

# Intelligent Smart Agriculture Using Artificial Intelligence and IOT: Research Trends and Open Challenges

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**Abstract-** Today's agriculture industry is data centred, precise, and smarter than ever. The rapid emergence of the Internet-of-Things (IoT) based technologies redesigned almost every industry including "smart agriculture" which moved the industry from statistical to quantitative approaches. Such revolutionary's changes are shaking the existing agriculture methods and creating new opportunities along arrange of challenges. This article highlights the potential of wireless sensors and IoT in agriculture, as well as the challenges expected to be faced when integrating this technology with the traditional farming practices. IoT devices and communication techniques associated with wireless sensors encountered in agriculture applications are analysed in detail. What sensors are available for specific agriculture application, like soil preparation, crop status, irrigation, insect and pest detection are listed. How this technology helping the growers throughout the crop stages, from sowing until harvesting, packing and transportation is explained. Furthermore, the use of unmanned aerial vehicles for crop surveillance and other favourable applications such as optimizing crop yield is considered in this article. State-of-the-art IoT-based architectures and platforms used in agriculture are also highlighted wherever suitable. Finally, based on this thorough review, we identify current and future trends of IoT in agriculture and highlight potential research challenges.

**Keywords:** Food quality and quantity, Internet-of-Things (IoT), smart agriculture, advanced agriculture practices, urban farming, agriculture robots, automation, future food expectation.

## I. INTRODUCTION

To improve the agricultural yield with fewer resources and labour efforts, substantial innovations have been made throughout human history. Nevertheless, the high population rate never let the demand and supply match during all these times. According to the forecasted figures, in 2050, the world population is expected to touch 9.8 billion, an increase of approximately 25% from the current figure. Almost the entire mentioned rise of population is forecasted to occur among the developing countries. On the other side, the trend of urbanization is forecasted to continue at an accelerated pace, with about 70% of the world's population predicted to be urban until 2050 (currently 49%).

Furthermore, income levels will be multiples of what they are now, which will drive the food demand

further, especially in developing countries. As a result, these nations will be more careful about their diet and food quality; hence, consumer preferences can move from wheat and grains to legumes and, later, to meat. In order to feed this larger, more urban, and richer population, food production should double by 2050. Particularly, the current figure of 2.1 billion tons of annual cereal production should touch approximately 3 billion tons, and the annual meat production should increase by more than 200 million tons to fulfil the demand of 470 million tons. Not only for food, but crop production is becoming equally critical for industry; indeed, crops like cotton, rubber, and gum are playing important roles in the economies of many nations.

Furthermore, the food-crops-based bioenergy market started to increase recently. Even before a decade, only the production of ethanol utilized 110 million tons of coarse grains (approximately 10% of

the world production) [7], [8]. Due to the rising utilization of food crops for bio-fuel production, bio-energy, and other industrial usages, food security is at stake. These demands are resulting in a further increase of the pressure on already scarce agricultural resources. Over the past decades, the total agriculture land utilized for food production has experienced a decline [9]. In 1991, the total arable area for food production was 19.5 million square miles (39.47% of the world's land area), which was reduced to approximately 18.6 million square miles (37.73% of the world's land area) in 2013 [10]. As such, the gap between demand and supply of food is becoming more significant and alarming with the passage of time.

Recently, the Internet-of-Things (IoT) is beginning to impact a wide array of sectors and industries, ranging from manufacturing, health, communications, and energy to the agriculture industry, in order to reduce inefficiencies and improve the performance across all markets. If looking closely, one feels that the current applications are only scratching the surface and that the real impact of IoT and its uses are not yet witnessed. Still, considering this progress, especially in the near past, we can predict that IoT technologies are going to play a key role in various applications of the agriculture sector. This is because of the capabilities offered by IoT, including the basic communication infrastructure (used to connect the smart objects from sensors, vehicles, to user mobile devices using the Internet) and range of services, such as local or remote data acquisition, cloud based intelligent information analysis and decision making, user interfacing, and agriculture operation automation. Such capabilities can revolutionize the agriculture industry which probably one of most inefficient sectors of our economic value chain today. To summarize this discussion, figure 1 provides the main drivers of technology, while figure 1 highlights the major hurdles of technology implementation in smart agriculture.

Researchers and engineers around the globe are proposing different methods and architectures and based on that suggesting a variety of equipment to monitor and fetch the information regarding crop

status during different stages, considering numerous crop and field types. Focusing on the market demand, many leading manufactures are providing a range of sensors, unmanned aerial vehicles (UAVs), robots, communication devices, and other heavy machinery to deliver the sensed data. In addition, various commissions, food and agriculture organizations, and government bodies are developing polices and guidelines to observe and regulate the use of these technologies in order to maintain food and environment safety.



Figure 1. Major hurdles in technology implementation for smart agriculture.

This manuscript examines the trends in IoT-based agriculture research and reveals numerous key issues that must be addressed in order to transform the agriculture industry by utilizing the recent IoT developments. The major contribution of this article is to provide real insight regarding:

- Expectations of the world from the agriculture industry.
- Very recent developments in IoT, both scholarly and in industry are highlighted and how these developments are helping to provide solutions to the agriculture industry.
- Limitations, the agriculture industry is facing.
- Role of IoT to cope these limitations and other issues like resources shortage and their precise use, food spoilage, climate changes, environmental pollution, and urbanization.
- Strategies and policies that need to be considered when implementing IoT-based technologies.

