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Internet of things for smart agriculture: Technologies, practices and future direction

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Abstract. The advent of Internet of Things (IoT) has shown a new direction of innovative research in agricultural domain. Being at nascent stage, IoT needs to be widely experimented so as to get widely applied in various agricultural applications. In this paper, I review various potential IoT applications, and the specific issues and challenges associated with IoT deployment for improved farming. To focus on the specific requirements the devices, and wireless communication technologies associated with IoT in agricultural and farming applications are analyzed comprehensively. Investigations are made on those sensor enabled IoT systems that provide intelligent and smart services towards smart agriculture. Various case studies are presented to explore the existing IoT based solutions performed by various organizations and individuals and categories according to their deployment parameters. Related difficulties in these solutions, while identifying the factors for improvement and future road map of work using the IoT are also highlighted.

Keywords: Internet of things, smart agriculture, precision agriculture

1. Introduction

Modern day agriculture and civilization together demand increased production of food to feed the global population. New technologies and solutions [11,34,39] are being applied in agricultural domain to provide an optimal alternative to gather and process information [7] while enhancing net productivity. At the same time, the alarming climate change and increasing water crisis [27] demand new and improved methodologies for modern age agricultural and farming fields. Automation and intelligent decision making are also becoming more important to accomplish this mission [22,68]. In this regard, Internet of Things (IoT) [1,21,44,46–51, 53,57,59], ubiquitous computing, wireless ad-hoc and sensor networks [14,31,33,66,78], Radio Frequency Identifier [55], cloud computing [12,38], remote sensing [6,35], etc. technologies are becoming increasingly popular.

1.1. *Motivation*

Various motivational factors have influenced to script this article as mentioned below.

– Among others, the agriculture domain is mostly explored area of concerning the application of IoT in improving the traditional methods of farming [79]. The rapid growth in nanotechnology that took place in last decade, has enabled the creation of small and cheap sensors.
– The self contained nature of operation, together with modular sized hardware platforms, scalable, and cost-effective technologies, has enabled the IoT as a potential tool towards the target of self-organized, decision making, and automation in the agriculture cum farming industry. In this regard, precision agriculture [5,10,15], automated irrigation scheduling [54], optimization of plant growth [25], farm land monitoring [13], green-house monitoring [32,61], and farming production process management [16] in crops, are among a few key applications.
– However, IoT is in nascent stage of development, hence it has a few limitations such as interoperability, heterogeneity, memory constrained hardware platforms, and security.
– These limitations invite challenges in the design of IoT applications in agriculture. In agriculture,

most of the IoT based applications are targeted for various applications. For example, IoTs for environmental condition monitoring with information of soil nutrients is applied for predicting crop health and production quality over time. Irrigation scheduling is predicted with IoTs by monitoring the soil moisture and weather conditions.

– Being scalable, the performance of an existing IoT based application can be improved to monitor more parameters by only including additional sensor nodes to the existing architecture.
– The issues present in such applications are centered on the device interoperability, technology heterogeneity, security, measurement interval, and routing protocols.
– In the overall scenario, the IoT based farming solutions need to be of very low cost to be affordable by end users. However, with the increasing population, the demand of food-grain is exponentially rising. A recent report warns that the growth in food grain production is less than the growth in population [60]. This has led the researchers to demand to boost production by incorporating advanced technologies. As per a recent report published by Food and Agriculture Organization [18], food grain requirements in world shall touch 3 billion tons by 2050. Consequently, new and modern technologies are being considered in many agricultural applications to achieve the target. This pace needs to be accelerated by incorporating IoT while making the agriculture smart and definite in nature.

1.2. Contribution

In this paper, important agricultural applications are highlighted, and applicability of IoT towards improved performance and productivity are discussed. Characteristics of IoT are presented. Usable hard ware platforms, wireless communication technology standards, and IoT cloud services for agricultural applications are analyzed. Various sensor based IoT systems also listed in this paper. Author also reviews and studies the existing IoT deployments in multiple domains. In summary, the contributions of this paper are listed as follows.

– Study of definition, functional blocks, IoT agricultural framework, and utilities of IoT.
– Analysis of the existing IoT deployments with respect to communication technologies, hardware platforms, and IoT cloud services.
– Investigation of the problems of the existing agricultural applications with IoT based case studies for global scenario.
– Highlighting the various important factors for improvements for the existing scenarios and present future road map.

This paper is organized as follows. Section 2 deals with IoT and its potential agriculture based applications. IoT supported technologies are discussed in Section 3. IoT based agricultural sensor systems are reviewed in Section 4. Section 5 points out few case studies. Section 6 elaborates about challenges and prescribes future road map. Section 7 concludes the paper.

2. Design of IoT and its potential for agricultural applications

2.1. IoT definition

Internet of Things (IoT) refers to the implementable Machine-to-Machine (M2M) communications which is a crucial component of recent growth in the digital market. IoT is has been described by various notions such as

– “a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual ’Things’ have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network” [30].
– “3A concept: anytime, anywhere and any media, resulting into sustained ratio between radio and man around 1:1” [67].
– IoT combines people, process, device and technology with sensors and actuators. This overall integration of IoT with human being in respect to communications, collaboration and technical analytics enables to pursue real-time decision [20].
– “Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts” [26].

The most acceptable definition is given by Smith [65] which is as below.

– “A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network, often communicate data associate with users and their environments".

2.2. IoT functional blocks

An IoT system is comprised of a number of functional blocks to facilitate various utilities to the system such as, sensing, identification, actuation, communication, and management [2]. Figure 1 presents these functional blocks as described below.

– Device: An IoT system is based on devices that provide sensing, actuation, control, and monitoring activities. IoT devices can exchange data with other connected devices and application, or collect data from other devices and process the data either locally or send the data to centralized servers or cloud based applications backends for processing the data, or perform some tasks locally and other tasks within IoT infrastructure based on temporal and space constraints (i.e., memory, processing capabilities, communication latencies, and speeds, and deadlines). The structure of device is given in Fig. 2 [2]. An IoT device may consist of several interfaces for communications to other devices, both wired and wireless. These include (i) I/O interfaces for sensors, (ii) interfaces for Internet connectivity, (iii) memory and storage interfaces and (iv) audio/video interfaces. IoT devices can also be of varied types, for instance, wearable sensors, smart watches, LED lights, automobiles and industrial machines. Almost all IoT devices generate data in some form of the other which when processed by data analytics systems generate leads to useful information to guide further actions locally or remotely, For instance, sensor data generated by a soil moisture monitoring device in a garden, when processed can help in determining the optimum watering schedules.
– Communication: The communication block performs the communication between devices and remote servers. IoT communication protocols generally work in data link layer, network layer, transport layer, and application layer. The details regarding the protocols have been discussed in Section 3.2.
– Services: An IoT system serves various types of functions such as services for device modeling, device control, data publishing, data analytics, and device discovery.
– Management: Management block provides different functions to govern an IoT system to seek the underlying governance of IoT system.

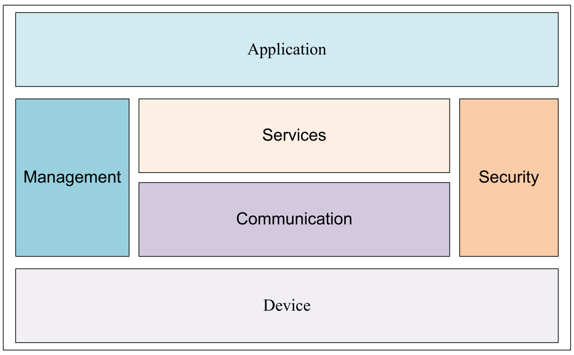


Fig. 1. Functional blocks of IoT.

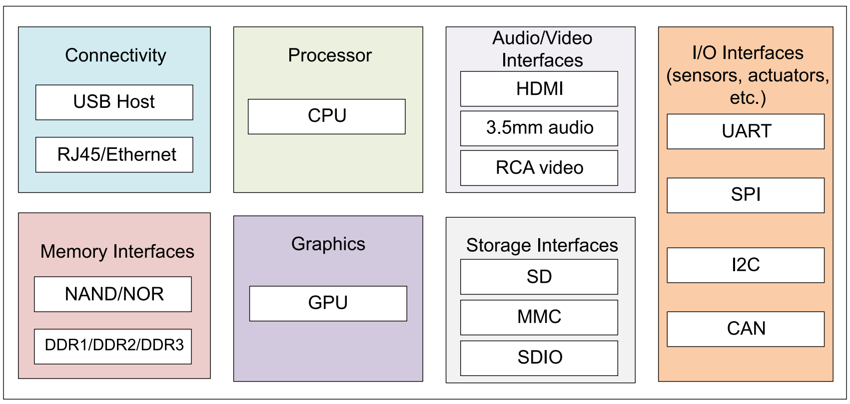


Fig. 2. Block diagram of an IoT device.

– Security: Security functional block secures the IoT system by providing functions such as, authentication, authorization, privacy, message integrity, content integrity, and data security.
– Application: Application layer is the most important in terms of users as it acts as an interface that provides necessary modules to control, and monitor various aspects of the IoT system. Applications allow users to visualize, and analyze the system status at present stage of action, some times prediction of futuristic prospects.

2.3. *IoT agriculture framework*

This section provides a detailed framework to cater full fledged agricultural-solutions using IoT (Fig. 3). The presented framework is a six layered concept which includes hardware facilities, Internet and allied communication technologies, IoT middleware, IoT enabled cloud services, big data analytics, and farmer experience in full notion.

