Adoption of the Internet of Things (IoT) in Agriculture and Smart Farming towards Urban Greening: A Review

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Abstract—It is essential to increase the productivity of agricultural and farming processes to improve yields and cost-effectiveness with new technology such as the Internet of Things (IoT). In particular, IoT can make agricultural and farming industry processes more efficient by reducing human intervention through automation. In this study, the aim to analyze recently developed IoT applications in the agriculture and farming industries to provide an overview of sensor data collections, technologies, and sub-verticals such as water management and crop management. In this review, data is extracted from 60 peer-reviewed scientific publications (2016-2018) with a focus on IoT sub-verticals and sensor data collection for measurements to make accurate decisions. Our results from the reported studies show water management is the highest sub-vertical (28.08%) followed by crop management (14.60%) then smart farming (10.11%). From the data collection, livestock management and irrigation management resulted in the same percentage (5.61%). In regard to sensor data collection, the highest result was for the measurement of environmental temperature (24.87%) and environmental humidity (19.79%). There are also some other sensor data regarding soil moisture (15.73%) and soil pH (7.61%). Research indicates that of the technologies used in IoT application development, Wi-Fi is the most frequently used (30.27%) followed by mobile technology (21.10%). As per our review of the research, we can conclude that the agricultural sector (76.1%) is researched considerably more than compared to the farming sector (23.8%). This study should be used as a reference for members of the agricultural industry to improve and develop the use of IoT to enhance agricultural production efficiencies. This study also provides recommendations for future research to include IoT systems’ scalability, heterogeneity aspects, IoT system architecture, data analysis methods, size or scale of the observed land or agricultural domain, IoT security and threat solutions/protocols, operational technology, data storage, cloud platform, and power supplies.

Keywords—Internet of Things; IoT; agricultural; smart farming; business; sensor data; automation

I. INTRODUCTION

IoT is a combination of worldwide data, web associated items or things, and is an integral component of the future Internet. IoT focuses on the automation of processes by lessening human interaction. In the process of automation, IoT collects data using sensors and processes the data using controllers and completing the automation processes by using actuators [1], [2]. IoT in agriculture and farming focus is on automating all the aspects of farming and agricultural methods to make the process more efficient and effective. Traditional approaches in livestock management (such as cattle detection) are not fully automated and have many inefficiencies such as higher human interaction, labour cost, power consumption, and water consumption [1], [3], [4], [5], [6]. The central concept of this review is to analyse the IoT sub-verticals, collected data for measurements and used technologies to develop applications. It is essential to identify the most researched sub-verticals, data collections and technologies to create new IoT applications in the future.
This review provides an overall picture of currently developed IoT applications in agriculture and farming between 2016 and 2018.

As a solution to the existing problems, researchers have focused on smart agricultural and farming automated systems with the help of IoT [7], [8], [9], [10]. IoT is the network of things which identifies elements clearly with the help of software intelligence, sensors and ubiquitous connectivity to the Internet. In IoT, the data that collects from Internet-connected items or things contains with gadgets, sensors and actuators [1]. Many researchers have focused on smart systems for monitoring and controlling agricultural parameters by enhancing productivity and efficiency. Smart systems collect data for measurements to get accurate results that can lead to appropriate actions. Current use of smart agricultural systems relates to collecting data on environmental parameters such as temperature, humidity, soil moisture and pH [11], [12], [13]. With accurate sensor data collection using a range of different sensors, researchers have implemented smart agricultural systems to make the farm process more effective [9], [14]. Research has mainly focused on sub-verticals such as water management, crop management and smart farming to make processes automated by reducing human intervention, costs, power consumption and water consumption.

The automation process of agricultural and farming reduced human interaction and improve the efficiency. The reason for that is every country population depends on agriculture thus consumers of these resources should have water and land resources optimally [19], [20]. Moreover, it is imperative to have good quality production and crop management in order to maximize profitability. Hence, IoT base agricultural management systems are integral for an agriculturally based country. The new systems developed using IoT technologies have reduced the drawbacks associated with traditional approaches and provided many advantages to farmers. For example, IoT-based water management systems collect environmental attributes such as temperature, water level and humidity through the sensors and provide accurate irrigation timing [19], [21]. In addition, crop management systems developed using IoT monitor the temperature, humidity and soil through sensors thus providing adequate information so that farmers can manage the crops appropriately [25]. Overall, these IoT-based systems help to reduce human interaction, power utilization and reduce cost in the field of agriculture. Moreover, IoT-based agricultural related applications have been used in the area of pest control, weather monitoring, nutrient management and greenhouse management.

IoT for agriculture uses sensors to collect big data on the agricultural environment. It discovers, analyses and deals with models built upon big data to make the development of agriculture more sustainable [34]. IoT can provide efficient and low-cost solutions to the collection of data. Weather, Water Scarcity, Soil fertility and Pesticides are the significant players in it. IoT will make agriculture beneficiary. Agriculture and farming depend on water [35]. Farmers depend on rainfall for all their agricultural needs.

Fertilizer also plays a very significant role in the field of agriculture by helping to increase the productivity of plants [36]. By using IoT, farmers can manage soil condition more effectively and at less expense by monitoring them from any location [37]. The primary objective of this study is how IoT and technologies are used in conserving water, fertiliser and energy in the agricultural industry by combining new technologies. This has benefits for the development of the economy of countries as well as the wealth of the people [38]. With the combination of both advanced technologies in hardware and software, IoT can track and count all relevant aspects of production which can reduce the waste, loss and cost [39]. The information needed to make smart decisions can be obtained merely by using electronic devices [40]. IoT transforms the agriculture industry and enables farmers to overcome different challenges. Innovative applications can address these issues and therefore increase the quality, quantity, sustainability and cost-effectiveness of crop production [41], [42], [43].

