Internet of Things for Sustainable Environment and Smart Agriculture: Technologies, Applications, Challenges and Solutions

[1,*] Mohammad B. Alrayaan, [2]Abdullah G. Alhamed

[1,*] Environmental Protection Department, Saudi Aramco, Saudi Arabia.
[2] Environmental Protection Department, Abqaiq Plants-Saudi Aramco

Abstract: Environment Industry along with Agriculture are going through immense renovations with the origination of technology coined as Internet of Things (IoT) and have huge market value. Many groups and technology startups have invested in providing smart devices for the Smart Agriculture and Sustainable environment. Smart sustainable Environment provides the perks of remote Air Quality Monitoring, Water Quality monitoring and treatment along with other applications. Smart agriculture has many benefits like providing remote monitoring of animals for cattle farming, their health, Soil health monitoring along with pesticide control. Smart irrigation systems reduces water waste resulting in better yield and cost benefits for the farmer. This paper provides a review of IoT, its evolution, and applications in domains of Sustainable environment and agriculture by identifying key technologies for delivering smart systems for the domains, followed by the key applications of IoT in sustainable environment and agriculture. Next a fog based architecture is proposed for the key applications in the fields based on the review. Finally Key challenges in IoT for sustainable environment and agriculture are identified such as standardization, cost, network etc. Solutions to these challenges are also discussed.

***Index Terms*— Internet of Things Applications in Smart Agriculture, Intelligent Environment Monitoring Devices, Sustainable Environment.**

I. INTRODUCTION

The concept of Automation has always been a fascinating idea for human kind. Automation is considered as the ability to make decision, execution of task or communication without human intervention. Over the course of years automation has expanded to every industry, from hospitals to transportation, education and data processing[1]–[5]. This automation requires communication for transfer of data b/w machines for which they need to be interconnected[1]–[4]. In the area of communication, a novel paradigm introduced as Internet of things (IoT) was coined as uniquely identifiable things that are interconnected and can communicate wirelessly. IoT devices are able to communicate with each other without human intervention[6], [7]. IOT is a network of interconnected devices/nodes or things that can transfer data and communicate with each other. IOT has found its way in almost every industry out there for reliable data communication.

According to international data corporation, IoT spending will grow to $942 billion in the end of 2022 (dropped due to Covid-19 pandemic) with applications in healthcare, IT, data collection/sensors and others [8]. According to the World Economic Forum, by the end of 2025 there will be more than 75 billion active IoT devices that will be live capturing the data[9].

IoT has revolutionized the tasks and industries such as sustainable environment monitoring, agriculture, irrigation, Sensor data collection, monitoring, robotics, Automation and weather forecasting. Conventional way for all these tasks was to collect the data and store it in some device and then transfer the data manually to some computing device for manual analysis compromising the quality of the data due to human error and slow processing. This required time, efforts, expertise and was totally dependent on the experience of the professional performing the tasks. IoT solve these issues by wireless transfer of the data to the computing device providing control, real time monitoring, tracking and tweaking due to two way communication[10].

Smart Environmental Monitoring market is expected to reach 17.9 billion USD by the end of 2026[11]. IoT is gradually making its way in sustainable environment applications for the tasks of monitoring, processing and control of data to alert the users. Due to the applications of IoT in smart environment monitoring, people are getting more aware of their surroundings to take necessary precautions. Smart sustainable Environment requires following

- Remote Monitoring of the modules and key factors of Environment parameters
- Monitoring and Alert system for anomaly
- Data availability for readily access

Agriculture market works in five different segments which are Irrigation means, Pesticides, Soil health monitoring, Greenhouse and cattle farming. Smart agriculture sector is expected to reach USD 15.88 billion dollars by the end of 2022[5]. Conventional processes have been replaced with IoT and autonomous real time monitoring has become possible for the tasks. It has also revolutionized smart agriculture in its practices and methods for the growth, monitoring and control to get the best yield out of the crops. IoT is major contributor of converting agriculture to smart agriculture. Smart agriculture requires following.

- Improving efficiency by minimizing waste
- Monitoring of the modules and key factors of farming
- Make control of systems remote
- Data availability for readily access

Based on the potentials of IoT in the domains described in previous lines, this study targets the identification of solutions and applications in the fields of sustainable environment and agriculture that have been developed over the course of years along with the technologies of IoT.