– Physical Layer: This is the bottom most layer that comprises of different types of sensors, actuators, microcontroller modules, and other network equipments such as gateways, router, switches etc. Sensing of environment parameters, actuating according to the predefined tasks, and processing the whole ground level jobs are done here. Microcontroller is key part of this layer which holds the supervisory role over the networking related functionalities and other op-

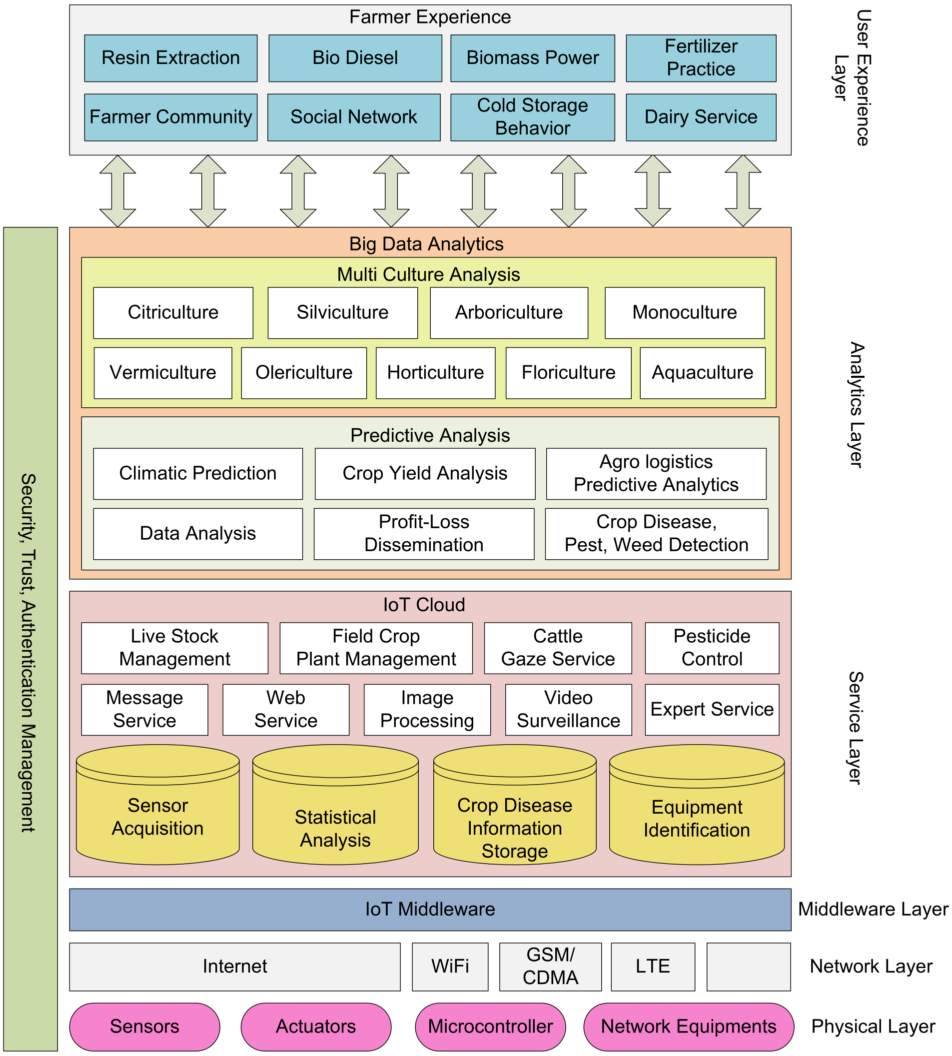


Fig. 3. IoT based Agricultural Framework.

erations (done by sensors and actuators). Transferring the processed root-level data to higher abstraction layers is the main task of this layer.

- Network Layer: This layer comprises of Internet and other relevant communication technologies. Wi-Fi, GSM, CDMA, LTE (4G) technologies are prevalent to act in agricultural fields in appropriate manner. ZigBee is one of the most suitable enablers that sorts out the long range communication when none of the GSM/CDMA/LTE services are present. HTTP, WWW, SMTP protocols suits the pavement of Internet facility in agricultural scenario.
- Middleware Layer: IoT based middleware do perform device management, context awareness, interoperation, platform portability, and security related tasks [3]. Various types of middleware are such as HYDRA, UBIWARE, UBIROAD, and SMEPP are best at context aware functionality; on other hand, SOCRADES, GSN, SIRENA etc. are good at implementing security and user privacy in their architecture.
- Service Layer: IoT cloud assisted service layer plays crucial role in providing cloud storage and Software-as-a-Service (SaaS) to agricultural problems. Sensor data acquisition, equipment identification, crop disease information storage, and statistical analysis services are paved to facilitate the sensing, actuating, and disease identification activities. Besides, live stock management, field crop plantation management, pesticide control, automatic cattle gaze monitoring services are meant to create value from agriculture data. Farmer can get information through web service, message service, and expert services. Image and video analysis of the received data help in real time monitoring of on demand services. For instance, farmer wants to know about the cattle gazing in the field, soil condition by virtual imagery, and insect intrusion in to the fields etc. User friendly, web based control panel leverages all the necessary requirements from the farmer side to solve through numerous services.
- Analytics Layer: In this layer, big data processing is performed to necessitate predictive analysis and multi cultural analytics. Prediction is meant for measuring probabilistic chance of yield productivity in next season. Farmer may know about the futuristic climatic condition of the filed area including soil moisture, temperature, heat, light intensity, rain fall etc in advance. This results in taking precaution to save crop field. Detection capability is provided here to predict the probable situation of occurrence various crop disease based on the past data. Farmer can understand the behavior and pattern of pest attack and weed origination in the field. Agro-logistics facility has been added to predict the optimized cost for maintenance of the vehicles such as tractors etc. and how these vehicles are used to increase the profit margin by selling the products in the market. This has a strong impact on the retention ratio of crop and vegetables as a large percentage get rotten due to lack of utilization in timely manner. Prediction may also be used to know about the profit or loss statement that may happen in coming season. Hence, big data analytics is suitable for agricultural aspects to minimize several risk factors in scientific way. One important level of multi culture analytics is also introduced into the framework to formulate, process, and efficiently manage a few forms of farming. Aquaculture may be equipped with big data analytics to ascertain the growth rate of water featured botanics. The same could be initiated to predict the fish breeding, and growth in pisciculture. Horticulture, floriculture, and citriculture when enabled with big data analytics may get direct benefit of decision making regarding seasonal growth, pest control, and profit margin analysis for fruits, flowers, and citric fruits such as lemon etc. Vermiculture is used to rear or cultivate of earthworms. Vermicompost is an organic fertilizer that is originated after vermiculture. Forest being important part of human life, silviculture may be efficiently practiced to control the establishment, growth, composition, health, and quality of forests to validate various needs of population. Big data can enhance the forest growing process by utilizing environmental data analysis. Arboriculture is a special form of cultivation that is related to shrubs, vines, and other perennial woody plants. Big data analytics could be implied over it to know how these plants grow and respond to their environment through statistical modeling. Olericulture has the capacity to predict the growth rate of vegetable plants for food consumption of human society. Big data analytics may help in simulating the water needs, along with temperature and proper fertilization to enhance the productivity of herbaceous plants.

– User Experience Layer: This is the top most layer which is totally designed for farmer's own experience. This layer facilitates the farmer to communicate with the community members using social network activities to inform and disseminate the knowledge of various features of agricultural domains stating from politics, to economics. Cold storage is used to store the crops for consumption in multiple seasons. Behavioral study and pattern analysis of cold storage could uplift the profit generation to the farmer. Farmer is empowered with identifying the appropriateness about the fertile selection for the effective growth of the crops. Besides, a few industrial applications are also integrated with this layer. Resin extraction from trees could always be attached with the IoT framework to know the pattern of resin production among the tree, this may result in collective practice of scientific application while making high revenue generation. Dairy services such as milk production, filtering of milk, marketing, control of disease of cattle etc. shall be merged with the IoT framework to earn huge gain in terms of money and prosperity. Power generation from tree and crops has become an alternative to the conventional energy sources such as hydro, thermal, and nuclear etc. Bio mass power generation could be leveraged with IoT framework while connecting, managing, and monitoring of power consumption using smart grids. Bio diesel is a source of a renewable energy that is a form of a biodegradable fuel. Bio diesel can be manufactured from vegetable oils and other sources such as animal fats, or recycled restaurant grease. Bio diesel generation, consumption, and dissemination may be monitored and controlled using IoT framework.

2.4. *Utilities of IoT*

IoT may be characterized as the holder of key utility factors as given below [71].

– Dynamic and self adapting: IoT devices and systems should have the capability to dynamically adapt with the changing contexts and take actions based on their operating conditions, user's context, or sensed environment. For example, consider a surveillance system comprising of a number of surveillance cameras. The surveillance cameras can adapt their modes (to normal or infra-red night modes) based on whether it is day or night. Cameras could switch from lower resolution to higher resolution modes when any motion is detected and alert nearby cameras to do the same. In this example, the surveillance system is adapting itself based on the context and changing (e.g., dynamic) conditions.
– Self-configuring: IoT devices may have self-configuring capability, allowing a large number of devices to work together to provide certain functionality (such as weather monitoring). These devices have the ability to configuring themselves (in association with IoT infrastructure), setup the networking, and fetch latest software upgrades with minimal manual or user intervention.
– Interoperable communication protocols: IoT devices may support a number of interoperable communication protocols and can communicate with other devices and also with the infrastructure.
– Unique identity: Each of IoT device has a unique identity and unique identifier (such as IP address or URI). IoT systems may have intelligent interfaces which adapt based on the context, allow communicating with users and environmental contexts. IoT device interfaces allow users to query the devices, monitor their status, and control them remotely, in association with the control, configuration and management infrastructure.
– Integrated into information network: IoT devices are usually integrated into the information network that allows them to communicate and exchange data with other devices and systems. IoT devices can be dynamically discovered in the network, by other devices and/or network, and have the capability to describe themselves (and their characteristics) to other devices or user applications. For example, a weather monitoring node can describe its monitoring capabilities to another connected node so that they can communicate and exchange data. Integration into the information network helps in making IoT systems "smarter" due to the collective intelligence of the individual devices in collaboration with the infrastructure. Thus, the data from a large number of concerned weather monitoring IoT nodes can be aggregated and analyzed to predict the weather.

