Wind speed sensor

Assessment of wind speed and direction is a major consideration in smart farming [30]. Wind Sensor WM30 is a compact wind speed and direction sensor. The rotating cup at the top provides a linear response to wind speed and vane attached to the body of the unit gives a fast response to wind direction [31]. Jiang et al. [32] discussed the problems faced by traditional methods of wind speed measurement. A novel method for measuring wind speed and direction is proposed and a prototype of an ultrasonic anemometer is developed. Indranil Sarkar et al. [33] used wind speed and direction sensors in designing a model weather station.

G. Raindrop sensor

Due to rapid climate changes, heavy rainfall is unpredictable which has negative impacts on our agriculture and safety. So specialized monitoring devices are needed to count raindrops. Raindrop sensor is used to sense rain, which consists of two modules, a rain board that detects rain and a control module [34]. Eko Murdyantoro et al. [35] used raindrop sensor in developing a model of weather station which is based on LoRa technology. Soon-Hyung Kwon et al. [36] provided a detailed description of the specifications and working of the raindrop sensor.

H. Droplet Sensor

The precise application of plant protection chemicals is in urgent demand, as over usage of pesticides will damage the crop and eco-system. Pei Wang et al. [37] implemented a sensor system with a leaf-like capacitor that can measure deposit mass of pesticide spray immediately after application.

Based on the literature, a few other parameters are identified which find applications in precision agriculture. Methane(CH_4) is considered as the second most prevalent greenhouse gas [38]. So to monitor the quantity of toxic gases in greenhouses, gas sensors are used in which low range factor starts from 0 to 10,000 and high range from 0 to 100,000 [39]. Ultraviolet(UV) sensors are transmitters to measure the intensity of incident UV radiation. The output signals from these sensors are electrical signals which can be used to generate graphs and reports [40], which is required for effective crop health monitoring [41]. A Motion detector sensor is a sensor unit with three major components a sensor unit, embedded computer, and hardware, which detects and measures movement [42]. Farmers can take corrective actions as alert messages from motion sensors indicate the presence of unwanted objects or animals in the field. Passive Infrared sensors are made up of Pyro Electric sensor that detects the level of infrared radiations emitted from an object, thus used for object detection purpose in fields [43].

Pressure sensors are used to measure the atmospheric pressure, which consists of a pressure-sensitive element to measure the actual pressure applied to the sensor and the information converted into an output signal [44]. The major fertilizers such as Nitrogen(N), Phosphorous(P), Potassium(K), plays an important role in soil quality improvement. Marianah Masrie et al. [45] developed an optical transducer to detect and measure N, P and K values of soil and evaluate NPK soil content as excessive, medium and low. Electromagnetic sensors, Airflow sensors, Acoustic sensors, Optical sensors, Mechanical sensors, and Electrochemical sensors are the other sensors which proved to be helpful in the field of precision agriculture [46]. Table I presents various types of agriculture sensors used in e-agriculture.

The relation between the above mentioned environmental parameters is also studied. Linear regression is performed to observe the relationship between these parameters, which shows that an increase or decrease of one parameter is affecting another parameter. The linear regression is a linear approximation of a causal relationship between two or more variables. A simple linear regression model is used here to find the relationship between parameters that are obtained from the dataset. The datasets subjected to the study are taken from Kaggle.com. Based on the parameter values in this dataset, the correlation between the parameters such as air temperature, air humidity, soil pH, and soil Electrical Conductivity(EC) are plotted using Python programming language packages. Equation (1) represents the estimated simple linear regression equation where $\hat{y}$ is the estimated or predicted value, b_0 is the regression constant, b_1 is the value which quantifies the effect the independent variable (x) on the dependent variable (y), x_1 is the sample data for independent variable [65]. The variables b_0 and b_1 are obtained from the data which represents the y-intercept and slope of the line respectively.

$$\hat{y} = b_0 + b_1 x_1 \tag{1}$$

Fig. 1 presents the correlation between soil pH and soil Electrical Conductivity, which shows that both are negatively correlated. Fig. 2 shows that air humidity and air temperature are negatively correlated.