Our study has analyzed recently developed IoT applications in the fields of agriculture and farming to address current issues such as unnecessary human interaction leading to higher labour cost, unnecessary water consumption and water-saving measures for the future, higher energy consumption, energy-saving measures for the future and crop monitoring difficulties. According to our analysis, we can identify a focus on water and crop management as sub-verticals in the agriculture and farming sectors. This survey also focuses on other agriculture and farming sub-verticals to identify the gap between IoT application developments in the least researched areas. The IoT generates enormous data, so-called big data (high volume, at a different speed and different varieties of data) in varying data quality. Analysing the IoT system and its key attributes are the key to advancing smart IoT utilization. Therefore, the primary aim of our paper is to explore recently created IoT applications in the agriculture and farming industry to give the more profound understanding about sensor data collection, used technologies, and sub-verticals, for example, water and crop management. The secondary aim of this study is to analyse the current issues such as higher human interaction, high labour cost, higher water consumption and save water for future, higher energy consumption and save energy/electricity for future, crop monitoring difficulties in IoT for agriculture and farming.

The remainder of this paper is as follows: In Section II we include raw data collection methodology, data inclusion criteria, and data analysis methods. Finally, the results of Agriculture and Farming based on IoT Sub verticals, Sensor Data, and Technologies are presented in Section III, and in Section IV we discuss the results. Section V concludes the paper. The raw data collected from 60 peer-reviewed publications used in this paper are summarised in Table I.
II. MATERIALS AND METHODS

Data collection involves identifying important criteria in research articles on the Internet of Things (IoT) in the agriculture and farming sectors.

As shown in Table I, these essential criteria were used to analyse relevant research papers. In particular, 60 peer-reviewed scientific publications on IoT in the agriculture and farming sectors published in scientific journals between 2016 and 2018 were used.

1) Collection of raw data: The data gathered for this review is from 60 peer-reviewed publications (2016-2018) that were collected from the IEEE database. All these publications have different data applications that have been studied and analyzed in this survey. The attributes compared were sub-verticals, data collection measurements, used technologies, challenges in current approach, benefits, countries and drivers of IoT.

2) Data inclusion criteria: To evaluate the data inclusion criteria a comparison table was drawn to include as the following attributes: Author, Sub vertical, Data collection measurements, Technologies, Benefits, Challenges, Solutions and Drivers of IoT. Nevertheless, in our study, articles were excluded when the selected attributes were not present. In our analysis, the number of sensors, amount of data collected, underlying technologies, sensor topology and other intermediate gateways were not included since no information can find with the all the peer-reviewed publications (2016-2018).

3) Data analysis: We pooled and analyzed the reported studies based on data collected through peer reviewed articles and displaying emerging themes in a table. The data sets included attributes such as Sub vertical, Data collection measurements, Technologies, Benefits, Challenges, Solutions, Countries focused on automation of the agriculture proses and Drivers of IoT. The descriptive details of the study based on the publication year were analyzed to observe the results from 2016 to 2018.

III. RESULTS

This review aims to analyse the incorporation of IoT for the development of applications in the agriculture and farming sectors. The study focuses on sub-verticals and collecting data for measurements and technologies in the field of agriculture and farming to increase productivity and efficiency with the help of the Internet of Things (IoT). This study of IoT in agriculture and farming focuses on developing a criterion approach with the help of agricultural environmental parameters and IoT measures and technologies. In the field of agriculture, there are many environmental parameters that need to be considered to enhance crops, reduce water consumption and human involvement [44]. Moreover, there are many sub-verticals that can be identified depending on the differences in approach.

In this review, we have gathered articles which have focused on agricultural and farming sub-verticals from 2016 to 2018. As shown in Fig. 1, 23 sub-verticals were found according to the results obtained and the topmost area was water management (28.08%).

As IoT depends on sensor data collections, a vast amount of data needs to be gathered to identify or predict accurate results. This study indicates that many researchers have focused on environmental temperature (24.87%), humidity (19.79%) and soil moisture (15.73%) as environmental measurements. As shown in Fig. 2, 28 types of data were collected for measurements with environmental temperature and humidity being considered the most critical parameters for agriculture and farming.

As shown in Fig. 3, we have categorised all technologies used in the articles. This study has identified Wi-Fi as the most used technology (30.27%) followed by Mobile Technology (21.10%) for both agriculture and farming. ZigBee, another data transfer technology, is also used but to a lesser extent.

According to Fig. 4, the use of IoT was more prominent in the agriculture industry than the farming industry (Agriculture ~ 76.1%, Farming ~ 23.8%).

![IoT Sub verticals](image)

Fig. 1. Agriculture and Farming Sub Verticals: different Agricultural and Farming Sub Verticals Considered to Enhance Efficiency and Productivity—Pooling
Data from the 60 Scientific Peer-Reviewed Publications Published in 2016-2018.

**Sensor Data**

Fig. 2. Utilization of Sensor Data based on Farming Activities Referred to in the Data Pool of 60 Peer Reviewed Published Articles.

**Technologies**

Fig. 3. Overview of different Technologies Referred to in the Data Pool of 60 Peer Reviewed Published Articles and Frequency of Mentions Shown in Order of High Frequency to Low.