Critical issues that are left to solve and possible solutions that are further required, while suggestions are provided considering these challenges.

This article is a compendium of knowledge that can help the researchers and agriculture engineers implementing the IoT-based technologies to achieve the desired smart agriculture. The rest of this document is organized as follows. Section II provides a deep overview of major applications of IoT in agriculture and what we can achieve by utilizing these technologies. Section III gives insight regarding the role of IoT in advanced agriculture practices, like vertical farming (VF), hydroponics, and phenotyping, to manage the issues of increased urban population. Section IV highlights various technologies and equipment, like sensors, robots, tractors, and communication devices, being used to implement IoT in this industry. Accepting the worth of UAVs in precision agriculture, Section V caters application achievements that are not possible even using other latest technologies. Food safety and transportation are other critical areas requiring focus to overcome the hunger issues which did not get the attention of researchers as it deserves. Section VI supplies the role of the IoT to ensure food quality for longer periods and to deliver to remote areas. Section VII identifies current and future trends of this technology in the crop industry by highlighting potential research challenges. Finally, Section VIII concludes this article.

## II. MAJOR APPLICATIONS

By implementing the latest sensing and IoT technologies in agriculture practices, every aspect of traditional farming methods can be fundamentally changed. Currently, seamless integration of wireless sensors and the IoT in smart agriculture can raise agriculture to levels which were previously unimaginable. By following the practices of smart agriculture, IoT can help to improve the solutions of many traditional farming issues, like drought response, yield optimization, land suitability, irrigation, and pest control. Figure 2 lists a hierarchy of major applications, services and wireless sensors being used for smart agriculture applications. While, major instances in which the advanced technologies

are helping at various stages to enhance overall efficiency are discussed below.

### A. Soil Sampling and Mapping

Soil is the “stomach” of plants, and its sampling is the first step of examination to obtain field-specific information, which is then further used to make various critical decisions at different stages. The main objective of soil analysis is to determine the nutrient status of a field so that measures can be taken accordingly when nutrient deficiencies are found. Comprehensive soil tests are recommended on an annual basis, ideally in Spring; however, based on soil conditions and weather consents, it may be done in in Fall or Winter.

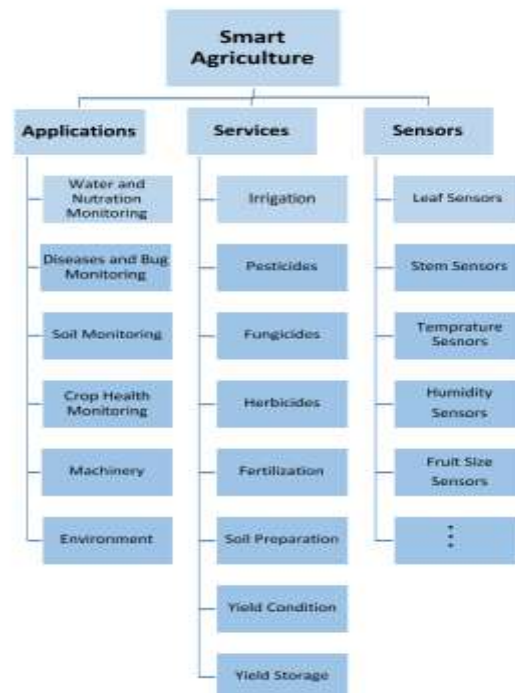


Figure 2. General hierarchy of possible applications, services and sensors for smart agriculture.

The factors that are critical to analyze the soil nutrient levels include soil type, cropping history, fertilizer application, irrigation level, topography, etc. These factors give insight regarding the chemical, physical, and biological statuses of a soil to identify the limiting factors such that the crops can be dealt accordingly. Soil mapping opens the door to sowing different crop varieties in a specific field to better match soil properties accordingly, like seed

suitability, time to sow, and even the planting depth, as some are deep-rooted and others less. Furthermore, growing multiple crops together could also lead to smarter use of agriculture, simply making the best use of resources.

Currently, manufacturers are providing a wide range of toolkits and sensors that can assist farmers to track the soil quality and, based on this data, recommend remedies to avoid its degradation. These systems allow for the monitoring of soil properties, such as texture, water-holding capacity, and absorption rate, which ultimately help to minimize erosion, densification, salinization, acidification, and pollution (by avoiding excessive use of fertilizer). Lab-in-a-Box, a soil testing tool kit developed by AgroCares, is considered a complete laboratory in itself based on its offered services. By using this, any farmer, without having any lab experience can analyze up to 100 samples per day (overall, more than 22,000 nutrient samples a year) without visiting any lab.

Sensors and vision-based technologies are helpful to decide the distance and depth for sowing the seed efficiently. Like in, sensor and vision based autonomous robot called Agribot is developed for sowing seeds. The robot can perform on any agricultural lands on which the self-awareness of the robot's placement is ascertained through the global and local maps generated from Global Positioning System (GPS) while the on-board vision system is paired with a personal computer.

Advancing further, various non-contact sensing methods are proposed to determine the seed flow rate as in where the sensors are equipped with LEDs; consist of infrared, visible light and laser-LED as well as an element as a radiation receiver. The output voltage varies based on the movement of the seeds through the sensor and band of light rays, and falling of shades on the elements of receiver. The signal information, linked to the passing seeds, is used to measure the seed flow rate.