III. ANALYSIS OF IoT PLATFORMS IN SMART FARMING

In this section, relevant researches on various IoT platforms designed and developed for supporting farmers in crop selection, crop demand prediction, weather forecasting, crop yield enhancement, and livestock monitoring are discussed. Numerous relevant works have been done in IoT based smart farming and to obtain an understanding of the recent methodologies used, a systematic survey on IoT in agriculture context is needed. IoT which comprises devices with unique identities [66], gained its attention in 1999 [43], and within a few years, IoT research trends in agriculture acquired its shape. IoT solutions and sensors used in agricultural applications of the recent past three years are subjected to this study. Since enormous work has been done in this direction, papers which found to be relevant based on their range of applications were discussed.

Deepak Vasisht et al. [67] developed an end-to-end platform, Farmbeats, that is capable of collecting data from various sensors, cameras, and drones. This data-driven agriculture model deployed in two US farms used a weather-aware IoT base station design which addresses the issue of poor connectivity within the farm. A Gateway based design which resolves the challenge of shipping high bandwidth drone videos to the cloud is used. A path planning algorithm is also incorporated which helps drones in saving their battery life. Tomo Popović et al. [68], designed and implemented an IoT platform that supports researchers and developers working on various agriculture domains such as precision agriculture, ecological monitoring and aquaculture. The detailed description of the proposed architecture of the IoT platform is provided that enables researchers to implement various prototypes that are needed to create fully functional applications for high-level use cases such as smart soil fertilization, disease forecasting, and detection.

TABLE I: TYPES OF AGRICULTURE SENSORS

Sensors	References	Examples	Parameters measured
Soil temperature sensor	J.D. Jabro et al. [47], R. Hou et al. [48], A. A. El-magrous et al. [49], J. A. Lake et al. [50], C. Brogia et al. [51], S. T. Oliver et al. [75]	Pogo portable soil sensor	ST[a], SM[b]
		EC sensor (EC250)	SM[b], ST[a], SL[c], CT[d]
		109SS-L [52]	ST[a]
		THERM200 [53]	ST[a], AT[e].
Plant temperature sensor	T. Sakamoto et al. [54]	PTM-48A photosynthesis monitor	PT[f], PM[g], Photosynthesis, PW[h], CO_2
		237 leaf wetness sensor	PT[f], PW[h], PM[g]
		TT4 multi-sensor thermocouple	PT[f], PM[g]
		LT-1 M (leaf temperature sensor)	PT[f]
Air temperature sensor	J. Lina et al. [55], A. Thorat et al. [74], S. T. Oliver et al.[75]	CM-100 Compact Weather Sensor	AT[e], AH[i], AP[j], WS[k]
		HMP45C	AT[e], AH[i], AP[j]
		109 Temperature probe [56]	AT[e]
		XFAM-115KPASR	AT[e], AH[i], AP[j]
Humidity sensor	M. Danita et al. [57], A. Thorat et al.[74], S. T. Oliver et al. [75]	DHT11 [58]	AH[i], AT[e]
		AM2321 [80]	AH[i], AT[e]
		Met Station One (MSO)	AT[e], AH[i], AP[j], WS[k]
Soil moisture sensor	P. S. de Paula Herrmann et al. [22], J.D. Jabro et al. [47], A. A. El-magrous et al. [49], I. Mat et al. [59],S. T. Oliver et al. [75]	ECH2O soil moisture sensor	SM[b], ST[a], CT[d]
		Hydra probe II soil sensor	SM[b], ST[a], SL[c], CT[d]
		MP406 Soil moisture sensor	SM[b], ST[a]
		EC sensor (EC250)	SM[b], ST[a], SL[c], CT[d]
Raindrop sensor	E. Murdyantoro et al. [35], Soon-Hyung Kwon et al. [36], S. T. Oliver et al. [75]	Raindrop sensor module [60]	Rain
Soil pH sensor	H. Wei et al. [25], S. Bhattacharyya et al. [26], V. Bhatnagar et al. [27], A. A. El-magrous et al.[49]	Soil pH meter PCE-228S [61]	SP[l]
		Veris pH Manager [62]	SP[l]
Wind speed sensor	Jiang et al. [32], S. T. Oliver et al.[75]	WE550 wind speed sensor [63]	WS[k]
		WE570 wind direction sensor [64]	WD[m]