**IoT Vertical**

Fig. 4. Overview of Comparing the usage of Internet of Things in two Verticals as Agriculture and Farming in 60 Peer-Reviewed Research Articles to understand which is mostly used Internet of Things from Year 2016-2018.
| No | Year/Authors                  | IoT Sub Verticals          | Measures (Data collection) | Technologies Used          | Benefits of Proposed System                                      | Challenges in Current Approach                      | Solution for Current Issues | Drivers of IoT                      | Application          |
|----|------------------------------|----------------------------|-----------------------------|-----------------------------|--------------------------------------------------------------------|-----------------------------------------------------|--------------------------------|----------------------------------|----------------------|
| 1  | Venkate et al (2017) [1]     | Water Management           | Environmental temperature, Humidity, Soil moisture | Raspberry pi, Wi-Fi, RFID, Bluetooth, Zigbee | Can detect the temperature, humidity and moisture. Continuous monitoring all the places including critical areas. | Human interaction, Labour cost, Wasteage of water, Crop from abnormal irrigation. | Detect temperature, humidity, moisture using sensors. | Maximize the yield of crop by monitoring agricultural parameters. | Can deploy it in any type of environment for, monitoring, flexibility, robust | Agriculture          |
| 2  | Athira et al (2017) [2]      | Pest controlling, Weather monitoring | Soil moisture, Temperature, Water level | ZigBee | Irrigation process is completely controlled by computer-based systems. System analyses the weather reports. Keep pest away from the crops. Help to faster the growth of plants. Power efficient. | Only works based on the commands from user | Low cost, Efficient growth of crops, Faster growth of plants. | Users can remotely access irrigation system and check the status. | Predict and tackle drought situations to prevent to loss of crops. | Agriculture          |
| 3  | Zhao et al (2017) [3]        | Water Management           | Water level                 | LoRa technology             | To identify the appropriate time and in the right amount of water. High power consumption. High cost. Low coverage of ZigBee and Wi-Fi. | Can utilize the water usage. | Minimize the cost of deployment and maintenance. More efficient. Cover wider area than ZigBee and Wi-Fi. Energy consumption is low. | Users can remotely access irrigation system and check the status. | Higher the revenue by faster the growth of crops. | Agriculture          |
| 4  | Sagar S et al (2017) [4]     | Flood Avoidance           | Water level, Soil moisture | Mobile technology          | Lessen the human intercession. Lessen the probability of the flood occurrences. Faster the growth of the crops. | Save water for the future. Save electricity for the future. | Flood avoidance, Power cutoff is being reduced. | Ensure the durability of the soil. | Higher the revenue by faster the growth of crops. | Agriculture          |
| No. | Authors                          | System Type             | Water Level | Soil Moisture | Environment Temperature | Humidity | Water Requirements | Wi-Fi | Mobile Technology | Water Management | Description                                                                 |
|-----|---------------------------------|-------------------------|-------------|---------------|-------------------------|----------|--------------------|-------|-------------------|------------------|-----------------------------------------------------------------------------|
| 5   | Saraf et al (2017) [5]           | Water Management        | ✔           | ✔             | ✔                       | ✔        | ✔                  | ✔     | ✔                 | ✔                | -                                            |
| 6   | Upadhyaya et al (2017) [6]       | Water Management        | ✔           | ✔             | ✔                       | ✔        | ✔                  | ✔     | ✔                 | ✔                | -                                            |
| 7   | Udhayakumar S et al (2017) [7]   | Water Management        | ✔           | ✔             | ✔                       | ✔        | ✔                  | ✔     | ✔                 | ✔                | -                                            |
| 8   | Kumar et al (2017) [8]           | Water Management        | ✔           | ✔             | ✔                       | ✔        | ✔                  | ✔     | ✔                 | ✔                | -                                            |
| 9   | Mathew et al (2017) [9]          | Nutrient Management     | ✔           | ✔             | ✔                       | ✔        | ✔                  | ✔     | ✔                 | ✔                | -                                            |
| 10  | Suhas et al (2017) [10]          | Water Management        | ✔           | ✔             | ✔                       | ✔        | ✔                  | ✔     | ✔                 | ✔                | -                                            |
| No. | Authors (Year) | Application | Sensor Types | Wi-Fi | Water Management | Yield | Water Consumption | Water Management | Other Benefits |
|-----|----------------|-------------|--------------|-------|----------------|-------|------------------|-----------------|---------------|
| 11  | Wicha et al (2017) [11] | Water Management | Soil level, Temperature | Wi-Fi | Efficient water management | High water | Managed water system effective manner | Reveals the positive comparison results from the adaptive Wetting Front Detector (WFD). | Agriculture |
| 12  | Rajakumar et al (2017) [12] | Crop Production | Soil level, Soil nutrient | Mobile technology | Increase the crop production. Can get current fertilizer requirement | Due to improper maintenance, the crop becomes damaged which causes a huge loss for a farmer. | Enhance the crop. Control the agricultural product costs. | Interfacing different soil nutrient sensors. | Agriculture |
| 13  | Sachapara et al (2017) [13] | Crop Production, Water Management | Temperature, Humidity, Soil moisture, Leaf wetness, Wind speed/direction, Rainfall detection, Soil ph, Seed recognition | Raspberry Pi, Mobile technology | Enhanced crop production. Enhanced quality. Reduced costs. | Poor risk management. Poor water management. Poor infrastructure. Poor crops yield and big loss for farmers. | Enhanced crops yield by proper water management. Seed recognition system helps to know sustainable environmental conditions. | Agriculture |
| 14  | Pooja S et al (2017) [14] | Weather Monitoring, Precision Farming | Temperature, Humidity, Soil Moisture, Light intensity | Raspberry-Pi, Wi-Fi | Improve the crop traceability. Increase overall yield. | Wastage of crops. Poor water system management. | Crop productivity increased. Reduced wastage of crops. Reduced water use. Minimal maintenance required. High accuracy | Use of decision making algorithm. | Agriculture |
| 15  | Kavitha et al (2017) [15] | Crop Management | Soil moisture, pH level, Temperature, Humidity, Light intensity, Water level | Mobile technology | Improved crop growth. Efficient watering system. | Difficulties in monitoring. Harvesting related problems. Poor crop growth. Poor power management. Poor water management. | Effective water management. Effective power management. Reduced costs between central server and software. | Agriculture |
| 16  | Jawahar et al (2017) [16] | Crop Management, Water Management | Temperature, Humidity, Soil moisture, Water level | Mobile technology | Prevent crops from spoilage during rain. Recycling rain water in an efficient manner. | Wastage of water. Human interaction. Hard to monitor field every time to avoid intrusion attacks. | Update farmer with live condition of the field. Lessen human interaction. Notify intrusion detections with an alarm. | Excess water from the cultivation field and recycled back to the tank. | Agriculture |