Section 1 discusses the introduction along with the methodology of the study and contributions. Chapter 2 provides overview of the IoT with an emphasis on the evolution. IoT Technologies are discussed in section 3. In section 4, State of the art developments of IoT for sustainable environment and agriculture are discussed and summarized followed by Methodology and discussions in section 5. Based on the literature survey, Fog based IoT architecture is proposed for the IoT applications in agriculture and environment in section 6. Section 7 highlights the challenges and limitations of IoT followed by section 8 concluding the findings of the study along with future direction based on the challenges.

Internet of Things

II. INTERNET OF THINGS

Internet of Things term uses two words, internet and things meaning a network of interconnected devices or things that can communicate with each other. The term was coined by Kevin Ashton who was executive director of Auto-ID director at MIT[12], [13]. Kevin Ashton presented IOT as interconnected uniquely identifiable devices which can share data and are based on the RFID technology[6]. Although term was coined in 1999, but IoT was implemented back in the day when Coke machine was able to communicate about the number of present drinks and their temperature status [14]. Over the decades, definition of Things has changed due to the advent in technology, but the idea/goal of making a computing device sense data without human intervention has remained the same. It can be regarded as a progressive evolution of the internet into network of connected devices that harvests information from the environment but also interacts with the physical world by providing command, actuation and control using the existing protocols of the internet[15]. The word Internet of Things means interconnected network of things (devices) which are uniquely identifiable and have computational power for sensory data collection, monitoring, and control. These things comprise of sensors, actuators and embedded systems with controllers. Things require to communicate with each other arising the need of machine to machine communication. These communications can be short ranged using Bluetooth, Wifi Zigbee or they can be wide ranged communications using 4G, 5G, LTE, LoRa, GSM and other mobile networks[16], [17]. IOT was initially used for automation, control, monitoring and remote access due to its ability of data transfer to cloud which can be accessed/controlled or even more data can be uploaded using the computer or other device connected to the internet. This communication of the IOT is two way, providing control over the devices. Wireless communication of the devices has enabled the IOT to expand to those industries where the concept of automation was never perceived to exist. Increasing development in technology has opened new horizons for IOT to find its applications in. Each passing year is yielding into devices availing internet services which has brought the world/devices closer making control, information sharing, monitoring easy and quick.

Evolution of IoT

Evolution quoted from [12], [18], [19] on date 2 May 2022.

1990 – First IoT Device: Smart toaster that could be controlled via internet, invented and presented at INTEROP conference by John Romkey.

1999- IoT concept Born: Kevin Ashton coined the term while giving presentation on RFID.

2000- First smart household item: LG announced its series of internet connected Refrigerators

2002- Ambient Orb: A internet based desk device changing colours to show change in weather patterns, stock portfolio. Released by MIT

2003-2004- IoT widespread use: Term used in mainstream publications. RFID deployed at wide scale by US department of Defense and Walmart

2005: United nation's international telecommunications unit published first report on IoT.

WiFi based robot released by Nabaztag capable of talking to user about stock market alerts, weather changes, alarm clock and news headlines.

2006-2008: Recognition by EU, First IoT conference held. IPSO alliance formed to promote the smart things and enable IoT by use of Internet Protocols

2008-2009: U.S. National Intelligence Council listed IoT in top 6 disruptive Technologies.

2010: China plans to make big investments in IoT

2011: IPV6 was launched. It was turning point for IoT.

IBM, Cisco started marketing and educational initiatives in IoT.

Arduino and other platforms matured enough to make IoT easy and accessible for public interested in field. IoT based smart agriculture introduced.

2013: IoT devices started using sensors such as home lighting and thermostat. Automation was introduced in homes to control devices and garage doors.

2014: Sigfox sets up Ultra Narrow Band Wireless data network

2014-First smart city: Dublin becomes first IoT city. City functions were improved.

2017 IoT devices widely used:

IoT becomes widely used technology in military. U.S. army research lab for IoT uses in military.

2017 recorded a total of 8.7 billion IoT enabled devices

2018- Healthcare: IoT found its way in healthcare industry. Technology allowed medical representatives to access patient's data.

2019-Largest IoT Investments: Samsara an IoT based company raised 300M$ in funding. IoT-based vertical farming received 100M$ in investments. Terminus Tech received 286M$ as investments for smart city. **2019 recorded a total of 20.0 billion connected devices.**

IoT Requirements

There are three requirements for successful implementation of IoT device. One is hardware system comprising of actuators, sensors, embedded systems and communication unit. Middleware for storage and on demand data using cloud and computing tools. And the third one is Presentation ware, tools that can visualize the data for analysis for different applications[13].

III. IoT Technologies

IoT utilizes different hardware and software computing platforms for the smart devices which are known as key technologies and listed below.