## **B. Irrigation**

About 97% of Earth's water is salt-water held by oceans and seas, and only the remaining 3% is fresh

water more than two-third of which is frozen in the forms of glaciers and polar ice. Only 0.5% of the unfrozen fresh water is above the ground or in the air, as the rest lies under-ground. In short, humanity relies on this 0.5% to fulfil all its requirements and to maintain the ecosystem, as enough fresh water must be kept in rivers, lakes, and other similar reservoirs to sustain it. It is worth mentioning that solely the agriculture industry uses approximately 70% of this accessible fresh water.

The current situation of irrigation methods is expected to be changed by adopting the emerging IoT technologies. A significant increase in crop efficiency is expected with the use of IoT based techniques, such as crop water stress index (CWSI)-based irrigation management. For this, attaining crop canopy at different periods and air temperature are needed for the calculation of CWSI. A wireless sensors-based monitoring system where all the field sensors are connected to collect the mentioned measurements, further transmit to processing centre where corresponding intelligent software applications are used to analyse the farm data. Not only this but information from other sources including weather data and satellite imaging is applied to CWSI models for water need assessment, and finally specific irrigation index value is produced for each site. A prominent example is VRI (Variable Rate Irrigation) optimization by Crop Metrics, which works according to topography or soil variability, ultimately improves the water use efficiency.

## **C. Fertilizer**

A fertilizer is a natural or chemical substance that can provide important nutrients for the growth and fertility of plants. Plants mainly need three key macronutrients: nitrogen for leaf growth; phosphorus (P) for root, flowers, and fruit development; potassium (K) for stem growth and water movement. Any sort of nutrients deficiency or applying them improperly can be seriously harmful for the plant health. More importantly, excessive use of fertilizer not only results in financial losses but also creates harmful impacts to the soil and environment by depleting the soil quality, poisoning ground water, and contributing to global climate changes. Overall, crops absorb less than half the nitrogen

applied as fertilizer, while remaining either emitted to the atmosphere or lost as run off. Unbalanced use of fertilizer leads to an imbalance in both soil nutrient levels and global climate as, reportedly, around 80% of the world's deforestation has occurred due to agricultural practices alone. Based on recent outcomes, fertilization is considered as the best management practice to improve the effectiveness of many agriculture matters; most importantly, it can be integrated with IoT-based smart farming infrastructure seamlessly.

#### **D. Crop Disease and Pest Management**

Recent IoT based intelligent devices, such as wireless sensors, robots and drones are allowing the growers to slash pesticide uses significantly by precisely spotting crop enemies. Compared to traditional calendar or prescription-based pest control procedures, modern IoT-based pest management provides real-time monitoring, modelling, disease forecasting, hence proving more effective.

Generally, the reliability of crop disease monitoring and pest management depends on three aspects: sensing, evaluating, and treatment. The advanced disease and pest recognition approaches are based on image processing in which raw images are acquired throughout the crop area using field sensors, UAVs, or remote sensing satellites. Usually, remote sensing imagery covers large areas and, hence, offers higher efficiency with lower cost. On the other hand, field sensors are capable to support more functions in collecting data, like environment sampling, plant health, and pest situations, in every corner throughout the crop cycle. For example, IoT-based automated traps can capture, count, and even characterize insect types, further uploading data to the Cloud for detailed analysis, which is not possible through remote sensing. Approaches like vehicle precise spray and automatic VRT chemigation, commonly used under smart fertilization, can also be utilized for disease treatment and other pesticide applications.

Moreover, the advancement of robotic technology offers new solutions. When equipping an agricultural robot with multispectral sensing devices and precision spraying nozzles, it can locate and deal

with pest problems more precisely under the manipulation of a remote IoT disease management system. This IoT-based pest management system has many advantages, as it can reduce the overall expenditures while, at the same time, support the restoration of the natural climate. For example, recently, it has been found that yields of many crop types are facing severe threat due to the lack of pollination. In fact, the pollination is being affected due to bee colony collapse disorder resulting from the uncontrolled pesticides.

#### **E. Yield Monitoring, Forecasting, And Harvesting**

Yield monitoring is considered an essential part of precision farming not only at the time of harvest but even before that, as monitoring the yield quality plays a crucial role. Yield quality depends on many factors, e.g. sufficient pollination with good quality pollen especially when predicting seed yields under changing environmental conditions. Currently, when we are dealing with more open markets, buyers around the world become more particular about fruit quality; hence, effective production depends on the right fruit size to the right market at the right time. Crop forecasting is an art to predict the yield and production (tons/ha) before the harvest takes place. This forecasting helps the farmer for near-future planning and decision making.

Furthermore, analyzing the yield quality and its maturity is another critical factor which enables the determination of the right time for harvesting. This monitoring covers various development stages and uses fruit conditions like its color, size, etc., for this purpose. Predicting the right harvesting time not only helps to maximize the crop quality and production but also provides an opportunity to adjust the management strategy. Although, harvesting is the last stage of this process, proper scheduling can make a clear difference. To obtain the real benefits from crops, farmers need to know when these crops are actually ready to harvest. Figure 3 represents a snapshot of a farm area network (FAN) that can portrait the whole farm to the farmer in real time.