| Page | Authors             | Topics and Technologies                                                                 | Benefits                                                                                           | Applications                                                                 |
|------|---------------------|----------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| 17   | Nishi K V et al (2017) [17] | ✓ Whether management ✓ Crop management ✓ Soil moisture ✓ Temperature ✓ pH level ✓ Mobile technology ✓ Wi-Fi | ✓ Provide advice for farmers to properly grow and treat the crops. ✓ Provide suggestions to monitoring crops. ✓ Ex: Irrigation timings ✓ Optimum usage of fertilizers. ✓ Provide whether information. | ✓ Provide efficient suggestions about when and how much to irrigate. ✓ Provide adequate fertilizer information. ✓ Provide farmer friendly alerts and guidance with their local language. ✓ Agriculture |
| 18   | Tran et al (2017) [18] | ✓ Crop management ✓ Nutrient Detection ✓ Temperature ✓ Humidity ✓ ZigBee ✓ Raspberry Pi | ✓ Could prevent soil erosion. ✓ High energy consumption. ✓ Soil and nutrient depletion. | ✓ Reduced energy consumption. ✓ Could react changes in environment and soil. ✓ Reduce the consumption of energy ✓ Increase the number of sensors ✓ Agriculture |
| 19   | Muhammad et al (2017) [19] | ✓ Water Management ✓ Water level ✓ Soil Moisture ✓ Wireless Sensor Network ✓ Radio Communication | ✓ Efficient water management ✓ Climate changes. ✓ Scarcity of water. | ✓ Monitoring water in watercourses. ✓ Smart water metering system. ✓ Agriculture |
| 20   | Viswanathan et al (2017) [20] | ✓ Crop management ✓ Warehouse Management ✓ Temperature ✓ Humidity ✓ Soil Moisture ✓ Rainfall ✓ Light intensity ✓ Wi-Fi | ✓ Remote controlled processes to perform such tasks as: ✓ Spraying ✓ Weeding ✓ Bird and animal scaring ✓ Keeping vigilance ✓ Provide smart warehouse management ✓ Theft detection in warehouse. | ✓ Reduced cost. ✓ Lessen human interaction. ✓ High reliability. ✓ Improved crop production. ✓ Smart warehouse management. ✓ Agriculture |
| 21   | Dai et al (2017) [21] | ✓ Water Management ✓ Agricultural Greenhouse Management ✓ Soil environment: ✓ Temperature ✓ Humidity of soil ✓ Soil CO2 ✓ Soil pH ✓ Environmental: ✓ Temperature ✓ Humidity ✓ Wind speed ✓ Air pressure ✓ Rainfall ✓ ZigBee | ✓ High irrigation efficiency. ✓ High flexibility. | ✓ Low irrigation efficiency ✓ High labour cost ✓ Low precision ✓ High water consumption. ✓ Lessen labour cost. ✓ Reduced water wastage. ✓ Powerful servers to handle storage data. ✓ Agriculture |
| 22   | Yuan et al (2017) [22] | ✓ Agricultural Greenhouse Management ✓ Temperature ✓ Humidity ✓ ZigBee | ✓ More flexible. ✓ Low power consuming. | ✓ Short distance communicatio n. ✓ High power consumption. ✓ Lessen power consumption. ✓ Automated greenhouse management. ✓ Agriculture |
| No. | Authors (Year) | Water Management | Energy Management | Soil Management | Nutrient Detection | Crop Management | Soil Quality Management | Water Management | Soil Characteristics and Water Level Measurement | Water Quality Analysis | Soil Quality and Crop Yield Monitoring | Recommendations and Benefits |
|-----|----------------|------------------|-------------------|-----------------|-------------------|-----------------|-------------------------|-----------------|-----------------------------------------------|------------------------|-------------------------------------------------|------------------------------------------------------------------------|
| 23  | Garcia et al (2017) [23] | ✓ Water Management | ✓ Energy Management | ✓ Soil Measures: Soil pH, Soil Temperature, Soil Humidity | ✓ Soil Moisture | ✓ Water quality parameters | ✓ Soil moisture, Soil pH, Soil water level | ✓ Water flow rate, Pressure, Wind speed | ✓ Irrigation events: Flow level, Pressure level, Wind speed | ✓ Low cost irrigation control, Autonomous decision making without human interactions | ✓ Device scalability is low, Device manageability is low | ✓ Lessen human interaction, EFFICIENT water management, EFFICIENT power management, Autonomous decision making without human interactions | ✓ Agriculturere |
| 24  | Janani V et al (2017) [24] | ✓ Soil Management | ✓ Nutrient Detection | ✓ Soil Measures: Soil pH, Soil Temperature, Soil Humidity | ✓ Soil Moisture | ✓ Water quality parameters | ✓ Soil moisture, Soil pH, Soil water level | ✓ Water flow rate, Pressure, Wind speed | ✓ Irrigation events: Flow level, Pressure level, Wind speed | ✓ Low cost irrigation control, Autonomous decision making without human interactions | ✓ Device scalability is low, Device manageability is low | ✓ Lessen human interaction, EFFICIENT water management, EFFICIENT power management, Autonomous decision making without human interactions | ✓ Agriculturere |
| 25  | Jyothi et al (2017) [25] | ✓ Crop Management | ✓ Water Management | ✓ Soil Measures: Soil pH, Soil Temperature, Soil Humidity | ✓ Soil Moisture | ✓ Water quality parameters | ✓ Soil moisture, Soil pH, Soil water level | ✓ Water flow rate, Pressure, Wind speed | ✓ Irrigation events: Flow level, Pressure level, Wind speed | ✓ Low cost irrigation control, Autonomous decision making without human interactions | ✓ Device scalability is low, Device manageability is low | ✓ Lessen human interaction, EFFICIENT water management, EFFICIENT power management, Autonomous decision making without human interactions | ✓ Agriculturere |
| 26  | Javale et al (2017) [26] | ✓ Water Management | ✓ Energy Management | ✓ Soil Measures: Soil pH, Soil Temperature, Soil Humidity | ✓ Soil Moisture | ✓ Water quality parameters | ✓ Soil moisture, Soil pH, Soil water level | ✓ Water flow rate, Pressure, Wind speed | ✓ Irrigation events: Flow level, Pressure level, Wind speed | ✓ Low cost irrigation control, Autonomous decision making without human interactions | ✓ Device scalability is low, Device manageability is low | ✓ Lessen human interaction, EFFICIENT water management, EFFICIENT power management, Autonomous decision making without human interactions | ✓ Agriculturere |
| 27  | Sathyadevan et al (2017) [27] | ✓ Soil Quality Management | ✓ Water Management | ✓ Soil Measures: Soil pH, Soil Temperature, Soil Humidity | ✓ Soil Moisture | ✓ Water quality parameters | ✓ Soil moisture, Soil pH, Soil water level | ✓ Water flow rate, Pressure, Wind speed | ✓ Irrigation events: Flow level, Pressure level, Wind speed | ✓ Low cost irrigation control, Autonomous decision making without human interactions | ✓ Device scalability is low, Device manageability is low | ✓ Lessen human interaction, EFFICIENT water management, EFFICIENT power management, Autonomous decision making without human interactions | ✓ Agriculturere |
| 28  | Kulkarni et al (2017) [28] | ✓ Soil management | ✓ Water Management | ✓ Soil Measures: Soil pH, Soil Temperature, Soil Humidity | ✓ Soil Moisture | ✓ Water quality parameters | ✓ Soil moisture, Soil pH, Soil water level | ✓ Water flow rate, Pressure, Wind speed | ✓ Irrigation events: Flow level, Pressure level, Wind speed | ✓ Low cost irrigation control, Autonomous decision making without human interactions | ✓ Device scalability is low, Device manageability is low | ✓ Lessen human interaction, EFFICIENT water management, EFFICIENT power management, Autonomous decision making without human interactions | ✓ Agriculturere |
| 29  | Mahalakshmi et al (2016) [29] | ✓ Water Management | ✓ Energy Management | ✓ Soil Measures: Soil pH, Soil Temperature, Soil Humidity | ✓ Soil Moisture | ✓ Water quality parameters | ✓ Soil moisture, Soil pH, Soil water level | ✓ Water flow rate, Pressure, Wind speed | ✓ Irrigation events: Flow level, Pressure level, Wind speed | ✓ Low cost irrigation control, Autonomous decision making without human interactions | ✓ Device scalability is low, Device manageability is low | ✓ Lessen human interaction, EFFICIENT water management, EFFICIENT power management, Autonomous decision making without human interactions | ✓ Agriculturere |
| Page | Authors | Methodology | Benefits | Limitations | Comments |
|------|---------|-------------|----------|-------------|----------|