Sensors

Worldwide network of interconnected smart devices is known as IoT. Sensors are the core components of the IoT based smart devices which are utilized for the acquisition of the data which is used for the processing and making smart devices. IoT sensors are compact, require minimal power and have unique feature of sensing specific parameters. These sensors are characterized based on the mode of their communication protocol (I^2C/UART) and power requirements (Input Voltage). These sensors are utilized for monitoring applications such as air quality monitoring, weather patterns monitoring, Water quality monitoring and Smart agriculture. Different type of sensors utilized for making an intelligent IoT based system can be seen in the Figure 1. Sensors are also listed in the table with their applications.

Mobile Sensors

There are different sensors embedded in the mobile phones which are being utilized for IoT based systems. Sensors like gyro, GPS, Accelerometers in the smart phones or mobile devices are used for movement detection, location, number of steps taken and related. With the use of cellphones increasing day by day for connection and data collection due to compact size of the phones, scientists have focused on the potential uses of the phones for IoT based connected data communication by utilizing the Embedded sensors in mobiles. Developed applications can be installed and utilized on the phone for collection or communication of the data of the sensors.

Actuators

Actuators find their applications in IoT based systems where movement or decision requires the work in terms of distance travelled or dislocation or displacement. Actuator is a device which provides valuable autonomy to the system by movement of the system. There are different type of actuators which can mainly be classified into three distinct categories which are Pneumatic, pressure driven and Electrical actuators. Pressure driven actuators use liquid or gas for mechanical movement, pneumatic actuators use air weight and electrical actuators use electrical power for movement.

Figure 1: Different types of sensors [20],[21]

RFID

RFID is a system that wirelessly broadcasts the ID of an object using radio waves in the form of tag or number[13], [22]. They act as the barcode for objects or persons wearing them. RFID was first time used in 2nd world war for identification of a friend or foe[13]. Same technology was being further developed in 1999 at Auto-ID center, MIT where the term IoT was coined. An RFID mainly consists of reader, tag, antenna, software and server. RFID is further classified into three categorized based upon the power source of tag. Passive RFID, tags rely on the waves transmitted by the reader for power and find their uses in shopping marts, passports, electronic tolls etc. While in Active RFID, tags are battery powered and communicate with the reader. Semi-Passive RFID are dependent on reader for communication while battery is used only to power microchip[23]. RFID plays a vital part in identification of the things due to being cost efficient and is being used in Animal identification, monitoring, tracking and record maintenance applications in Smart farming.

Wireless Sensor Network

A WSN is a wireless network of autonomous devices/nodes that are spatially distributed in an environment capable of measuring/sensing some parameter such as temperature, humidity, light using sensors. These nodes comprise of controller, sensors, actuators, wire-less communication module and power source to sense and transfer the data. A wireless sensor network in IoT is of

vital importance as they have been revolutionizing the concept of data collection and monitoring. Wireless sensor network is being used for environment monitoring, agricultural monitoring, water quality monitoring, soil monitoring and health care[24], [25]. Different sensors based systems are attached to the patient's body to keep a track of effects of medication[26].

Cloud Computing

Cloud Computing provides configurable resources for the process computations of the algorithm. This service is accessible using internet from anywhere providing the computational power and resources based on pay per service or billed as per plan. Startups or organizations having low revenue utilize cloud computing to gain and access computational power, storage and other compulsory tools for the growth of their business online. Cloud computing is one of the key technologies for IoT. Cloud computing is implemented at the middleware layer of the architecture. Data generated by the sensors can be stored and computed at the cloud which can be accessed by the user for viewing functions such as wildlife monitoring, forest fire detection or making smart farming decisions. Data of the sensors need to be uploaded to the cloud for processing and computing via internet which is time consuming process and may lead to delays in making faster decisions for applications like animal health monitoring or forest fire alert systems, This issue is overcome by the use of Fog computing which is discussed in next sub section.

Fog Computing

Data upload and delay caused at the cloud computing is overcome by use of Fog computing which puts the processing capabilities and storage closer to the sensor nodes. Fog Nodes are placed near the sensor layer which perform the preliminary data processing which can be immediately utilized for making critical decisions such as alerting the concerned person in case of an emergency at the forest, the anomaly at the air quality or in smart agricultures. Fog computing is employed at the perception layer and networking layer of the IoTs layered architecture due to the advantages of faster speed and reduced latency.

All of these enabling technologies are utilized for different applications in fields of smart agriculture and sustainable environment. IoT has many applications in the mentioned fields which are discussed in the next section.