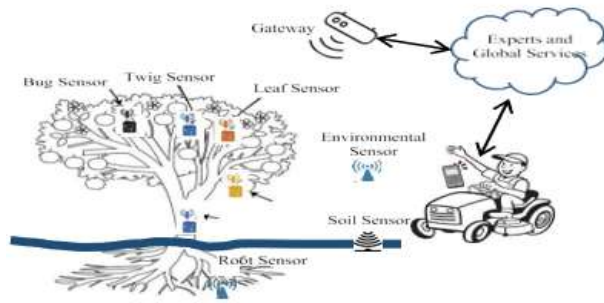


Figure 3. An IoT based farm area network (FAN).

### III. ADVANCED AGRICULTURAL PRACTICES

Adopting the novel methods to enhance the quality and quantity of food is not something new, as humans have been doing this for centuries. Initially, we tried to enhance the crop production by focusing on seed variety, fertilizers, and pesticides. Soon it was realized that these conventional ways were not adequate enough to fit this demand gap; hence, agriculture scientists have begun thinking of other alternatives, like bioengineered (BE) foods. BE foods, also known as genetically modified (GM) or genetically engineered (GE) foods, are foods produced by introducing changes into their DNA using the methods of genetic engineering. However, several studies highlight their serious effects on human health, including infertility, disruption in immune system, accelerated aging, faulty insulin regulations, etc. The importance and involvement of new technologies is more critical, as we are moving toward more cultured and urban farming. In fact, it would not be incorrect for one to say that the success of these advanced practices is in doubt without using sensor-based technologies.

#### A. Greenhouse Farming

Greenhouse farming is considered the oldest method of smart farming. Although, the idea of growing plants in controlled environment is not new as found since Roman times but it gained popularity in 19th century where largest greenhouses were built in France, Netherlands and Italy. Further, the practice was accelerated in the mid-20th century and highly pro-moted in countries that facing harsh weather conditions. Crops grown indoors are very less

affected by environment; most importantly, they are not limited to receiving light only during the daytime. As a result, the crops that traditionally could only be grown under suitable conditions or in certain parts of the world are now being growing anytime and anywhere. This was the actual time in which sensors and communication devices started to support various agriculture applications genuinely.

The success and production of various crops under such controlled environment depend on many factors, like accuracy of monitoring parameters, structure of shed, covering material to control wind effects, ventilation system, decision support system, etc. A detailed analysis is provided in, where all these factors, their impacts, and how wireless sensors can help for all this are considered. Precise monitoring of environment parameters is the most critical task in modern greenhouses, where several measurement points of various parameters are required to control and ensure the local climate. In, an IoT-based prototype is proposed to monitor the greenhouses where MicaZ nodes are used to measure the inside parameters like humidity, temperature, light, and pressure.

#### B. Vertical Farming

The world needs more farmable lands to fulfil increased food demands, but reality is that one-third arable land was lost during the last four decades due to erosion and pollution. Unfortunately, current agricultural practices based on industrial farming are damaging the soil quality far faster than nature can rebuild it. Overall, it is estimated that erosion rates from cultivated fields is 10 to 40 times greater than the soil formation rates.

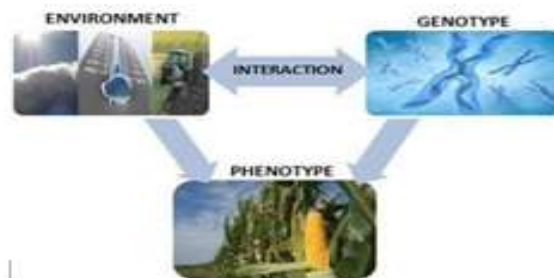


Figure 4. The Process of Phenotyping.

Considering the reduction of arable land issues, it could be a disaster for food production in the near future with current agriculture practices. Further, as we mentioned, 70% of fresh water is only used for agriculture purpose, which can increase the burden on existing limited water reservoirs. Vertical Farming (VF) is an answer to meet the challenges of land and water shortages. Under this farming method, many parameters are important, but CO<sub>2</sub> measurements are most critical; hence, nondispersive infrared (NDIR) CO<sub>2</sub> sensors play a critical role to track and control the conditions in vertical farms. Boxed Gas card, developed by Edinburgh Sensors is specially designed by considering such an environment, which employs a pseudo dual beam NDIR measurement system to enhance the stability and reduced optical complexity. Human hands are not required to touch the crops at any stage when following the IoT-connected vertical farm; this is the claim made by Mint Controls developers who offer a wide range of solutions, like waste containers and sensors and their integration for various VF applications.

### **C. Hydroponic**

Under this application, the precision of nutrient measurements is crucial, as such, a highly reliable wireless control system for tomato hydroponics is proposed in which they focused on various communication standards that are least affected by plants' presence and their growth. The monitoring of solution contents and their precision is most critical under this method; for this purpose, many systems are offered to check the presence of contents considering the plant demands. In a wireless sensor-based prototype is proposed to deliver a turn-key solution for the hydroponic cultivation which offers real time measurements for soil less indoor growing. Further, a compact sensor module is presented in which uses oscillator circuits to measure the presence and concentrations of various nutrients and water levels.