| 30   | Zaman et al (2016) [30] | Prescriptive farming | High human interaction. with the help of low-cost sensors. Reduces water consumption. Reduced power consumption. Increased crop productivity. Reduced wastage of crops. | n up to great extent. | Agricultu re |
|      |         | Light intensity |          |             |          |
|      |         | the irrigation system. |          |             |          |
|      |         | Detect appropriate time for water supply. Keep track of water level. |          |             |          |
|      |         | Cannot predict the time for watering. |          |             |          |
| 31   | Biradar et al (2017) [31] | Water management | Helps for decision making process Can monitor and control the temperature, humidity and soil PH. It can sense the amount of the change through the integration of components. Reduce cost | Crop management by providing required amount of water. Multidisciplina ry monitoring leads to improvement of agricultural management. | Agricultu re |
|      |         | Moisture level |          |             |          |
|      |         | Light intensity |          |             |          |
|      |         | Raspberry Pi Wi-Fi Mobile Technology |          |             |          |
|      |         | Detect appropriate time for water supply. Keep track of water level. |          |             |          |
|      |         | Cannot predict the time for watering. |          |             |          |
| 32   | Ismail et al (2017) [32] | Soil moisture level monitor | Farmers can face the any environmental challenges easily. Reduce the harmful risk percentage Save money and water. Reduce pest population. | Climatic change. Take long time to harvesting. Burnings in land preparation. Limitation of space. | Agricultu re |
|      |         | Soil moisture Water content Temperature |          |             |          |
|      |         | Wireless Sensor network Mobile technology ZigBee RFID |          |             |          |
|      |         | Helps for decision making process Can monitor and control the temperature, humidity and soil PH. It can sense the amount of the change through the integration of components. Reduce cost | Crop management by providing required amount of water. Multidisciplina ry monitoring leads to improvement of agricultural management. | Agricultu re |
|      |         | Detect appropriate time for water supply. Keep track of water level. |          |             |          |
|      |         | Cannot predict the time for watering. |          |             |          |
| 33   | Amandeep et al (2017) [33] | Machines for routine operations Warehouse management | Increasing the crop productivity. Prevent thefts. Prevent attacking from birds, animals and other facts. | Manual distribution of seeds. Pattern of two crops year. Unscientific system of cultivation. Unequal watering system. | Farming |
|      |         | Soil moisture Temperature Humidity Water level |          |             |          |
|      |         | ZigBee Mobile technology Wi-fi |          |             |          |
|      |         | Helps for decision making process Can monitor and control the temperature, humidity and soil PH. It can sense the amount of the change through the integration of components. Reduce cost | Crop management by providing required amount of water. Multidisciplina ry monitoring leads to improvement of agricultural management. | Agricultu re |
|      |         | Detect appropriate time for water supply. Keep track of water level. |          |             |          |
|      |         | Cannot predict the time for watering. |          |             |          |
| 34   | Dolci (2017) [34] | Precision farming Prescriptive farming | Improving malt quality and efficiency in production with using Artificial Intelligence | low cost sensors open source application | Farming |
|      |         | Temperature humidity Soil PH CO2 |          |             |          |
|      |         | Mobile technology |          |             |          |
|      |         | Cost reduction Reduce the frequency |          |             |          |
|      |         | Unequal distribution of air flow. |          |             |          |
|      |         | Helps for decision making process Can monitor and control the temperature, humidity and soil PH. It can sense the amount of the change through the integration of components. Reduce cost | Crop management by providing required amount of water. Multidisciplina ry monitoring leads to improvement of agricultural management. | Agricultu re |
|      |         | Detect appropriate time for water supply. Keep track of water level. |          |             |          |
|      |         | Cannot predict the time for watering. |          |             |          |
|      |         | PSU efficient |          |             |          |
| Page  | Livestock management | Smart lighting | Smart ventilation | Water management | Temperature | Humidity | Milk production | Mobile technology | Wi-Fi | Identifying the emergency conditions | Improves location tracking | Improves cattle health | Improves availability | Make | Infrastructure of cattle farming smarter | Implement a noninvasive wearable to track physiological and biological activities of cattle | Improve the smart lighting and ventilation system | Farming, Agriculture |
|-------|----------------------|----------------|------------------|------------------|--------------|----------|-----------------|------------------|-------|---------------------------------------|--------------------------|-------------------|-----------------|-------|------------------------------------------|--------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------|--------------------------------------------------|
| 35    | Gokul et al (2017) [35] | ✓ Livestock management | ✓ Smart lighting | ✓ Smart ventilation | ✓ Water management | ✓ Temperature | ✓ Humidity | ✓ Milk production | ✓ Mobile technology | ✓ Wi-Fi | ✓ Identifying the emergency conditions | ✓ Improves location tracking | ✓ Improves cattle health | ✓ Improves availability | ✓ Make | ✓ Infrastructure of cattle farming smarter | ✓ Implement a noninvasive wearable to track physiological and biological activities of cattle | ✓ Improve the smart lighting and ventilation system | ✓ Farming, Agriculture |
| 36    | Rajkumar et al (2017) [36] | ✓ Irrigation management | ✓ Temperature | ✓ Humidity | ✓ Soil Moisture | ✓ Mobile technology | ✓ Wi-Fi | ✓ Provides real time information | ✓ Cost reduction | ✓ Resource optimization | ✓ Reduce water logging and shortage | ✓ Water shortage | ✓ Different environmental conditions | ✓ Improving | ✓ Developing smart irrigation system to monitor at anywhere | ✓ Installing a water meter to estimate the amount of water | ✓ Using Wireless sensors | ✓ Agriculture |
| 37    | Sri et al (2017) [37] | ✓ Crop management | ✓ Irrigation management | ✓ Soil | ✓ Temperature | ✓ Humidity | ✓ Rainfall | ✓ Fertilizer efficiency | ✓ Mobile technology | ✓ Wi-Fi | ✓ Provides real time information | ✓ Improves the yield | ✓ Low cost | ✓ Improving | ✓ Providing reliable and efficient agricultural system to monitor the field | ✓ Improving by adding several modern techniques like irrigation | ✓ Method, solar power source usage | ✓ Agriculture |
| 38    | Rajarsri et al (2017) [38] | ✓ Water management | ✓ Water level | ✓ Mobile technology | ✓ Improve the efficiency | ✓ Optimize resource | ✓ Maximize the profit | ✓ Unequal water distribution | ✓ Improving | ✓ Build a well-connected farming network and create a knowledge sharing platform | ✓ Agro loan | ✓ Inexpensive | ✓ Agricultura l consultatio n | ✓ Better ROI | ✓ Agro networking | ✓ Low cost products | ✓ Agriculture |
| 39    | Ruengittinun et al (2017) [39] | ✓ Smart farming | ✓ Temperature | ✓ Humidity | ✓ PH | ✓ Electrical conductivity | ✓ Wi-Fi | ✓ Can farm in less space | ✓ Provides many products | ✓ Differential of temperature | ✓ Lack of time to manage and plant | ✓ Build a smart hydroponic eco system | ✓ Symmetric al | ✓ plantation to check the accuracy of the HFE across multiple farms in the same area | ✓ Agriculture | ✓ Farming |