– Context-awareness: Based on the sensed information about the physical and environmental parameters, the sensor nodes gain knowledge about the surrounding context. The decisions that the sensor nodes take thereafter are context-aware [19].
– Intelligent decision making capability: IoT multi-hop in nature. In a large area, this feature enhances the energy efficiency of the overall network, and hence, the network lifetime increases. Using this feature, multiple sensor nodes collaborate among themselves, and collectively take the final decision.

2.5. *IoT based agriculture applications*

This section presents the list of possible agricultural, farming and related applications that are currently being implemented using IoT.

– Irrigation management system: Modern day agriculture requires an improved irrigation management system to optimize the water usage in farming and related activities [45,62,70]. Four factors are popularly being used in smart irrigaton system such as, integration of real-time weather forecast data, control of farmer's system from anywhere in the world using home, enabling WiFi and Ethernet connection, adding syncronization with moisture sensors installed in farmer's yard, and reducing farmer's monthly bills while helping to conserve limited water resources. IoT is constantly getting popularlity in irrigation management related systems around the world.
– Pest and disease control: Controlled usage of pesticides and fertilizers helps increasing the crop quality as well as minimizing the farming cost. However, for controlling the usage of pesticides, we need to monitor the probability and occurrence of pests in crops. To predict this, we also need collecting disease and insect pest information using sensor nodes, data processing and mining, etc. with help of IoT infrastructure [75]. A three layered IoT architecture is proposed that may identify the disease occurred and take necessary actions to point out the responsible pest which has caused the disease. Farmer can imply upon the required medicine to save the corp.
– Cattle movement monitoring: A herd of cattle grazing a field can be monitored using IoT. Thus, real-time monitoring of any cattle is also achieved. [73] has demonstrated IoT based environmental control system for nursery pig.
– Dairy monitoring: IoT based cloud solutions, such as, Connecterra are being currently popular to monitor dairy in smart way. It is able to provide multiple behavior detection and predictions including animal heat & estrus cycles, health analysis and also provide a forward looking prediction of the next cycle start dates. Further, individual activity assessment and location aware functionalities can be added on top of the services.
– Water quality monitoring: Placing sensor nodes empowered with wireless communication help in monitoring the water quality. A recent article develops a real time monitoring of the water quality using IoT. The system measures physical and chemical parameters of the water such as, temperature, pH, turbidity, conductivity, dissolved oxygen. The sensor data is viewed on Internet using cloud services [42].
– Greenhouse condition monitoring: Greenhouse and agriculture are closely related to each other. Greenhouse gases are responsible for increasing the climate temperature, and thus has direct impact on agriculture. On the other hand, greenhouse gas emission depends on pH, temperature, CO_2, etc. HarvestGeek provides an IoT cloud based services to monitor the greenhouse condition remotely which can further be controlled by the user or by self autonomously.
– Soil monitoring: Soil property is crucial for agricultural domain. Knowledge of soil adds an advantage to the production of corps. [77] has incorporated 6LoWPAN technology with IoT to remotely aggregate the condition of soil while implementing various sensor nodes. SNMP is used to monitor the network in real time.
– Precision Agricultural by UAV: Agricultural precision can be obtained by utilizing advanced technologies such as, UAV and Drone, for productive outcome of the farm. PrecisionHawk (www.precisionhawk.com) enterprise leverages UAV, GIS and sensors enabled IoT cloud platform to deploy artificial intelligence through in-the-air flight path calculations for detection of weather conditions in the air. Further, in-flight diagnostics and monitoring processes continually monitor its own status while in flight and counts

on the operational weather/wind limitations, land mapping, and real time analytics supports.

– Agricultural means production supply chain management: Agricultural products need to be efficiently managed so that farmer can gain profit, hence the operating efficiency on it. Supply chain management on the argi-products can be monitored by IoT. [80] analyzes the application of IoT in product supply chain business processes, and the driving factor in the adoption of agricultural products by supply chain effects in IoT. It further provides a reference framework for the node enterprises of the product chain for necessary implications.

Research in traffic classification, which avoids payload inspection, has accelerated over the last five years. It is generally difficult to compare different approaches, because they vary in the selection of features (some requiring inspection of the packet payload), choice of supervised or unsupervised classification algorithms, and set of classified traffic classes. Further complicating comparisons between different studies is the fact that classification performance depends on how the classifier is trained and the test data used to evaluate accuracy. Unfortunately, a universal set of test traffic data does not exist to allow uniform comparisons of different classifiers.

3. IoT supported technologies used in agriculture

In this section, I discuss the details of the IoT technologies such as, hardware platforms, and wireless communication technologies used in various agricultural applications. Different IoT cloud service providers, which are being popular in the current market for use in these applications, are also studied.

3.1. Hard ware platform

A number of different IoT supported hardware platforms do exist for use in the agricultural domains. In Table 1, the existing platforms are classified according to key parameters.

3.2. Wireless communication standards

Communication Protocols form the backbone of IoT systems and enable network connectivity and coupling to applications. Communication protocols allows devices to exchange data over the network. The protocols define the data exchange formats, data encoding, addressing schemes for devices and routing of packets from source to destination. Other functions of the protocols include sequence control, flow control, and retransmission of lost packets. Table 2 compares different wireless communication technologies with respect to various parameters.

3.2.1. 802.11 – WiFi

IEEE 802.11 is a collection of Wireless Local Area Network (WLAN) communication standards. For example, 802.11a operates in the 5 GHz band, 802.11b and 802.11g operate in the 2.4 GHz band, 802.11n operates in the 2.4/5 GHz bands, 802.11ac operates in the 5 GHz band and 802.11ad operates in the 60 GHz band. Theses standards provide data rates from 1 Mb/s to 6.75 Gb/s. WiFi provides communication range in the order of 20 m (indoor) to 100 m (outdoor).

3.2.2. 802.16 – WiMax

IEEE 802.16 is a collection of wireless broadband standards. WiMAX (Worldwide Interoperability for Microwave Access) standards provide data rates from 1.5 Mb/s to 1 Gb/s. The recent update (802.16m) provides data rate of 100 Mb/s for mobile stations and 1 Gb/s for fixed stations. The specifications are readily available on the IEEE 802.16 working group website (IEEE 802.16, 2014).

3.2.3. 802.15.4 – LR-WPAN

IEEE 802.15.4 is a collection of Low-Rate Wireless Personal Area Networks (LR-WPAN) standards. These standards form the basis of specifications for high level communications protocols such as ZigBee. LR-WPAN standards provide data rates from 40 Kb/s to 250 Kb/s. These standards provide low-cost and low-speed communication doe power constrained devices. It operates at 868/915 MHz and 2.4 GHz frequencies at low and high data rates, respectively. The specifications of 802.15.4 standards are available on the IEEE802.15 working group website (IEEE 802.15, 2014).

3.2.4. 2G/3G/4G – mobile communication

There are different generations of mobile communication standards including second generation (2G including GSM and CDMA), third generation (3G-including UMTS ad CDMA2000) and fourth generation (4G-including LTE). IoT devices based on these standards can communicate over cellular networks. Data rates for these standards rage from 9.6 Kb/s (2G)

Table 1

Comparison of the existing IoT supported hardware platforms

Parameters	Arduino Uno	Arduino Yun	Arduino Nano	Intel Galileo Gen 2	Intel Edison	Beagle Bone Black	Electric Imp 003	Raspberry Pi B+	Raspberry Pi Zero	ARM mbed NXP LPC1768
Processor	ATMega328P	ATmega32u4, and Atheros AR9331	ATMega328/168	Intel® Quark™ SoC X1000	Intel® Quark™ SoC X1000	Sitara AM3358BZCZ100	ARM Cortex M4F	Broadcom BCM2835 SoC based ARM11 76JZF	Broadcom BCM2835 ARM11 core	ARM Cortex M3
GPU	–	–	–	–	–	PowerVR SGX530 @520 MHz	–	VideoCore IV® Multi media@ 250 MHz	–	–
Operating Voltage	5 V	5 V, 3 V	5 V	5 V	3.3 V	3.3 V	3.3 V	5 V	5 V	5 V
Clock Speed (MHz)	16	16, 400	16	400	100	1 GHz	320	700	1 GHz	96
Bus Width (bits)	8	8	8	32	32	32	32	32	32	32
System Memory	2 kB	2.5 kB, 64 MB	1 kB, 2 kB	256 MB	1 GB	512 MB	120 KB	512 MB	512 MB	32 KB
Flash Memory	32 kB	32 kB, 16 MB	16 kB, 32 kB	8 MB	4 GB	4 GB	4 MB	–	–	512 KB
EEPROM	1 kB	1 kB	512 B, 1 kB	8 kB	–	–	–	–	–	–
Communication Supported	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet, Serial
Development Environments	Arduino IDE	Arduino IDE	Arduino IDE	Arduino IDE	Arduino IDE, Eclipse, Intel XDK	Debian, Android, Ubuntu, Cloud9 IDE	Electric Imp IDE	NOOBS	NOOBS	C/C++ SDK, Online Compiler
Programming Language	Wiring	Wiring	Wiring	Wiring, Wyliodrin	Wiring, C, C++, Node.JS, HTML5	C, C++, Python, Perl, Ruby, Java, Node.js	Squirrel	Python, C, C++, Java, Scratch, Ruby	Python, C, C++, Java, Scratch, Ruby	C, C++
I/O Connectivity	SPI, I2C, UART, GPIO	SPI, I2C, UART, GPIO	SPI, I2C, UART, GPIO	SPI, I2C, UART, GPIO	SPI, I2C, UART, I2S, GPIO	SPI, UART, I2C, McASP, GPIO	SPI, I2C, UART, GPIO	SPI, DSI, UART, SDIO, CSI, GPIO	UART, SDIO, CSI, GPIO	SPI, I2C, CAN, GPIO

Table 2
Comparison of the existing communication technologies

Parameters	WiFi	WiMAX	LR-WPAN	Mobile Communication	Bluetooth	LoRa
Standard	IEEE 802.11 a/c/b/d/g/n	IEEE 802.16	IEEE 802.15.4 (ZigBee)	2G-GSM, CDMA.-3G-UMTS, CDMA2000, 4G-LTE	IEEE 802.15.1	LoRaWAN R1.0
Frequency Band	5 GHz–60 GHz	2 GHz–66 GHz	868/915 MHz, 2.4 GHz	865 MHz, 2.4 GHz	2.4 GHz	868/900 MHz
Data Rate	1 Mb/s–6.75 Gb/s	1 Mb/s–1 Gb/s (Fixed) 50–100 Mb/s (mobile)	40–250 Kb/s	2G: 50–100 kb/s 3G:200 kb/s 4G:0.1–1 Gb/s	1–24 Mb/s	0.3–50 Kb/s
Transmission Range	20–100 m	<50 Km	10–20 m	Entire Cellular Area	8–10 m	<30 Km
Energy Consumption	High	Medium	Low	Medium	Bluetooth: Medium BLE: Very Low	Very Low
Cost	High	High	Low	Medium	Low	High

to 100 Mb/s (4G) and are available from the 3GPP websites.