### **D. Phenotyping**

The previously discussed smart methods look more promising for the future of agriculture, as they are already being used to produce different crop products under precise environments. Other than

these, a few advanced techniques are under experiment to further enhance the crop capabilities by controlling their limitations with the help of advanced sensing and communication technologies. Among these methods, the more prominent is phenotyping, which is based on emerging crop engineering, which links plant genomics with its eco-physiology and agronomy, as shows in Figure 5. The progress in molecular and genetic tools for various crop breeding was significant in the last decade. However, a quantitative analysis of the crop behaviour, e.g. grain weight, pathogen resistance, etc., was limited due to the lack of efficient techniques and technologies that we can now enjoy.

## **IV. MAJOR EQUIPMENT AND TECHNOLOGIES**

The success of precision agriculture is based on the accuracy of collected data, which is usually done in two ways. The first entails the usage of multifunctional imaginary devices equipped with remote sensing platforms, such as satellites, agriculture airplanes, balloons, and UAVs; the second is from various types of sensors those that are mostly deployed for specific purpose across various sites of our interest. The gathered data is identified with the precise location information by using GPS devices so that the site-specific treatment can be provided afterwards. Based on these facts, during the period of 2017 to 2022, the global smart farming market is predicted to rise at a growth rate of 19.3% per year to touch \$23.14 billion in 2022.

Here it is worth mentioning that UAV/drones are generating and further expected to generate the highest revenue amongst all agricultural robots utilized in smart farming (UAVs are discussed in Section V). Evergreen demand for higher crop yield, increased incorporation of information and communication technology (ICT) in farming and the rapid global climatic changes are some of the major drivers resulting to such high market growth. Manufacturers in the market offer a variety of products and solutions, mostly based on sensors and efficient communication for a range of applications; a few are shown in figure 7. The key technologies and

equipment's that are currently available for this purpose are discussed in following.

**A. Wireless Sensors**

Among all the equipment for smart farming currently available in the market, wireless sensors are the most crucial and play a key role when it comes to collecting the crop conditions and other information. Wireless sensors are being used standalone wherever required, further integrated with almost every portion of advanced agricultural tools and heavy machinery, depending on application requirements. In the following, major sensor types are discussed according to their working procedure and purpose and the benefits they offer.



Figure 5. Selected IoT based products and prototypes for smart agriculture.

1. **Acoustic Sensors** - Miscellaneous Appliance.
2. Field-Programmable Gate Array (Fpga) Based Sensors Flexibility of Reconfiguration.
3. **Optical Sensors - Soil** Organic Substances, Soil Moisture and Color.
4. **Ultrasonic Ranging Sensors** - Potential to Operate in A Variety Of Applications.
5. **Optoelectronic Sensors** - Differentiate Plant Type.
6. **Airflow Sensors** - Permeability and Percentage of Moisture and Identifying Soil Structure.
7. **Electrochemical Sensors** - Significant Soil Characteristics to Analyze the Soil Nutrient Levels, Such As Ph.

8. **Electromagnetic Sensors** - Record Electrical Conductivity and Transient Electro-Magnetic Response.
9. **Mechanical Sensors** - Soil Mechanical Resistance (Compaction).
10. **Mass Flow Sensors** - Yield Monitoring.
11. **Eddy Covariance-Based Sensors** – Quantifying Exchanges of Carbon Dioxide, Water Vapor, Methane or Other Gases.
12. **Soft Water Level-Based (Swlb) Sensors** – To Characterize Hydrological Behaviors.
13. **Light Detection and Ranging (Lidar)** - Estimating The Biomass of Various Crops and Trees.
14. **Telematics Sensors** - Telecommunication Between Two Places—More Precisely, Among Two Vehicles When Considering the Agriculture-Based Applications.
15. **Remote Sensing** - To Capture and Store the Geographic Information. A Satellite-Based Sensor System Used to Collect, Process and Disseminates Environmental Data from Fixed And Mobile Platforms Worldwide.

TABLE 1. Some selected sensors and their possible uses in IoT based agriculture.

Sensor/ System	Target/Placed				Considered Purpose/Parameters							
	Plant	Equipment	Soil	Weather	Yield	Temp	Moisture	Location/ Tracking	Wind	Pollution/Co2	Water	Fruit/ Stem Size
Lean S0001 [137]		✓				✓	✓					
XII-M214 [138]			✓				✓					
Ag Premium Weather [139]		✓		✓		✓		✓	✓			
FI-MM [140]	✓											✓
PYCNO [141]			✓	✓		✓	✓				✓	
MP406 [142]			✓			✓	✓					
			✓			✓	✓					



Recent years have seen rapid expansion of research, with researchers conducting a growing number of studies and developing various models to highlight the scope of smartphone crop applications. These researchers mostly belong to developing nations, as proposed systems are based primarily in countries like Kenya, Ghana, Nigeria, Mali, Uganda, and Zimbabwe. Although, the scope of smartphone utilization in agriculture has been more commonly observed in Africa, experiments in countries like Cameroon, China, Turkey, and India are also increasing. Analyzing the success of m-services depends on many factors. One of the most comprehensive studies regarding the use of mobile phones for various agriculture applications was conducted to review all the important factors. This study concludes that the service will be of no effect if the developer of the application does not truly understand the farmer needs.