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|   | Authors                          | Contributions                                                                 |
|---|----------------------------------|-------------------------------------------------------------------------------|
| 40 | Yoon et al (2018)                | Smart farming, Irrigation management, Temperature, Humidity, CO2, Bluetooth, Wi-Fi, LPWAN, can overcome distance, and place constraints, save maintenance cost of existing devices, provide compatibility with new devices, Power problem, Space limitation, difficulties in installing additional devices, Build a system with using Bluetooth and LPWAN to solve the power problem and space limitation. |
| 41 | Ezhilazhahi et al (2017)          | Smart Farming, Plant health, Soil Moisture, Temperature, Humidity, WSN, Zig Bee, Wi-Fi, Raspberry pi, GPRS, Enrich the productivity of food grains, Prevent the plant from blight and harmful insects, water scarcity, unpredictable weather conditions, Developing a system to monitor continuously soil moisture of the plants, Increasing the number of sensors. |
| 42 | Tanmayee (2017)                  | Crop management, Temperature, Soil Moisture, Raspberry pi, Mobile technology, Reduces the wastage of pesticides, Reduces the human effort, Increase agricultural productivity, Bacterial diseases, unpredictable weather conditions, Implementing a rice crop monitoring System, Using multicolor detection for detect the disease in any stage. |
| 43 | Takecar et al (2017)             | Machines for routine operations, Soil Moisture, Temperature, Humidity, Wi-fi, Increase the income, Cost reduction, Lack of Resource Management, Implementing a system to look after the plantation without disturbing busy schedule, Improve the component in the PATRIOT system. |
| 44 | Krishna et al (2017)             | Smart Farming, livestock management, Soil Moisture, Light intensity, Humidity, Temperature, Soil pH, Raspberry pi, Zig Bee, Wi-Fi, Reducing labor costs, Help to track the changes accurately occurring instantly in real time at the field, lack of moisture in the fields, salinity, lack of application of fertilizers, Different sowing time, Using wireless mobile robot performing various operations of the field. |
| 45 | Li et al (2017)                  | Irrigation management, Green house management, Humidity, Temperature, Zig Bee, Wi-Fi, Bluetooth, LAN, Reduce the labour cost, Improve the efficiency of agricultural production, low production efficiency, Waste of resources, Environmental pollution, Green house management to improve the agricultural production, Implement a comprehensive promotion system. |
| 46 | Suciuc et al (2016)              | Smart Farming, Temperature, Mobile technology, GPRS, Improve the quality and safety of the products, Detecting plant diseases, flood, etc., Climatic change, High temperature, Low profit margin, Assist for crop management by using smart agriculture, Allowing system to measure basic parameters for irrigation management. |
| 47 | Putjaija et al (2017)            | Intelligent farming, Humidity, Temperature, Soil moisture, Light intensity, Wi-Fi, Improve the production process, Managing resources, Unpredictable weather, Implement a system to monitor the harmful diseases, Developing the sensor and control system by adding more components. |
| 56 | Okayasu et al (2017) [48] | Growth measurement | Humidity | Temperature | Solar radiation | CO2 | Wi-Fi | Reduce production cost | Improve the quality of the products | High production cost | Less quality in products | Monitoring the plant growth measurement using smart agriculture. | Improve the accuracy of measurements. | Farming |
| 55 | Sreekantha et al (2017) [49] | Irrigation management | Soil moisture | Temperature | Weather | Fertility of soil | Zig Bee | Mobile technology | Wi-Fi | Detection of seed, water level, pest, animal intrusion to the field. | Reduce cost and time | Enhance productivity | Environmental changes | High water consumption | Enhance the productivity by using crop monitoring system. | Generalize event-condition-action framework for programming reactive sensor networks | Agricultur e |
| 54 | Rajendrakumar et al (2017) [50] | Water management | Soil moisture | Temperature | Humidity | Soil pH | Mobile technology | Wi-Fi | Increase harvest efficiency | Decrease water wastage | Uncertain monsoon | Water scarcity | Climatic variation | Providing information to understand how to monitor and control the data remotely and apply to the fields. | Develop multiple systems. | Agricultur e |
| 53 | Ferreira et al (2017) [51] | Smart Farming | Temperature | Soil pH | Oxygen flow | Mobile technology | Wi-Fi | Improve the production. | Climate changes. | Insufficient available lands. | Air toxins. | Researching modules related to IoT, event processing, situational awareness and data harmonization | Developing all the apps and experiment with real cases. | Farming |
| 52 | Vermandhes et al (2017) [52] | Livestock management | Temperature | Humidity | Light | Mobile technology | Wi-Fi | Improve the cultivation | Limited lands. | Water scarcity | Smart aquaponic system to monitor and control cultivation | Increase the manual response speed. | Farming |
| 51 | Vaughan et al (2017) [53] | Livestock management | Animal Weight | Mobile technology | Can monitor the performance of their animals. | Improve the livestock production | Weather condition | Maintaining balance | Large number of measurements. | Gaining data under the hostile conditions of a livestock farm. | Upstream and downstream the supply chain. | Farming |
| 50 | Padalalu et al (2017) [54] | Water management | Temperature | Humidity | Light | CO2 | Soil pH | Mobile technology | Conserve water | Avoidance of constant vigilance. | Remote automation | Water scarcity | High power consumption | Implementing system to make the irrigation system smart, autonomous and efficient | Estimate the irrigation cost. | Introducing wireless sensor. | Automatic watering | Agricultur e |
| 49 | Bellini et al (2017) [55] | Cattle detection management | Temperature | Milk consumption | LoRa | Increase milk production | Heat detection | Intensification management techniques | By collecting activity data for heat detection for the cattle. | Developing power reduction systems. | Farming |
| 48 | Cambra et al (2017) [56] | Energy management | Temperature | Humidity | Mobile technology | WSN | Energy efficiency | Reduction in fertilizers in products | Saving water | Scalability | Manageability | Implement a smart communication system to monitor the agriculture | Developing irrigation services system in the domain of agricultural decision systems | Agricultur e |
| 47 | Moon et al (2017) [57] | Smart farming | Temperature | Humidity | Rain fall | Wind speed | Wi-Fi | Improve crop yield. | Reduce unnecessary | Managing big data | Applying lossy compression on IoT big data. | Use lossy compression techniques | Farming |