[a]ST-Soil temperature, [b]SM-Soil moisture, [c]SL-Salinity level, [d]CT-Conductivity, [e]AT-Air temperature, [f]PT-Plant temperature, [g]PM-Plant moisture, [h]PW-Plant wetness, [i]AH-Air humidity , [j]AP-Air pressure, [k]WS-Wind speed, [l]SP-Soil pH , [m]WD-Wind direction.

Sehan Kim et al. [69] developed Farm as a Service(FaaS) integrated system along with an IoT-hub network that ensures the stability of technology and high-level application services used for agriculture environments. The performance of this system is evaluated using a strawberry infection prediction system. Nurzaman Ahmed et al. [70] proposed a scalable network architecture to connect rural regions. The IoT-based control system that focused on farming applications in rural areas used fog computing and WiFi-based long distance network in the framework.

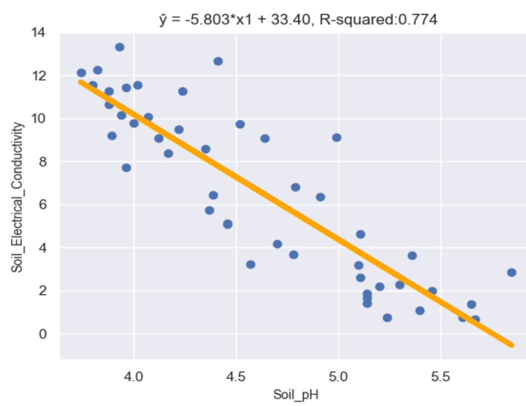

Fig. 1. Correlation between soil pH and soil electrical conductivity.

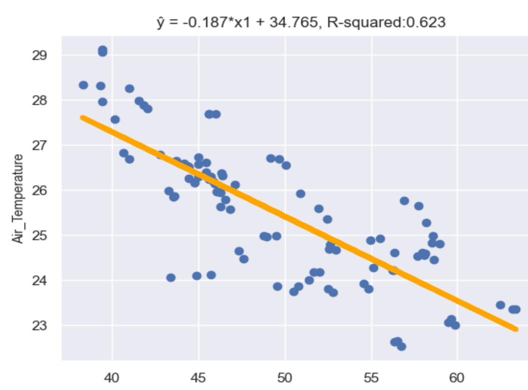

Fig. 2. Correlation between air humidity and air temperature

Wen-Liang Chen et al. [71] designed and developed AgriTalk, an inexpensive IoT platform. The system was deployed in Mountain Bao in Taiwan for turmeric cultivation and a web-based dashboard and controller were implemented so that farmers can transparently access AgriTalk resources through any smartphone without installing any mobile application. A good comparison of soil cultivation and hydroponic cultivation is done and concluded that it is easier to deploy IoT technology for hydroponic cultivation, but the cost of soil cultivation is lower than hydroponic cultivation. Wen-Liang Chen et al. [72] deployed a non-image IoT device in which sensors generate non-image data that is utilized by Convolutional Neural Networks(CNN) to automatically recognize the feature patterns over a period of time. Table II shows IoT platforms, the parameters measured as input and five major applications in smart farming.