#### **F. Cloud Computing**

Precision agriculture is showing its potential and benefits by improving agricultural operations through better data-driven decision making. However, to continue this success, precision agriculture not only requires better technology and tools to process data efficiently but also at a reasonable cost such that the received data can be used to make field decisions efficiently. For this purpose, farmers can use Cloud services to access information from predictive analysis institutes so that they can choose the right product available according to their specific requirements. Cloud computing offers an edge to farmers to use knowledge-based repositories that contain a treasure of information and experiences related to farming practices as well as on equipment options available in the market with the necessary details. In most cases, all this comes along with expert advice from a wide range of sources (for example, on farming and the processing of agricultural products). To make it more effective, the scenario can be extended further to include access to consumer databases, supply chains, and billing systems.

## **V. UAVS IN AGRICULTURE**

Recently, the IoT has made remarkable progress in many industries, including farming sectors like poultry, fishing, etc. but when we talk about agriculture, the communication facilities like base stations or Wi-Fi are very limited, which prevents the growth of the IoT in this sector. Such communication infrastructure and related facilities are even worst in developing counties and rural areas, which is one of the major hurdles when introducing the IoT in the agriculture industry. The data acquired through the wireless sensors cannot be transmitted in the absence of reliable communication infrastructure. In such a scenario, UAVs offer an alternative, as they visit and communicate with the wireless sensors spread over large areas in order to harvest data for further processing and analysis. Furthermore, UAVs, better known as drones, fitted with high-resolution cameras and precise sensors, can be flown over thousands of hectares of farms.

The UAVs, used for agricultural applications usually fall into two categories: fixed-wing and multi-rotor drones. Although both are available in various ranges in terms of cost, payload capacity and mostly distinguished based on hardware differences. For example, when it is required to cover a large area, fixed-wing drones are suggested due to their long-range flight capacity, most importantly they are crash tolerant e.g senseFly's eBee SQ and DATAhawk. on the other hand, multirotor drones are more common due to their easy and faster set up a scan take off and land vertically. Multi rotors actually have many advantages over the fixed wings as they are easier to operate, require no advance wind planning and have the ability to fly more precisely. Moreover, in scenarios where low altitude flight is required in order to capture extremely detailed images, which is more common in agriculture applications then the multirotor are considered the better choice, some major examples belong to this type are DJI Matrice 200 and Introducing Scout by American Robotics which considered a fully autonomous drone for daily agriculture scouting.

Currently, agriculture is being considered one of the most favorable fields where UAVs can offer solutions

to resolve many dominant and long-lasting issues. Some of key areas in which drones are already playing key roles to assist farmers throughout the crop cycle are highlighted below.

- Soil and field analysis
- Planting
- Crop monitoring
- Irrigation
- Plant counting and gap detection
- Spraying the pesticides/herbicides
- Health assessment
- Detection / recognition of plant species

## VI. FOOD SAFETY AND TRANSPORTATION

A research study conducted by Indian School of Business in which students worked with a local grower to transport fruits and vegetables in refrigerated trucks from Punjab to Bangalore, a distance of more than 2,500 km through rough roads under high temperatures. The results were highly encouraging to implement the cold chain to transport the agriculture products. The out of conducted study brought benefits in three ways: (1) increased food shelf-life from one week to two months; (2) an up to 23% higher profit for everyone linked in the supply chain was observed; (3) a 76% reduction of food wastage (post-harvest). Besides all this, another critical factor is the emission of greenhouse gases was observed to be reduced by 16%. To provide the recommended environment, a device with supported technology can be installed at the storage site, even in transport trucks. Further, it is linked to an online dashboard FIGURE 6. Fluid computing infrastructure for smart farming that can be configured to send alerts in the event of abnormal temperature levels to trigger swift remedial action. Some of key technologies available for this purpose and their use cases are mentioned here.

### A. Compliance Mate

Compliance with hazard analysis and critical control points (HACCP) offers a food safety and quality monitoring program which collects temperature data inside coolers and other kitchen equipment continuously. For example, its integration with Touch

block is used to capture temperatures in coolers and prep rooms at every minute.