IV. DISCUSSION

In this review we have identified important attributes to analyse the research findings in agriculture and farming processes. We have gathered and analyzed data by using 60 recent scientific articles. Our survey shows the most researched sub-verticals are water management, crop management and smart farming. Water management is the most researched sub-vertical for the last few years as most countries mainly focus on the utilization of water resources due to its lack of abundance [61]. Irrigation patterns in agriculture influence crop production making irrigation management a central focus to increase productivity [8], [10]. The second most considered sub-vertical is crop management due to the importance of producing food for a growing global population. It is important to manage the quality, quantity and effectiveness of the agricultural production for sustainability [13]. Although a study [18] discussed that the widely used sensor data collections for measurements are soil conditions as pH and humidity, as per our analysis it shows environmental temperature followed by humidity and soil moisture are the most commonly measured data.

IoT can further be defined as a fusion of heterogeneous networks including chip technology that scopes gradually more and more, expanding due to the rapid growth of Internet applications such as logistics, agriculture, smart community, intelligent transposition, control and tracking systems. According to researchers’ analysis, in 2020 IoT objects will be semi-intelligent and an important part of human social life [46]. As analyzed in our review Wi-Fi, mobile technology are the technologies which have a wide range of demand in agriculture and farming domain to monitor land and water resources in contrast to other technologies [33], [35]. Although our results demonstrate the results in such a way, a study [62] analyzed that use of RFID, a Wireless Sensor Network (WSN) technology that can be effectively used to increase the crop production to meet the growing needs of the increasing population. In developing countries with limited Internet speed, the other IoT technologies utilised rather than Wi-Fi include Low-Power, Short-Range IoT Networks, low-rate wireless PAN (LoRaWAN) or Low-Power and Wide-Area Networks.

Further research [61] shows that WSN is used in many applications such as health monitoring, agriculture, environmental monitoring, and military applications whereas our study demonstrates the agriculture sector using IoT in and farming sector using IoT. Our observations show that Agriculture is the primary source of income in developing countries, such as India with the sizeable geographical area when comparing with other countries [9].

Most of the research studies have performed on water management by monitoring such environmental parameters as temperature, humidity and soil moisture [1], [3], [5], [19], [25]. Many of the findings have focused on better water utilization, reduction in human intervention and the cost of production [18], [27]. Future research could draw more attention to further automate current processes in waste management, smart lightening and pest controlling sub-verticals by reducing existing drawbacks since it has received the least research attention in the considered period. Fog computing, as an innovation with cross over any barrier between remote data centres and IoT devices, should be considered in future IoT analysis [63], [64], [65], [66], [67]. While IoT has solved many issues related to agriculture and farming there are limitations that we need to consider. Lack of
interoperability and compatibility in devices, network flexibility issues when more devices are connecting, and sensor lifetime is some of the limitations to be addressed in future research.