IV. SIGNIFICANCE OF DATA SCIENCE IN SMART FARMING

Data Science is an interdisciplinary field that is used to process, analyze and derive insights from different types of data that make use of a plethora of techniques such as statistics, machine learning and data mining [86] which are now important in meeting the challenges faced in the global agricultural sector. Big sensor data is generated due to wide range deployment of sensor nodes for field operations which includes crop monitoring, irrigation monitoring, fertilizer application, disease detection, weather forecasting and so on. Agricultural data is transformed into information that will become useful for farm management. Various data processing methods are developed and applied over IoT sensor data that would enable farmers and researchers to extract value from it. In this section, data science applications in agriculture and methods applied for the analysis of data from farms in the recent past three years are reviewed.

In [87], the authors have discussed the different stages of data science life cycle and recent developments in the Indian farming sector using data science techniques. Market price analytics of agricultural commodities is explained as a specific example. The study shows that the traces of data science applications in the Indian agricultural scenario can be seen from the early years of post-independence period.

Ignacio A. Quiroza et al. [88] followed IBM Foundational Methodology for data science which consists of ten iterative stages and deployed an image recognition system for Legacy blueberries in the rooting stage using Convolutional Neural Network(CNN) as a solution implemented in Tensorflow. Eugˆenio Pacceli Reis da Fonseca et al. [89] applied data science methodology in developing Agro 4.0, a sustainability management system. The system Agro 4.0, enables the users to vary and analyze several indicators such as soil fertility over a set of rural properties from which data is gathered.

Jharna Majumdar et al. [90] done an extensive study on agricultural data analysis by comparing the data mining techniques such as PAM(Partition around medoids), CLARA(Clustering Large Applications), DBSCAN(Density-based spatial clustering of applications with noise) and Multiple Linear Regression model. This

TABLE II: AGRICULTURAL APPLICATION DOMAINS OF IoT PLATFORMS

IoT platform	Input parameters measured	CM[a]	IM[b]	GM[c]	WM[d]	LM[e]
P. Rekha et al. [73]	SM^f, SP^j	✓	✓		✓	
I. Mat et al. [59]	AT^g, AH^h, SM^f		✓	✓		
A. Thorat et al. [74]	SM^f, AT^g, AH^h	✓				
S. T. Oliver et al. [75]	ST^k, AT^g, SM^f, AH^h, Pressure, Rainfall, WS^l, WD^m.	✓				
J. Bauer et al. [76]	SD^n, AT^g, AH^h	✓				
R. Prabha et al. [77]	AT^g, SP^j, AH^h, WS^l, SD^n, Pressure, Rain	✓	✓			
M. A. Zamora-Izquierdo et al. [78]	SD^n, AH^h, AT^g, CO_2, SP^j, Electrical conductivity, Pressure.	✓		✓		
R. K. M. Math et al. [79]	AT^g, AH^h, Pressure, Rain, Light intensity				✓	
L. Germani et al. [80]	AT^g, RH^i, CO_2, NH_3 concentration, Illuminance					✓
N. G. S. Campos et al. [81]	SM^f, AT^g, AH^h, Matric potential, WS^l, Pressure, Rainfall.		✓			
Xue-Bo Jin et al. [82]	AT^g, RH^i.		✓			
D. Popescu et al. [83]	SM^f, ST^k AT^g, RH^i, SD^n.	✓				
R. S.Alonso et al. [84]	AT^g, RH^i, Gas(CH_4, H_2S, NH_3, CH2O/ H-CHO), ST^k, SM^f, WS^l, WD^m, Evapotranspiration, SD^n, Rainfall.	✓				✓

L. Hang et al. [85]	Water level, Oxygen level					✓

[a]CM-Crop monitoring, [b]IM-Irrigation monitoring, [c]GM-Greenhouse monitoring, [d]WM-Weather monitoring, [e]LM-Livestock monitoring, [f]SM-Soil moisture, [g]AT-Air temperature, [h]AH-Air humidity, [i]RH-Relative humidity, [j]SP-soil pH, [k]ST-Soil temperature, [l]WS-Wind speed, [m]WD-Wind direction, [n]SD-Solar radiation.

comparison is done by categorizing various districts of Karnataka based on multiple sets of parameters gathered. The districts which are having similar temperature, rainfall, and soil type are clustered by using a modified approach of DBSCAN method and districts with maximum crop production are clustered using PAM and CLARA. Multiple Linear Regression Model is applied in the study to predict annual crop yield. The results of their study reveal that DBSCAN generates better clustering quality.