3.2.5. 802.15.1 – BlueTooth

Bluetooth (http://www.bluetooth.org) is based on the IEEE 802.15.1 standard. It is a low power, low cost wireless communication technology suitable for data transmission between mobile devices over a short range (8–10 m). The Bluetooth standard defines a personal area network (PAN) communication. It operates in 2.4 GHz band. The data rate in various versions of the Bluetooth ranges from 1 Mb/s to 24 Mb/s. The ultra low power, low cost version of this standard is named as Bluetooth Low Energy (BLE or Bluetooth Smart). Earlier, in 2010 BLE was merged with Bluetooth standard v4.0.

3.2.6. LoRaWAN R1.0 – LoRa

LoRaWAN (https://www.lora-alliance.org) is a recently developed long range communcation protocol designed by the LoRa™ Alliance which is an open and non-profit association. It defines Low Power Wide Area Networks (LPWAN) standard to enable IoT. Mainly its aim is to guarantee interoperability between various operators in one open global standard. LoRaWAN data rates range from 0.3 kb/s to 50 kb/s. LoRa operates in 868 and 900 MHz ISM bands. According to Postscapes (http://postscapes.com/long-range-wireless-iot-protocol-lora) LoRa can communicates between the connected nodes within 20 miles range, in unobstructed environments. Battery life for the attached node is normally very long, up to 10 years.

3.3. *Cloud solutions*

IoT cloud solutions pave the facilities like real time data capture, visualization, data analytics, decision making, device management etc. tasks through remote cloud servers implying pay-as-you. Various cloud service providers are becoming gradually popular in the agriculture cum farming market. Some of the vendors are surveyed and compared based on some parameters in Table 3.

4. IoT based agriculture sensor systems

In this section, various commercial agriculture sensor systems are discussed. Table 4 compares between sensor systems with respect to a number of parameters.

4.1. *Automated hydroponics: Bitponics*

Bitponics [8] is a project that automates home plant growing via the stand alone sensor device and backend web service. The system works by first entering the details of type of plant and hydroponic system that he/she wants to grow. The service than takes this information to generate a custom growing plan that details out: (1) number of hours of light the plants need per day and time to change its schedule, (2) safe pH

Table 3
Comparison of the IoT cloud platforms

IoT Cloud Platforms	Real Time Data Capture	Data Visualization	Cloud Service Type	Data Analytics	Developer Cost
Xively (https://xively.com/)	Yes	Yes	Public (IoTaaS)	No	Free
ThingSpeak (https://thingspeak.com/)	Yes	Yes (Matlab)	Public	Yes	Free
Plotly (https://plot.ly/)	Yes	Yes (IPython, Matlab, Rstudio)	Public	Yes	Free
Carriots (https://www.carriots.com/)	Yes	Yes	Private (PaaS)	No	Limited up to: 10 devices
Exosite (https://exosite.com/)	Yes	Yes	IoTSaaS	Yes	2 devices
GroveStreams (https://grovestreams.com/)	Yes	Yes	Private	Yes	Limited up to: 20 stream, 10,000 transaction, 5 SMS, 500 Email
ThingWorx (www://thingworx.com/)	Yes	Yes	Private (IaaS)	Yes	Pay per use
Nimbits (www.nimbits.com/)	Yes	Yes	Hybrid	No	Free
Connecterra (www.Connecterra.io/)	Yes	Yes	Private	Yes	Pay per use
Axeda (www.axeda.com)	Yes	Yes	Private	Yes	Pay per use
Yaler (https://yaler.net)	Yes	Yes	Private (CaaS)	Yes	Pay per use
AMEE (www.amee.com)	Yes	Yes	Private	Yes	Pay per use
Aekessa (www.arkessa.com)	Yes	Yes	Private (CaaS)	Yes	Pay per use
Paraimpu (https://www.paraimpu.com/)	Yes	Yes	Hybrid	No	Limited up to: 4 things, 500 data items/thing
Phytech (http://www.phytech.com/)	Yes	Yes	Private	Yes	Pay per use

range for the plant, and (3) needs to run water pumps. The Bitponics device then monitors the setup using its sensors such as, water, air, temperature, humidity, and brightness, pH etc. Later on, it logs this data to user's online account for review and to make modifications over time. The device features two power outlets that may be controlled over Internet to manage any related parameters. The service free to a user limited by 50 logs per day, upload and share of 500 photos per day, alert notification by email, and 6 months storage for free.

4.2. *Botanicalls*

Botanicalls [9] is an IoT supported device that opens a new channel of communication between plants and humans. The project empowers plants that might otherwise be neglected, with the ability to call and text message people to request assistance. It connects users via Twitter status updates. As an example, when the plant needs water, it posts on its pal's account on social networking site in form of message. It is enabled by AT Mega368 microcontroller and can be made by DIY manner.

4.3. *Edyn*

Edyn [17] is a solar-powered smart garden monitor system. It includes sensors like soil, light, humidity, temperature, moisture, and acidity to provide best recommendations to the gardener for necessary actions to

Table 4
Comparison of the IoT sensor systems

Parameters	Location	Sensors	IoT Enabled	Cloud Supported	APP Based	Application Type
Bitponics	Indoor	Water/Air Temperature, Humidity, pH, Brightness	Yes	Yes	No	Irrigation
Botanicalls	Indoor/ Outdoor	Air Temperature, Humidity, Brightness, Soil Moisture	Yes	No	No	Garden
Edyn	Outdoor	Temperature, Light, pH, Soil Moisture, Soil Humidity	Yes	Yes	Yes	Irrigation
Parrot	Indoor/ Outdoor	Temperature, Light, pH, Soil Moisture, Soil Salinity	No	No	Yes	Garden
PlankLink	Indoor/ Outdoor	Soil Moisture	Yes	Yes	Yes	Irrigation
HarvestGeek	Indoor	Temperature, Light, pH, Soil Moisture, CO_2	Yes	Yes	Yes	Garden, Irrigation
Iro	Outdoor	–	Yes	No	Yes	Irrigation
Spruce	Outdoor	Temperature, Soil Moisture	Yes	No	Yes	Irrigation
Open Garden	Indoor/ Outdoor	Temperature, Humidity, Light, pH, Soil Moisture, Conductivity	Yes	Yes	Yes	Garden, Irrigation, Aquaponics
Koubachi	Indoor	Soil Moisture, Air Temperature, Soil Temperature, Ambient Light	Yes	Yes	Yes	Irrigation
Niwa	Indoor	Temperature, Humidity, Light	Yes	Yes	Yes	Aquaponics

be taken such as, type of fertilizer to use, amount of water to be poured etc. The system is based on a water valve that hooks up to the hose connected to the sprinkler system to automatically maintain the right moisture levels without overwatering. Once planted, the attached soil probe seeks various properties of soil. The data is then streamed over Internet to the Edyn cloud service. The cloud provides services to analyze and compare to the stored database of various plants and find their ideal growing conditions. Gardener can access the results from the cloud on a mobile app that provides a real time status of the garden's health. The moisture level is compensated with the appropriate amount of water using the valve.

4.4. Parrot: Flower power

Parrot [41] is a Bluetooth 4.0 enabled integrated sensor system that monitors and analyzes the four parameters such as, sun light, ambient temperate, fertilizer, and soil moisture essential to a plant's health. Parrot comes in form of a plastic stalk that measures plant's temperature, humidity, and soil salinity levels in a precise manner. Later, its sends this data to the user's smart phone or tablet.

4.5. Plantlink

PlantLink [43] is a system consists of a wireless sensor "Links" that measures soil moisture levels. The measured data is then sent to a base station connected to gardener's home router. The system is also attached with automatic watering valves. The system communicates to the router via Zigbee and store the information to a PlantLink cloud server. The cloud provides services to help gardener to track the plants' conditions, schedule automatic watering times, and alerts when plants are in need of water. Gardener find s all the related notifications, and via email and sms.

Soil moisture readings are taken every 5–10 minutes. When creating your plant watering schedule the system will adjust to your local weather patterns and is optimized based on a database full of different types of plants watering needs that you can select from.

4.6. HarvestGeek

HarvestBot [23] is an electronic device that is equipped with sensors like air temperature, soil moisture, ambient light, CO_2 ppm level etc. meant to monitor the vitals of the garden and communicates the information back to the cloud servers. HarvestBot allows gardener to gather information in real-time. Individual unit is specialized for own task and provides the versatility to be used in large commercial indoor operations. Upon the analysis at the server end, HarvestBot need to control actuators attached. Gardener gets alerts and information of various facts of the garden through email, or push notification on smart phones or tablets.