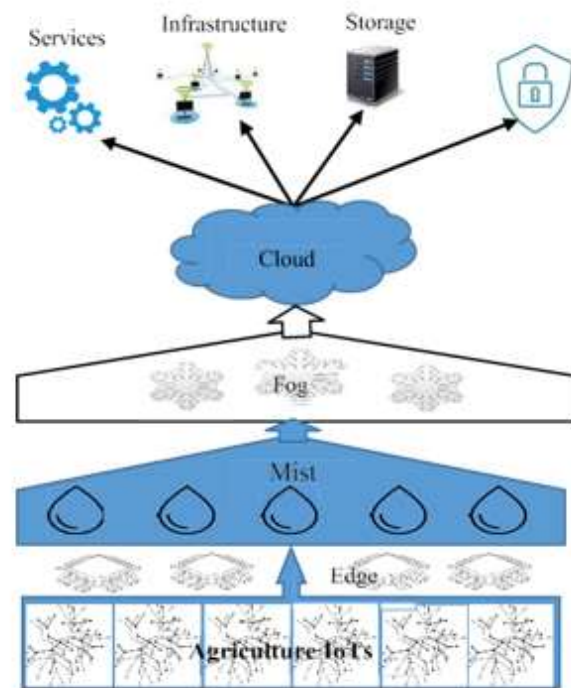


Figure 6: Fluid computing infrastructure for smart farming

### B. Laird's Sentrius

A battery-powered and long-range integrated sensor platform that leverages the benefits of LoRaWAN and Bluetooth Low Energy (BLE) connectivity. It provides LoRaWAN options at 868/915 MHz, based on the Semtech SX1272 and NordicnRF51 silicon. Further, it offers high RF performance in a precise temperature and humidity. Two major series, including RS1xx and RG1xx (multi-wireless gateways), work together in order to provide Cloud-based services. Most importantly, it requires an inexpensive endpoint radio and a more sophisticated base station to manage the network. As compared to LoRa, Sigfox communication tends to be better if it is headed up from the endpoint to the base station. Although it supports the bidirectional functionality, its capacity going from the base station back to the endpoint is constrained, as it provides less link width going down than going up.

### C. CCP SMART TAG (RC4)

CCP claims to be a complete monitoring solution for the food service and food retail industry. It is capable to automate the temperature environment which meets the food safety regulations suggested for various food items. Further, temperature and other data are interpreted and viewed on a service provider Cloud platform via web and mobile applications.

### D. Tempreporter

In compliance with HACCP (Hazard Analysis and Critical Control Points), it is used to monitor temperatures 24/7. Further, it logs the readings automatically. Reports are auto-filled by considering HACCP & HPR (Health Products Regulatory Authority) recommendations regarding temperature monitoring. According to Finisterre Ventures report, as of 2018, around \$2 billion has been invested globally in AgTech. Several investments are expected to cross these figures in 2019. Considering the future needs of IoT in agriculture applications, almost all leading technological giants are supporting this progress in their own way. Table 5 provides a list of several of the leading global organizations who have proposed and are proposing in AgTech especially in regard to IoT-based agriculture solutions.

resultant systems will converge into a single unit where farm machinery and management, starting from seeding to production forecasting, are combined. By involving the advanced technologies like agricultural robots, Big Data, and cloud-computing artificial intelligence, agriculture can create a new era of super fusion. Following is some of the key technologies and methods that need to apply; focusing to achieve sustainable future agriculture.

## VII. CURRENT CHALLENGES AND FUTURE EXPECTATIONS

Figure 7 presents a snapshot of major challenges that future agriculture expected to face in 2050. This diagram, basically presents three major issues: how to feed around 10 billion people; without using more land and; by reducing the emission of greenhouse gasses by more than 60%. However, when we look closely then these three challenges lead to many new, including smaller rural labor, continuously shrinking arable land, water scarcity, harsh weather conditions, and many more. As the world moves toward urbanization, the rural populations are not only shrinking but are rapidly aging; hence, fewer and younger growers need to step up to take the responsibility.

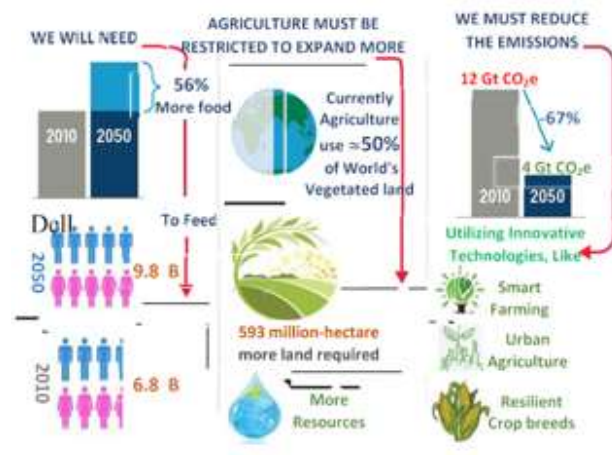


Figure 7. Major challenges for sustainable future agriculture.

Considering this scenario, future agriculture is expected to evolve as a high-tech industry where interconnected systems will enjoy the luxury of artificial intelligence and Big Data facilities. The

### A. Wireless Sensors and the IOT

Wireless sensors placed strategically around fields are providing farmers with up-to-date information in real time, allowing them to adapt the care that the crops need, which results in higher food production with less waste. Wireless sensor networks (WSNs) are also being used to inform farmers about nearly all aspects of their crop growth as well as about the readiness state of the farm's machinery, thus, helping in preventing loss of crop as well as enhancing the readiness of the equipment which cultivates it. WSNs with GPS capability are helping tractors in compensating for uneven terrain and optimizing land preparation for growing crops. Recently, advances in image recognition and digital signal processing gave even more capabilities to WSN to accurately determine crop quality and health.

Further, the future of the IoT can be shaped by the phenomenal advances in WSNs and the fifth generation (5G) of cellular mobile communication technologies to provide farmers with real-time data and information anytime and everywhere. their land is. Based on recent success, it is estimated that more than 75 million IoT-based devices will be operating in the agriculture industry by 2020. Further, the average farm is expecting to generate 4.1 million data points on a daily basis by 2050. Further, the future of the IoT can be shaped by the phenomenal advances in WSNs and the fifth generation (5G) of cellular mobile communication technologies to provide farmers with real-time data and information anytime and everywhere. their land is. Based on recent success, it is estimated that more than 75 million IoT-based devices will be operating in the agriculture industry by 2020. Further, the average farm is expecting to generate 4.1 million data points on a daily basis by 2050.