Fabrizio Balducci et al. [91] primarily focused on the various strategies to improve the management of diversified farm data. Various machine learning algorithms such as Neural Networks, Linear and Polynomial regression were applied over three real datasets under study. Fan-Hsun Tseng et al. [92] designed an Intelligent Agriculture IoT equipment that comprises IoT sensors, a solar power storage system, and an XMPP(Extensible Messaging and Presence Protocol) web platform. Data normalization with moving average algorithm and average variance are employed and 3D cluster analysis is used to study the relationship between various environmental factors. Table III presents the data modeling methods used in IoT platforms.

V. CHALLENGES

The agriculture sector has seen a tremendous usage of sensors and IoT-based applications. Various data mining and machine learning methods are studied and applied to process huge heterogeneous data generated from farms [97]. The main challenge of IoT platforms is the security and privacy issues. Mohamed Amine Ferrag et al. [98] explained the architecture of green IoT-based agriculture and discussed the security issues based on this four-tier architecture. Blockchain technology is proposed as an effective solution for privacy-preserving in IoT-based applications. Han Liu et al. [99] proposed an access control system to overcome the limitations of IoT. The open-source system combines the potential features of Hyperledger Fabric blockchain framework and attributed based access control(ABAC). Minhaj Ahmad Khan et al. [100] categorized security threats in IoT architecture as low-level, intermediate-level, and high-level security issues and discussed the blockchain features which are highly useful for ensuring IoT security. Nallapaneni Manoj Kumara et al. [101] listed the advantages of using blockchain technology as a security solution for the IoT system. Weather variations, hardware cost, interoperability of equipment are other open challenges that need to be addressed [11].

The confluence of Blockchain and IoT can bring significant transformations [102] in many industries including agriculture. A blockchain-based fish farm platform is proposed in [85] for fish farmers to ensure the secure storage of the farm data. Walmart, together with its technology partner IBM, implemented a blockchain-based food traceability system using the Hyperledger-fabric

TABLE III: DATA MODELING METHODS USED IN IoT PLATFORMS

Reference	Application	Main target	Methods used
J. Majumdar et al. [90]	Yield prediction	Crop(Wheat, Rice, Cotton, Groundnut, Jowar)	Multiple Linear Regression
F. Balducci et al. [91]	Yield prediction, Comparison between machine learning methods.	Crop (Apple, Pear)	Decision Tree, Artificial Neural Networks, Multiple Linear Regression.
V. G. Rybin et al. [93]	Beehive monitoring	Beehive	Artificial Neural Networks
M. G. Selvaraj et al. [94]	Crop diseases and pest detection	Banana	Deep learning
J. A. Tejada et al. [95]	Identifying macronutrient deficiency	Banana	Random Forests, Support Vector Machine, Artificial Neural Networks.
J. M. Duarte-Carvajalino et al. [96]	Crop disease detection	Potato	Multilayer perceptron, Convolutional Neural Networks, Support Vector Regression, Random Forests.

framework which increased trust across the food supply chain [103]. Yu-Pin Lin et al. [104] explained the role of ICT (Information and Communications Technology) in agriculture sustainability and how the blockchain infrastructure can improve the efficiency of the system. A blockchain-based ICT e-agriculture system was proposed that can be used at a local and regional scale. Akash Suresh Patil et al. [105] presented a secure communication framework for smart greenhouse farming that is based on the integration of blockchain with IoT.