4.7. WiFi sprinkler system: Iro

Iro or Rachio [76] is an irrigation controller designed to automate sprinkler controller. It is consists of a WiFi controlled smart device that the user can manage remotely from anywhere in the world. User is also leveraged with automatic adjustments of its settings based on the expected weather conditions obtained local weather stations or Internet.

4.8. Spruce

Spruce [64] is a zone specific irrigation controller device. Spruce has temperature and soil moisture sensors attached on it, which senses the present condition of soil and sends the data to the cloud server in real-time. Plants receive appropriate amount of water for necessary time period. User can seek the status on the smart phone any where.

4.9. Open garden

Open Garden [40] is a DIY device that is capable to perform in all the three scenarios: indoor (houses and greenhouses), outdoor (gardens and fields), and hydroponics (plants in water installations). The central component of Open Garden is a multi-communication technology enabled gateway that uploads the data to a web server via WiFi, GPRS, or 3G. The nodes can communicate each other using 433 MHz wireless radios. By attaching sensors to nodes, the user can collect data on air temperature, humidity, light levels, soil moisture (indoor/outdoor installations) or the temperature, pH, and conductivity (hydroponic installation) growing medium. The system enables the user to visualize real-time data of all the sensors online. The device is attached with various kinds of actuators such as, water pump and dropper (indoor), electric valve and sprinkler (outdoor), and oxygen pump and growing light (hydroponics). Basic knowledge of web programming can help the user to program the system to operate on an automatic schedule.

4.10. Koubachi

Koubachi [29] is an APP oriented automated water sprinkler system that waters the plants of the garden in an optimized way. Air temperature, soil temperature, ambient light, and soil moisture etc. sensors are attached to it. Koubachi is connected with the water valves to the hose pipes through the tap and sprinkles as and when required by the soil. An internet-connected gateway that lives in the home of the gardener connects to the Koubachi cloud servers over 6LoWPAN, a wireless networking protocol designed for low-power personal communications between devices. User can add as many as soil sensors or watering controllers to make a mesh. This topology enables each device to act as transceiver. The real-time data sent to the cloud, automatically controls the valves. User can find out the status of the garden from the smart phone or tablets at any point of time from any where of the world.

4.11. Niwa

Niwa [37] is an indoor smart hydroponic system that user can install at home at inbuilt container box. No explicit yard, or garden is required. Niwa is enabled by WiFi connectivity with the cloud servers via Internet. User can get intimation of what the plants want.

Table 5
Deployment Parameters [24]

Parameter	Value
Microcontroller Board	AT Mega328
Temperature Sensor	DS18B20
Gateway	Raspberry Pi
Battery	12 V lead acid
Power	Solar PV Panel 12 V
Communication	ASK 433 MHz RF
Range	$<$50 m

Hydropoinc system, water level, and heater system of Niwa can automatically be monitored from user's App installed in the smart phone. Light, ventilation, and humidity components are controlled remotely by user or cloud services.

5. Case studies

In this section, I present a few cases where IoT has performed tremendously to enhance the qualitative value in agriculture cum farming domain. IoT is being popular in various agricultural fields such as, bee keeping, green house service platform, wheat disease detection, tomato pest control, UAV based precision agriculture, etc.

5.1. Case study 1: Honey bee hive monitoring project

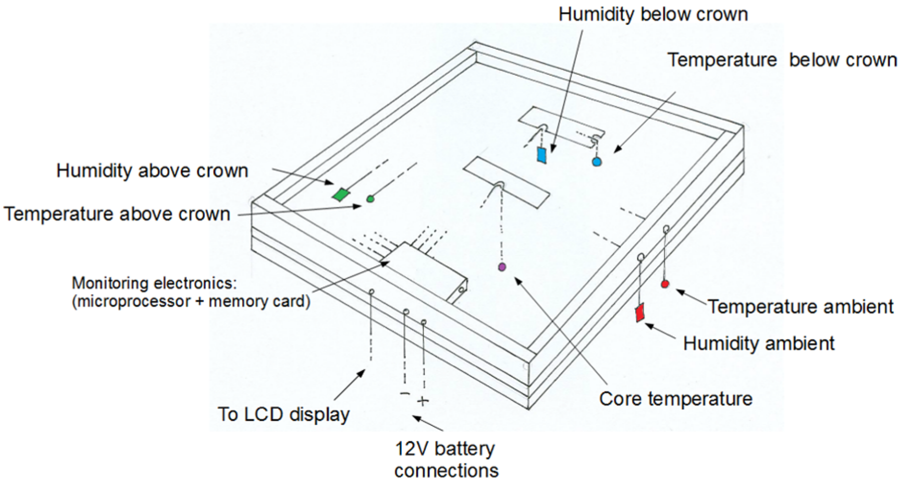
Bee keeping has recently been integrated with IoT concept. This project is associated with open energy monitoring which is meant for sustainable energy (solar energy) measurement purpose. This project uses national crown board as its platform to equip other electronic components. The monitoring system is constituted by various elements as given in Table 5. Primarily five types of materials are used in building the project: (1) Microcontroller, (2) Wireless communication module, (3) Power source, (4) Display unit, and (5) sensors. Live data is available at: http://emoncms.org/beehive/live; where bee keeper can visualize the present temperature of the bee hive and the amount of battery voltage in real-time. The data is sent every 60 seconds to the RF receiver based on Arduino which is connected to a Raspberry Pi enabled gateway that necessitates data logging, graphing, and analyzing tasks for user. Figure 4 shows the logical diagram of monitoring set up on National Crown Board. The board along with other sensor and electronic products are shown in the prescribed on the image. The bottom part of the Fig. 4 shows the practical frame structure. Pros: Elegant and easy design. Cons: Only temperature sensor has been deployed.

5.2. Case study 2: IoT-cloud based green house service platform

Greenhouse uses full use of solar energy in daytime and helps in keeping the indoor temperature warm and constant at night. This especially helps in producing winter vegetables in cold region on the earth [81]. The system works based on a five layered architecture consisting of following: perception and operating layer (this is the bottom most layer. It includes temperature and humidity sensors, light sensors, carbon dioxide concentration sensors, soil temperature sensors, and PH sensors; these sensor and actuators do act under control of system according to pre-set program or farmer's demand), data acquisition and control layer (this layer is the second bottom most layer which is responsible for collection and control of light intensity, atmosphere temperature, humidity, and the soil moisture, and video data from the greenhouse; the information is passed over ZigBee and RS485 protocols), network transport layer (here, a gateway fulfills the demands for short distance communication in the peripheral area, connection with the internet, conversion of protocols, data dispatch and control, and furnish the functions of signaling of exchange of encoding and decoding between various components), portal service layer (consists of a server, SMS cat pool, voice server, and other terminal support devices; a 128 GB SSD has been used along with the server to improve the information collection speed; various applications are served on this layer such as mail service etc.), back ground process and service layer (top most layer that performs leverages tenant management service, user management service, data analysis service etc.; it consists of PC clusters, cloud computing middleware, Hbase database system, and Linux operation system). Table 6 contains the vital information. Pros: Multiple sensors are engaged. Cons: Cloud integration is not feasible.

5.3. Case study 3: IoT based monitoring system of wheat diseases, pests and weeds

An IoT based diagnosis and prevention system to monitor and control of wheat diseases, pests and weeds has recently been implemented. The real-time IoT



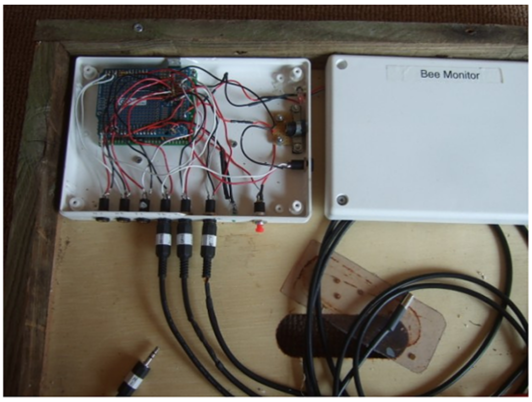


Fig. 4. Set up of national crown board.

Table 6
Deployment Parameters [81]

Parameter	Value
Processor type	Intel Core 2 Duo
Sensors	Temperature and humidity sensor, light sensors, carbon dioxide concentration sensor, soil temperature sensor, and PH sensor
Gateway Communication	ZigBee, RS485
Software used	Windows 2003 Server SP2
	Sun JDK 1.6
	Apache Tomcat 6.0
	Microsoft SQL Server 2005
	PC cloud cluster
	CentOS 5.7
	Hadoop 1.0.3
	Hbase 0.94
	Zookeeper 3.3.3
Microcontroller	Arduino Uno

based solution has incorporated ZigBee network along with Wi-Fi to develop remote collector and controller systems as shown in Fig. 5. Various sensors receive information about the environment and send the data to the collector module which in turn process the information and transmits over the gateway. The gateway according to the user's demand performs actuation tasks such as sprinkling water, light on-off etc. Data processing center is attached with the gateway in wireless mode. The monitoring center, equipped with the data center and a Web server, is responsible for data storage and early warning release regarding wheat diseases, pests and weeds. Data is stored permanently in a big data base which whenever required provide the relevant information for data classification and matching purposes. Table 7 provides the basic deployment parameters in compact form. Pros: Wireless gateway adoption is efficiently used. Cons: Collector wise things are less.