### **B. Communication**

The success of cellular technology is only possible when service providers leverage its real benefits like portability, flexibility and luxury of two-way communication to offer low cost but customized solutions. They must provide what the farmer is in need, at the place they choose. Furthermore, to provide fast penetration in agriculture industry, policy changes are required in order to provide access of reliable and quality inputs. The research conducted in which considers 23 studies where mostly belong to developing countries, concludes that the cellular services and smartphone technology carry a promising future for smallholder farmers being capable to improve their yields. Believing in its future success, it is expected that leading cellular operators with strong IoT ambitions can generate significant revenues by providing smart agriculture services when collaborating with LPWA technology providers.

In order to achieve long term success of these short, mid and long-range communication technologies, necessary steps for infrastructure construction are required towards attaining the technology-based agriculture.

### **C. UAVs and other Robots**

Drones are being widely used by farmers for crop growth monitoring and as a means to combat hunger and other harmful environmental impacts. Furthermore, they are being used to spray water and other pesticides efficiently, considering the tough terrains, especially when the crops possess different heights. Drones have proven their value, not only in terms of spraying speed but precision, as well, when compared with traditional machinery of same purpose. With recent advances in swarm technology and mission-based control, groups of drones equipped with heterogeneous sensors, including 3D cameras, can work together to provide farmers with comprehensive capabilities to manage their land. With the inclusion of UAVs in agriculture, farmers are able to put their eye in sky, but many challenges need to be addressed in order to enjoy the real advantages of this technology, especially the integration of other technologies and how to use them in poor weather conditions. Harmful environmental impacts. Furthermore, they are being used to spray water and other pesticides efficiently, considering the tough terrains, especially when the crops possess different heights.

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### **D. Machine Learning and Analytics**

Machine learning and analytics are used to mine data for trends. In farming, machine learning is used, for example, to predict which genes are best suited for crop production. This has been giving growers all over the world the best seed varieties, those which are highly suitable to respective locations and

climate conditions. Machine-learning algorithms, on the other hand, have indicated which products are of high demand and which products are currently unavailable in the market. Thus, for the farmer, this has given valuable clues for future farming. Recent advances in machine learning and analytics will make it possible for farmers to accurately classify their products and weed out less desirable crops before they arrive to customers.

#### **E. Power Consumption, Renewable Energy, Microgrids, And Smart Grids**

Despite its future opportunities, smart agriculture facing some limitations that are holding back the growth of IoT. Recent advances in energy storage devices, integrated electricity and heat systems will make DER even more attractive for farmers, as they will be able to store energy and use the heat generated by cooling and heating when needed. However, healthy investment requirements and public perceptions are two other barriers on the way to making these solutions successful.

#### **F. Hydroponics and Vertical Farming (VF)**

Other than employing the advanced technologies, new agricultural practices can be very crucial to overcome the geo- graphic and resource limitation challenges. On one side, arable land is shrinking, and, at the same time, it is estimated that three million people around the globe are migrating to cities, resulting in more pressure on the existing limited urban resources. Considering this rapid migration, it is estimated that by 2030, 60% of the world's population is going to depend on cities, and this number is further expected to rise to 68% until 2050. Considering both of these issues, it could be disaster for food production in the near future with current agriculture practices. VF is an answer of these issues, as it meets the challenges of land and water shortage and, at the same time, looks highly suitable to be adopted near the cities. VF is portrayed as the answer to the looming shortage of food and shrinking arable land, at least in some areas of the world. Further, hydroponics can play a key role, as this method lowers the requirements of water and space to a great extent. Rapid growths in computer power are propelling scientific discoveries in plant nutrition and

growth that would make VF even more appealing to growers.

Sensible use of technology can lead us where we can utilize these resources efficiently in order to ensure the food security of the current and coming generations. For this purpose, we need collective efforts to build such institutions that can shape long-term decisions and policies to eliminate hunger effectively. On this route, the experience, tools, and support from those nations that have succeeded in overcoming hunger should provide to those regions that are fighting to feed its local mouths. Although growth in every industry matter, growth in agriculture, particularly among small growers, can be highly effective to control the undernourishment issues, as more than 70% of the population of developing countries belongs to rural areas and somehow depends on agriculture sector.

### **VIII. CONCLUSION**

The focus on smarter, better, and more efficient crop growing methodologies is required in order to meet the growing food demand of the increasing world population in the face of the ever-shrinking arable land. The development of new methods of improving crop yield and handling, one can readily see currently: technology-weaned, innovative younger people adopting farming as a profession, agriculture as a means for independence from fossil fuels, tracking the crop growth, safety and nutrition labeling, partnerships between growers, suppliers, and retailers and buyers. This paper considered all these aspects and highlighted the role of various technologies, especially IoT, in order to make the agriculture smarter and more efficient to meet future expectations.

For this purpose, wireless sensors, UAVs, Cloud-computing, communication technologies are discussed thoroughly. Furthermore, a deeper insight on recent research efforts is provided. In addition, various IoT-based architectures and platforms are provided with respect to agriculture applications. A summary of current challenges facing the industry and future expectations are listed to provide guidance to researchers and engineers. Based on all

this, it can be concluded that every inch of farmland is vital to maximize crop production. However, to deal with every inch accordingly, the use of sustainable IoT-based sensors and communication technologies is not optional, it is necessary.

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