VI. DISCUSSIONS

As illustrated in section II of this paper, a large variety of easily deployable agriculture sensors are commercially available for smart farm management. Section III highlighted major IoT platforms developed and their application domains in the agriculture context. Section IV presented the significance of data science in smart farming and various data modeling techniques used. Towards the end, IoT security challenges were also discussed. Based on this study and motivated by the immense potentials of blockchain technology in security, it can be concluded that a smart farming platform based on the confluence of IoT, blockchain, and data science is capable of empowering farmers to improve the productivity of their farms. Farmers, especially in developing and under-developed countries are mostly illiterate and unaware of these technologies, which results in less productivity. So farmers must be educated and updated about these technologies so that they can enhance their farm production and thus improve the economy of the nation. The study shows that blockchain-based IoT platform with appropriate data modeling method provides a secure farming network that is suitable for farm digitization including small scale farms [106]. Fig. 3 illustrates a framework of blockchain-based IoT ecosystem for small-scale farms.

The three main components of the framework are an IoT system that includes sensors, a blockchain network, and end-users. Sensors such as soil moisture sensor, soil pH sensor, soil temperature sensor, plant temperature sensor are used to form the crop data. And weather data is collected from air temperature sensor, air humidity sensor, and rainfall sensor. Devices in the IoT system of small-scale farms can communicate using wireless communication protocols such as Zigbee, Wi-Fi, and for large farms communication standards such as LoRa can be used [107]. Farm data that is formed from crop data and weather data of each farm, undergoes data modeling methods such as M5-Prime Regression Trees, which is evaluated to be good for crop yield prediction [108]. Dataset used for modeling and the results are then securely stored inside a permissioned blockchain framework such as Hyperledger-fabric in which only authenticated users are allowed to perform operations on the framework. Blockchain network consists of six small-scale farms that are equipped with IoT devices. The end users are the farmers and other stakeholders who are authorized policy makers such as government agencies and agriculture-related officials. This ecosystem can support community farming in rural areas which increases interaction between farmers and agricultural experts, saving them from the exploitation of untrusted "middle men". It can also act as a platform for secured tamper-proof farm data.

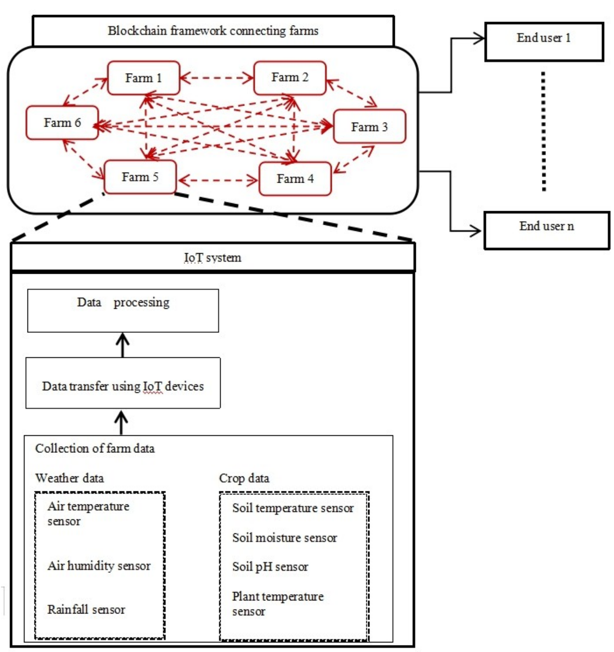

Fig. 3. A framework of blockchain-based IoT ecosystem for small scale farms

VII. CONCLUSION

The global climate change, increasing world population and degradation in food quality are forcing humanity to search for innovative methods and technologies that are capable of addressing agriculture-related issues. The digital agriculture domain perceived the significance of various agriculture sensors and IoT platforms in assisting farmers to attain sustainable solutions regardless of their geographical differences. In this paper, a comprehensive survey on agriculture sensors, environmental parameters measured as input in agricultural applications, IoT platforms and data processing methods over sensor data is presented. The recent works in which blockchain technology is proposed as a solution to address the security requirements of IoT in smart farming is also briefly reviewed under section V. It is expected that this review will be helpful to researchers who are working in IoT and agriculture-related domains.

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