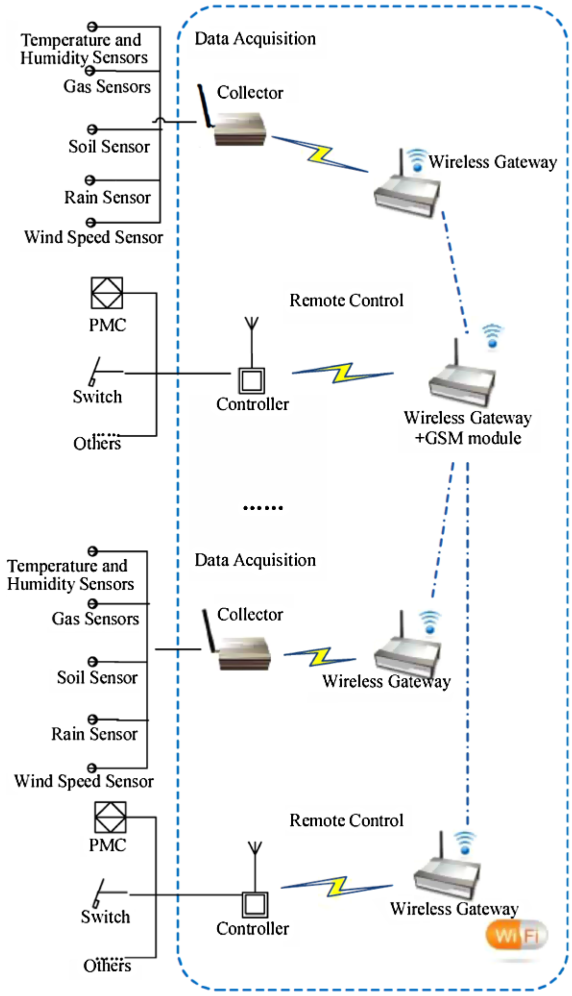


Fig. 5. IoT based data acquisition system [81].

Table 7
Deployment Parameters [81]

Parameter	Value
Sensors	Temperature, gas, Soil, Rain, Wind speed
Actuators	Relay, PMC, Alarm, Camera
Gateway Communication	ZigBee, 3G, Wi-Fi
Sensors per collector	5
Actuators per controller	4

5.4. *Case study 4: Vineyard monitoring*

The present deployment is made a vineyard in Pontevedra, a city in the North of Spain (http://www.libelium.com/smart_agriculture_vineyard_sensors_waspmote/). The system was deployed using three main components, (1) sensor nodes, (2) gateways, and (3) web based application. Various sensors such as, Ambient temperature/humidity, Atmospheric pressure, Pluviometer, Anemometer, Ultraviolet radiation, Solar radiation, Soil temperature, Soil moisture, and Leaf wetness are used in this project.

Table 8
Deployment Parameters [72]

Parameter	Value
Microcontroller	AT Mega1281
Sensors	Ambient temperature/humidity, Atmospheric pressure, Pluviometer, Anemometer, Ultraviolet radiation, Solar radiation, Soil temperature, Soil moisture, and Leaf wetness
Sensor node Communication	Zigbee (2.4 GHz), WiFi, RFID, NFC, Bluetooth 4.0
Gateway	Meshilium (http://www.libelium.com/products/meshlium)
Gateway collector Communication	WiFi/3G/GPRS/LoRa/868/900 MHz
Sensor nodes per gateway	10
User control panel	Internet enabled
Data access	Smart phone, tablets, PC

The deployment has been performed to cope up with precision farming activities like prediction of micro-climatic conditions, and possible plague occurrence in the field. Table 8 describes the deployment parameters. Figure 6 illustrates various components and results obtained from vineyard monitoring system such as (a) represents solution architecture, (b) Waspmote Agriculture Sensor Board, (c) Waspmote RFID module, (d) Waspmote Proto Sensor Board, (e) Vineyard System Sensor nodes, (f) Meshlium gathering data in Vineyard System, (g) PC based graphical visualization, (h) Mobile based visualization. Pros: Efficient system design is deployed. Cons: Complex to adopt.

5.5. *Case study 5: Precision farming*

Drone based IoT powered precision farming is now taking place in various places of the world (http://droneapps.co/case-study-drone-precision-farming/). Drone is being used to explore the potential of using aerial imaging to give farmers information on demand, about their crops. Agribotix is currently using its fixed-wing Hornet drone, and Enduro drone which are based on the RV Jet airframe from RangeVideo and fitted with Canon S100 and GoPro cameras modified with high quality non-distorting lenses and near-infrared (NIR) filters. Figure 7 presents a snap taken

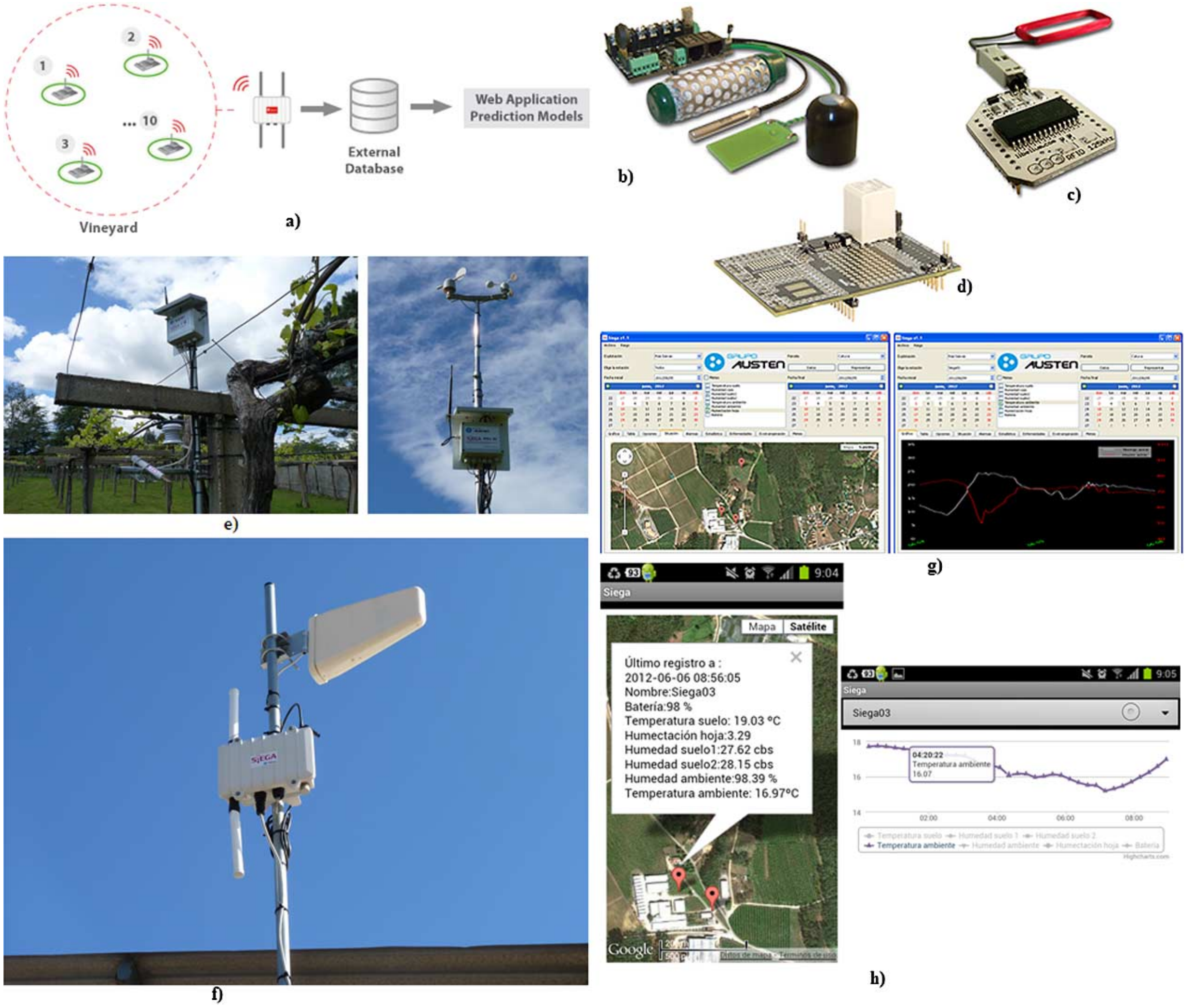


Fig. 6. IoT based vineyard monitoring system and visualization.

and analyzed by the drone while flying over the target field. Table 9 describes all the parameters associated with this system. Pros: Infra red imagery analysis algorithm is used. Cons: Cost and energy efficient need to be optimized

5.6. *Case study 6: Detection of borer insects in tomatoes*

A recent investigation has illustrated IoT based Borer insect detection in tomatoes in India [56]. The authors have used a robot attached to a wireless web camera and Azure cloud service. The web camera takes video of tomato plantation area in real-time and sends the video data to the Java enabled Software-as-a-Service (SaaS) where unripe tomato and border detec-

Fig. 7. Imagery analysis done by the drone of Agribotix (http://agribotix.com/) (Courtesy: Agribotix).

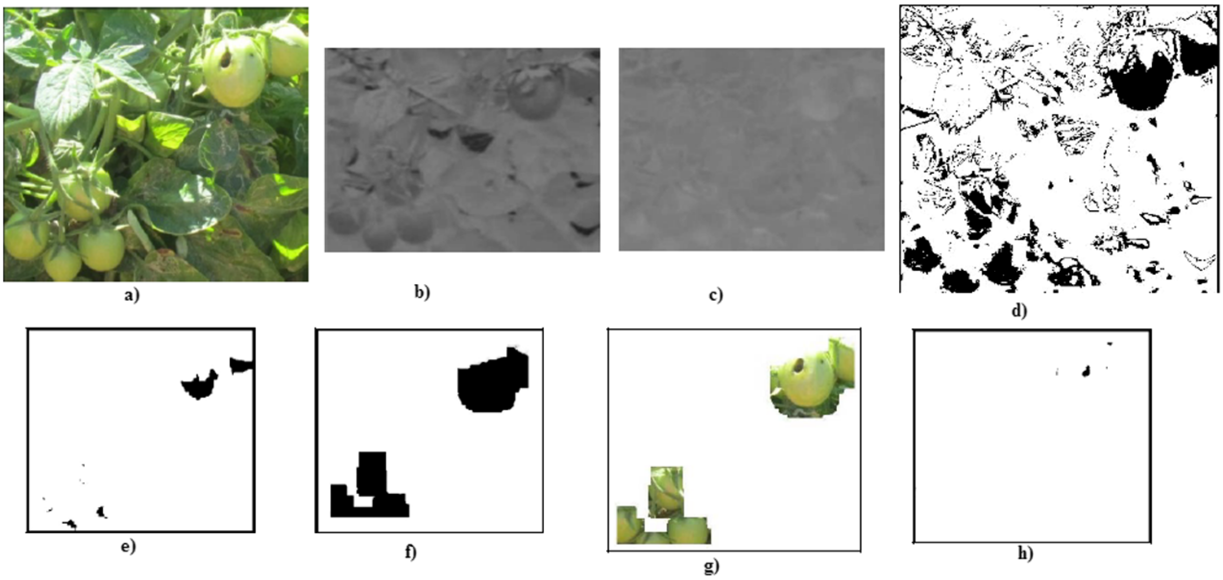


Fig. 8. Imagery analysis done by the image algorithm to detect Borer insect [56].