This study has found that industry 4.0 in agriculture focuses on IoT aspects transforming the production capabilities including the agricultural domain. This study has [68] considered soil quality, irrigation levels, weather, the presence of insects and pests as sensor data. Some of the significant aspects they have been researched are the driver’s assistance to optimise routes and shorten harvesting and crop treatment while reducing fuel consumption CI=SO [69]. Producing enough food for the entire world is a big challenge since the global population is rapidly changing as well as climate change and labour shortage. Currently researchers have focused more on robotics to address these problems. A growing number of researchers and companies have focused on Robotics and Artificial Intelligence (AI) to weeding by reducing the amount of herbicide used by farmers.

In contrast to edge computing, cloud computing requires a high-speed internet connection with sending and retrieving data from the cloud. As the process involves transferring and receiving data from the cloud, the process is time-consuming. Since the data capacity is higher than bandwidth, it is always essential to process data locally instead of sending data to the cloud. Edge computing is more efficient than cloud processing when processing data since the capacity doubles faster than the bandwidth doubles [70]. Since IoT uses sensor data collection for decision making, to process collected data, the cloud, or the edge based can be used on the system requirements.

Still, there are some challenges associated with IoT system deployment. Connecting so many devices to the IoT network is the biggest challenge in the future following lack of technical knowledge among farmers, current centralised architecture to support IoT systems is not much advanced as the growth of the network, centralised systems will turn into a bottleneck. Moreover, sensor battery capacity and lifetime and sensor data storage also more concentrated when IoT system deployment. Smart farming is the association with new advancements in technologies and the different crop and livestock, agriculture and farming in the digital age. Smart farming can deliver agriculture more beneficial for the farmer. This is because decreasing input resources will save farmers’ money and labour, and hence, will increase reliability [71] and business outcome [72], [73].

Furthermore, studying diverse approaches for fog computing structure [63], decision making using prediction or pattern analysis [74], [75], [76], big data databases [77] could be an exciting way to make the Internet of Things (IoT) into the future dominating technology.

This survey will fill the gap by the identification of the different IoT sub-verticals and data collections for the measurements in the agriculture and farming process. Results are clearly showing that most considered sub-verticals and data collections for measurements in the field of agriculture and farming. Our study also indicates the technologies used for IoT application development in the reviewed period. To summarise this survey, this has broader knowledge about IoT applications developed for automating the agriculture and farming process. Moreover, this study identifies most considered sub-verticals, collected sensor data and technologies for the development of IoT based applications in agriculture and farming sector towards the significant improvement of the business.

Table II shows the other necessary data collection criteria which were not included in all studies.

| Criteria                          | Information to be Collected in IoT Domain                                                                 | Addressed in this Review | To be Addressed in Future Research |
|-----------------------------------|------------------------------------------------------------------------------------------------------------|---------------------------|-----------------------------------|
| IoT Sub Verticals                 | What are the sub-areas addressed?                                                                        | ✓                         | ✓                                 |
| Measures (Data Collection)        | What sort of sensor data collected for measurements?                                                     | ✓                         | x                                 |
| Technologies Used                 | Used technologies to develop or to solve problems.                                                       | ✓                         | x                                 |
| Benefits of Proposed System       | Advantages of having the system to address existing issues.                                               | ✓                         | x                                 |
| Challenges in Current Approach    | Existing issues and problems in the current systems and methods.                                         | ✓                         | x                                 |
| Solution for Current Issues       | Proposed solution to solve the issues in the current problems.                                          | ✓                         | x                                 |
| Drivers of IoT Countries          | What are the novelty and future aspects of the proposed systems and methods?                            | ✓                         | x                                 |
| IoT systems’ Scalability          | Number of sensors are deployed, a variety of sensors, amount of data collection (volume), speed (velocity) of data collection (days-hours, hours-minutes, seconds-microseconds) | x                         | ✓                                 |
| Heterogeneity Aspects             | Are sensors and underlying technologies uniform or heterogeneous in the system?                        | x                         | ✓                                 |
V. CONCLUSION

From our observations from the 60 peer-reviewed publications (2016–2018) in discussing the potential applications of the Internet of Things, it was found that water management is the highest considered IoT sub-vertical followed by crop management, smart farming, livestock management, and irrigation management with the same percentage. As per the observation, the most critical sensor data collection for the measurement is environmental temperature, environmental humidity and also there are some other such sensor data also gathered for IoT applications as soil moisture and soil pH. Wi-Fi has the highest demand of usage in agriculture and farming industry, followed by mobile technology. Other technologies as ZigBee, RFID, Raspberry pi, WSN, Bluetooth, LoRa and GPRS have less demand in the agriculture and farming sectors. When compared to the agricultural sector, farming industry has a lesser percentage amount using IoT for the automation. This survey could be useful for researchers for finding new ways and solution to challenge in the current agricultural era and for agricultural and farming industries to make the automation process more effective and efficient, consequently, to obtain the good businesses outcome.

AUTHORS’ PROFILE

R.M., S.W., and M.N.H. conceived the study idea and developed the analysis plan. R.M. and S.W. analyzed the data and wrote the initial paper.

M.N.H. helped to prepare the figures and tables and finalizing the manuscript. R.M. completed the final editing and figures of the manuscript. All authors read the manuscript.

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Title:
Adoption of the Internet of Things (IoT) in Agriculture and Smart Farming towards Urban Greening: A Review

Date:
2019-04-01

Citation:
Madushanki, AAR; Halgamuge, MN; Wirasagoda, WAHS; Syed, A, Adoption of the Internet of Things (IoT) in Agriculture and Smart Farming towards Urban Greening: A Review, INTERNATIONAL JOURNAL OF ADVANCED COMPUTER SCIENCE AND APPLICATIONS, 2019, 10 (4), pp. 11 - 28

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