Table 9
Deployment Parameters [69]

Parameter	Value
Drones	Enduro, Hornet-fixed wing
Enduro drone	Cruising Speed 30 mph, Linear Flight Distance 13 Miles, Flight Endurance 25 min, Maximum Wind Tolerance 25 mph, Acres Covered/Flight 160 acres, Telemetry Range 1 mile, Batteries 2
Hornet long range	Cruising Speed 33 mph, Linear Flight Distance 40 Miles, Flight Endurance 80 min, Maximum Wind Tolerance 20 mph, Acres Covered/Flight 400 acres, Telemetry Range 1 mile, Batteries 2
Imaging hardware	IR: GoPro Hero4 Silver with non-distortion lens and red-notch filter, GP Hero4 Silver RGB camera with non-distortion lens
Transmitter	RC
Data access	Smart phone, tablets, PC

tion is done. The information is then processed by the data base stored at the Azure cloud for matching with appropriate pesticide amalgamation. The Intel processor does all the software related operations and based on the recommendation from Azure, it instructs the robot to spray appropriate amount of pesticides on the tomato plats for a predefined time. The whole process is comprised of two stages. In stage 1, real-time video feed from wireless webcam is accessed at Cloud end, which is then converted into grey scale imagery, later on image segmentation results in extraction of tomatoes, leaves, and branches which is processed to eliminate leaves and branches, further images of tomatoes are retained by performing dilation, RGB image of tomatoes are then retrieved back using masking of dilated image. In stage 2, number and type of pest on the tomatoes are identified, and adequate amount of pesticide is sprayed over the tomatoes. Figure 8 presents various stages of imagery analysis done by the image algorithm to detect Borer insect as follows (a) shows an example of an unripe tomato picture taken 1.5 feet away from the plant, (b) Cb components of the Tomato picture procured, (c) Cr components of the Tomato picture procured, (d) Image obtained after histogram based segmentation, (e) Images obtained after erosion, (f) Images obtained after dilation, (g) Image obtained after masking, and (h) Borer insect successfully extracted from the tomato. Pros: Efficient image algorithm implemented. Cons: Data transmission rate and real-time analysis not employed.

5.7. *Case study 7: Smart urban garden*

Urban gardening is a growing filed of IoT deployment. A project recently has developed an IoT enabled garden system (http://postscapes.com/smart-garden-sensor-hui) suitable for installation at any location in user's home. The system comprises of AT Mega 328 microcontroller at the processing unit which is con-

a) b) c)

Fig. 9. Smart urban garden implementation and output.

Table 10
Deployment Parameters

Parameter	Value
Microcontroller	AT Mega328
Sensors	Temperature, Light, Soil moisture
Sensor node Communication	Wi-Fi
Gateway collector Communication	WiFi
Data access	Smart phone, tablets
Battery	AA

nected to light sensor, temperature sensor, and a soil moisture sensor and an integrated Wi-Fi module. The system when placed on the soil near to the plant, being cultivated, after keeping 24 hours aside; informs about the best vegetable which may be planted in that condition. Otherwise, when it is running it notifies the farmer about its need (light, water) through messages to the smart phone. The system is intelligent and ubiquitous enough to understand voice of farmer (Natural Language Processing algorithms), to access specific information (Information Retrieval and Structured Knowledge Representation), and to manage that information by making logical deductions (Automated Reasoning). Table 10 describes all the parameters associated with this system. Figure 9 presents implementation of smart garden set up as follows (a) system implanted in various plant tub, (b) hardware structure, (c) web based output. Pros: Easy to use. Cons: Distributed approach is missing.

5.8. *Case study 8: Cloud supported plant factory*

In recent years, rapid population growth has generated a risk of disruption to the imbalance occurred between the supply and demand for food. It has also raised serious concerns about the reduction rate in the cultivation land area all over the world. Environmental change is another factor to add the risk to the food productivity and consumption. Hitachi supported project has developed a cloud supported and IoT enabled "plant factory" (a close growing system that enables a farmer to achieve constant and regular production of vegetables through out the year) [62] in Japan, to cope up with diminishing the need in of good in the agriculture sector. Figure 10 illustrates the overall plant factory management system. The system is comprised of three units – (a) Farm Gate Way (FGW), (b) data collection, storage, and distribution platform, and (c) Application module. FGW unit performs sensor data transmission, command reception from cloud services, and stores data at the attached data center. It collects various forms of data such as solar radiation, temperature, humidity, nutrient content, pH, electrical conductivity from the sensor. FGW collects important data about numerous operational activities such as heating and cooling of equipment, nutrient solution pumps, shading curtains, and other production equipments. A cloud based data collection, storage and distribution platform manages key-value storage (KVS), data conversion (HTTP protocol based), and push based data delivery mechanisms on the received sensory data. It also helps in servicing of command and control information management. Application module performs three fundamental operations such as data reception from the sensors, delivering any command to the FGW, and response reception from the FGW. Pros: Intelligent sensor system is deployed. Cons: Energy efficiency is not optimum.

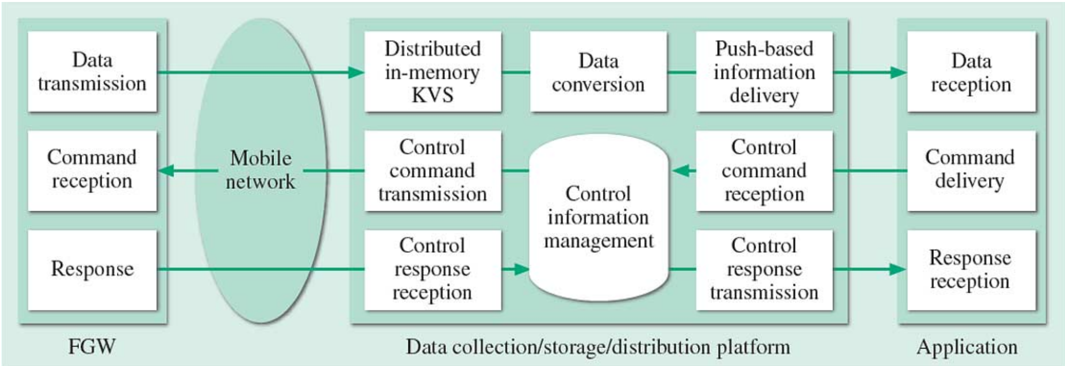


Fig. 10. Plant factory management system (from [19]).

6. Challenges and future road map

The existing solutions have incorporated IoT based smarter applications for solving a number of challenges in the agricultural and farming domain. I discuss the various prospects of these applications to improve the existing solutions as below, whereas the following sections shall show the path to improve the current situation point-wise.

- Cost-effectiveness: Researchers around the world are mainly focusing at the reduction of hardware and software costs in IoT deployments, while maximizing the system output. Developing country men seek cost effective equipments so that extra cost needed due to the use of foreign imported devices to build the systems get minimized. Though, international farms are developing cutting edge technologies in this regard, the challenge still exists how to bring down the cost further. Presented works do lack in cost effectiveness. Hence, such point is deliberately the need of the time.
- Standardization: Current works in do not conform to the standardized format of representation of data as well as the process. Standardization is another clot which may precisely be operated for growth of IoT. Standardization in IoT signifies to lower down the initial barriers for the service providers and active users, improvising the interoperability issues between different applications or systems and to perceive better competition among the developed products or services in the application level. Security standards, communication standards and identification standards need to be evolved with the spread of IoT technologies while designing emerging technologies at a horizontal equivalence. In addition, fellow researchers shall document industry-specific guidelines and specify required standards for efficient implementation of IoT. Agriculture related standardization while employing IoT should strictly be followed.
- Heterogeneity: IoT is a very complicated heterogeneous network platform. But the mentioned works in agriculture are unable to interact with heterogeneous modules or communication technologies. This, in turn enhances the complexity among various types devices through various communication technologies showing the rude behavior of network to be fraudulent, and delayed. [4] has clearly mentioned that the management of connected objects by facilitating through collaborative work between different things (hardware components or software services) and the administering them after providing addressing, identification, and optimization at the architectural and protocol levels is a serious research issue. However, to succeed at the agriculture domain, IoT need to be reassessed to sort out the depletion of the common platform.
- Context awareness: When billions of sensor enabled things are connected to the Internet, it may not be feasible for the user group to handle all the data collected by the sensors. Context-awareness computing techniques need to be used in better way to help decide what data needs to be processed. Discussed agri-tasks are void of context awareness. This seems to ascertain the negation of information validation in form of continuous disrupted process. Surrounding environmental parameters and self assessment may transfer the localized context to others while making

a well connected self cum periphery aware IoT ecosystem.

– Middleware: Most of the presented works follow the vertical silos designed for sole purposes. A middleware could provide a common platform to achieve the specific goals incorporating multi-localized (geographically) modules within a tenant. Middleware paves the horizontal flow of information among the devices, protocols, and applications with respect to itself. Applications can be performed over the whole data set and query be processed on the connected devices in a centralized manner.
– IoT node identity: The IoT is envisaged to include an incredibly high number of nodes. All the attached devices and data shall be retrievable; here in such context, the unique identity is a must for efficient point-to-point network conFig.uration.IPv4 protocol identifies each node through a 4-byte address. As it is well known that the availability of IPv4 numbered addresses are decreasing rapidly by reaching zero in next a few years, new addressing policies shall be countered where IPv6 is a strong contender. Presented systems do mostly use IPv4 for communication. But futuristic network may highly be populated so that the unique identity would get difficult to be imposed upon the nodes. Improved techniques to be alloyed with the current approach.
– Energy management: Energy management is the most important issue in Iot based systems. System components such as IoT devices, network antennas, and other dependent passive modules along with the core algorithms should properly be readdressed while indulging into the harvesting of energy. Otherwise, non-conventional source of energy harvesting solutions such as solar power, wind, biomass, and vibration cloud also be tested while designing IoT based smart agriculture systems. As of now, solar powered IoT systems are already in use. Hence, researchers may get involved to work on the other sources in future.
– Fault tolerance: Fault tolerance is mostly absent in the above solutions. To make a flawless system, fault tolerance level of the system should be kept very high so that despite of technical error, the system keep working. Hardware modules may fail due to depleted battery or any other reason. Similarly generation of erroneous value by the sensor, faulty calibration, and failure in communication may develop a fault situation. While seeking for solution, solar power may give an alternative to the battery operated modules. Usage of multitude of communication protocol may increase the power consumption but always provide seamless connectivity. Power consumption in such case, may be lower down by enacting one protocol to get activated at any instance. Proper calibration need to be done prior to final installation.
– Need of real-time solution: Most of the presented solutions do not involve real-timeliness into the account. However, to enable precision agriculture, climatic information, and soil parameters be smartly integrated with the current developments.

6.1. *Future road map*

I have presented many potential applications of IoT in the agriculture and farming area. The current implications include various devices, cloud solutions, and systems that work on irrigation management, vineyard monitoring, smart gardening, crop disease prediction, microclimatic prediction, and aquaculture etc.

6.1.1. *Factors needed for improvement*

The following list presents the factors associated with IoT that need further attention in the future.

– Autonomy: The future applications need to be fully autonomous to get leveraged with the specific needs.
– Cost: Low cost solutions are desirable for growth and usage of IoT based solutions.
– User control panel: Mostly, non technical people use IoT-agri based solutions in the field. Hence, it would be better to design a user friendly interface in form of a control panel for efficient applications.
– Energy: Green computing techniques need to be disseminated with the present IoT based agriculture where IoT devices shall consume very less amount of energy that may in tern increase their life expectancy and make them less faulty, hence highly productive.
– Interoperability: Interoperability issues are the most common in IoT devices. Devices should be capable enough to communicate with others from different genre so as the overall system be work as a live ecological setup.

- Artificial Intelligence: Machine learning, and artificial intelligence techniques to be implemented together to cope up with predictive and behavioral analysis functionalities through employments of advanced decision support system and real-time assessments.
- Maintenance: IoT systems shall be designed in such way that maintenance time and cost, both are reduced up to a descent level of acceptance towards the naive users.
- System Portability: The probability of current system architectures need to be enhanced to make them solicited enough with particular aspects agricultural requirements.
- Robustness: IoT architecture need to be robust and fault-tolerant so that applications may be ensured to be sustainable at their operation.
- Climate, soil, and water: While designing an IoT based system for agriculture, the most difficult part seems to be the different temperature, soil, and water properties around the globe. Farmers shall be equipped with local weather sensors that can communicate with national weather centers to make them aware about the environmental condition prior to the unwanted situation. This may increase the crop production and resist the destruction of agri-products in a precise manner.
- Segmented land structure: Partitioned land farming creates a problem in many countries around the globe. Suitable IoT architecture shall be developed to cater this specific problem. Appropriate policy and proper planning should be taken to tackle this problem before hand.
- Low maintenance: Involvement at maintenance at a time creates huge problem. Hence, it is necessary to design a low maintenance system that could perform the tasks automatically with out human intervention in optimized way.
- Portability: Portability is an important factor that may increase difficulty in handling the system. So, portable sized equipments such as SoC (System-on-Chip), SiP (System-in-Package) etc. could be used to deliver the final product.

6.1.2. Futuristic applications

In recent times, with the advent of sensor-cloud, big-data analytics and ubiquitous computing, new ground breaking applications are being envisioned. I briefly describe the concepts as below.

- Sensor-cloud enabled computing: It is a recent concept that refers to the on-field IoT applications empowered with cloud computing [56,63,80] and finding the meaningful information from large volume of data with various data types generated in high velocity. Moreover, the sensor cloud improves the data management, data access, and device management related tasks, while making agriculture smart in nature. Few applications may be based on below.
- A cloud-enabled storage system for measuring spatial variation of soil cum other environmental parameters depending upon various seasons.
- A mobile sensor-cloud service may be designed for crop health monitoring.
- A cloud based infrastructure may be developed to predict the futuristic yield in crop productivity.
- Smart irrigation system for large fields may be developed which shall be controlled by the autonomous sensor-cloud.
- A cloud controlled green house system may be developed to monitor the production of off-season fruits and vegetables under a predefined environmental model.
- Remote operated field crops planting system need to be developed so as farmer less field may be plated by autonomous planting equipments.
- Cloud based horticulture management system may be developed to produce fruits in any season during the year.
- Cloud enabled smart floriculture environments need to be developed so as the flowers be kept fresh and fragrant for a long period of time.
- Real-time livestock monitoring system may be empowered by the cloud services to uplift the economic status of the farmer in automatic way.
- Fish farming is an crucial area when cloud enabled services could monitor and control the process staring with breeding up to selling in the market.
- Cloud enabled agro-logistics system shall leverage high profit margin to the farmer by dispatching the vegetables, and other agri-products to the market in time.
- Big data analytics: According to [28,36], big data analytics can be applied to find the inner sight of large volume of data that is generated at very high speed and belong to different genre. Many aspects can be discovered using big data analytics such as finding futuristic business trends, unknown structural patterns, customer preferences, prediction of disasters, systematic correlation between many components of fact etc. I hereby list

a few agricultural applications suitable to be attached with big data.
- A system may be developed based on previous farm data to predict crop growth.
- Big data analytics may be used to solve the disease management among various crops using mathematical models.
- A big data supported cloud enabled web based information system may be designed to facilitate the knowledge of farmers about agriculture.
- Big data analytics shall be used to develop a centralized farming equipment control system that in turn be leveraged for large scale agriculture.
- Big data analytics could be used to develop a decision support system to enhance the yield of crop productivity.
- Development a predictive system to predicate the pollination period.
- Determination of patterns of cattle grazing around the field using big data analytics.
- Cost optimization techniques may be developed based on big data analytics that could be implied upon large scale agricultural sector.
- User friendly climatic information analytic service needs to be designed for the farmers.
- Big data analytics may be incorporated with supply chain management system to analyze the profit margin of the agri-products.
- Analytics may equip the farmer with the prior knowledge of probable rot time of the agri-products that shall reduce the loss and enhance the gain in terms of value.

Further, government should come forward to validate and control the agriculture domain by implying big data analytics on higher abstraction level. Policy makers should come together to pave a new policy of improving agriculture related ecosystem by employing big data into it.

- Ubiquitous computing: Ubiquitous computing signifies the concept-"existing everywhere" [52, 58,74]. The devices and the systems developed using ubiquitous computing are always connected and informed constantly during any instance of operation. The devices of ubiquitous computing are capable of performing crucial tasks such as identifying, communicating, and interacting with the surrounding devices. This empowers ubiquitous setups to provide reliable, real-time, and flexible control mechanism for on-field parameters. The mentioned words do advocate for the ubiquitous computing to be a potential solution for various agricultural applications, where similar contexts are prominent. A few ubiquitous computing based agricultural applications are given below.
- Development of cost and energy efficient RFID based identification modules for identification of crops and other agricultural components.
- Augmentation of physical farming situation using smart mobile phones.
- Development of remotely operated farm monitoring system.
- Development of ubiquitous system to perform counting of pests in fields.
- Design of web controlled system for scheduling of pesticide sprays based on crop genre, rate, and time.
- Monitoring of origin of leaks in water pipes and informs the farmer.
- Ubiquitous water flow control system needs to be designed.
- Remote monitoring of power consumption to the pumps installed in the fields.
- Development of cattle gaze monitoring system using ubiquitous devices.

7. Conclusion

The inclusion of IoT is envisioned to be useful for advancing the agricultural and farming industries by introducing new dimensions. In this analytical paper, I present a comprehensive review of IoT deployment for advanced agricultural applications. IoT based agricultural framework is proposed to leverage full fledged combination between agriculture and IoT. First, I introduce with IoT concept, definition, and its characteristics. Then, I highlight the various key applications of IoT in the agriculture field. The later section of this paper describes the hardware platforms available in market that may are currently being used in farming domain. Various wireless communication technologies which are suitable for agriculture applications are also presented. A few IoT cloud service providers are recently being popular in agricultural fields. I have tabled a list of cloud service providers active in this field of application based on a set of key attributes. It is followed by a survey of IoT based systems being presently deployed in various farms and areas of the globe. A a few case studies have been illustrated with deployment details in multiple applications such as, bee keeping, vineyard monitoring, precision farming, and river water quality monitoring etc. Finally, I present the difficulties of the existing applications. A list of several directions for future research and applications are envisaged. Specifically, low cost, autonomous, energy efficient, interoperable, standardized, heterogeneous and robust solutions with features like artificial intelligence, and decision support system and low maintenance is in demand. As a whole, the underneath descriptions of various aspects of IoT should be catered in such a way that agriculture be smart and ubiquitous.

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