Table 1: Key sensors for Smart Agriculture and Sustainable Environment applications

Sensor	Use
Humidity Sensor	Measures humidity
Temperature Sensor	Measures Temperature
IR Sensor	Obstacle detection
Metal Detector	Metal detection
Ultrasonic sensor	Distance measurement
Gas sensor	Gas type Detection
pH	pH monitoring
Accelerometer	Change in motion detection
soil moisture	Moisture Sensor
Rain sensor	Rain detection
PIR sensor	Intrusion detection
LDR	Light detection
Smoke sensor	Fire/Smoke detection
NKH Sensor	Soil nutrients test

IV. IoT Applications

IoT devices have made a major shift in our routine life. With the fast and updated network, advancement in sensors and computational capabilities, IoT is projected to be the next big thing of future that is revolutionizing the infrastructure and making the lives better and easier. IoT technological giants are already ensuring for a connected environment and as per research, connected devices will increase up to 71 billion by the end of 2025. These connected devices will cover the gap between digital and physical worlds with collection of data that can be utilized for monitoring, control, predictions, forecasting and related tasks.

IoT being the enabling source for completely smart houses, has resulted into the major companies comparing their smart devices and sensors for effective and productive. Wearable devices and technologies are also developing and hot topic. With the competitive launch of smart watches and health bands by Samsung, Apple and Huawei etc., we are set towards the life of always connected systems which would keep us updated with the latest trends and the world. With the potential of IoT, new ventures are being created that are working on the IoT and playing their part which has resulted in IoT attracting a lot of attention.

Some of the key applications of IoT in Environment Monitoring and Agriculture are reviewed as follows.

Sustainable Environment Monitoring and Public Safety

Environmental monitoring and public safety are the processes of observing the weather conditions, water quality monitoring, endangered species protection and monitoring of the other parameters that indirectly or directly relate to our environment [27]. Applications involve different sensors and actuators that are utilized for weather and environment monitoring. IoT has found its applications in different aspects of Environment monitoring and public safety which are categorized and discussed as follows

Air Quality Monitoring

IoT has found its applications for continuous or periodic Air quality monitoring, observation and evaluation by measuring different air quality parameters and pollution indicators to mitigate or avoid the possible negative effects and outcomes [28]. Forecasting of climate and weather changes is also possible in ecosystem. Over the course of years different systems and solutions have been proposed by the researchers for Air Quality Monitoring which are reviewed below.

In study [29], authors proposed monitoring system for microclimate which was based on wireless sensor networks. System utilized humidity sensors along with the temperature sensors which were powered by PVs and based on Zigbee. In study [30], IoT based Air quality monitoring system was proposed for orchard plants which utilized sensors for temperature, humidity and radiations. System was tested in 5 different zones of China. In study [31], Authors proposed (Air Quality Monitoring) AQM system which utilized ESP32/Wi-Fi for measuring different gases and particles using sensors. Parameters could be accessed by utilizing Android Application. In study [32], An AQM system is proposed which utilizes different sensors for measuring parameters of Particulate Materials and different kinds of gases. System utilizes Wi-Fi and cloud for collection and processing of data and in case of anomaly detection in the parameters, notifies the user. In study [33], AQM solution presented utilizes IoT sensors and LoRa for communication module to measure parameters such as particulate Materials, Carbon di oxide along with temperature, humidity and dust. In study [34], authors utilized sensors for AQM system to measure CO and other gases along with the Particulate Materials. System utilized Wi-Fi as communication link for the application. In study [35], Raspberry pi along with NodeMCU/Wi-Fi is used for creating an AQM system that measures Particulate Medium along with other gases and uploads the data to the server which is utilized for visualization.

Water Quality Monitoring

Water is an essential part of diet for human beings. Drinking contaminated or water of poor quality can lead to different complications of kidney, Abdomen and pelvis such as diarrhea, vomiting resulting in dehydration and in worst case scenarios can lead to death if contamination is of some hazardous material. Water that's viable for drinking is of very less amount and contamination of which can lead to serious issues for the ecosystem. With increasing population and limited fresh of drinkable water resources, dealing with the issues of global warming and environmental issues is really difficult. To overcome these issues, different methods of Water quality monitoring (WQM) have been utilized over the course of years. IoT has revolutionized these methods of WQM for sustainable environment by utilizing sensors and communication methods for the same. Some of these systems are reviewed as follows.

In study [36], IoT and Zigbee is utilized by authors to measure the WQ parameters such as turbidity, pH, temperature, dissolved oxygen and conductivity. Data is processed on cloud and can be accessed using web browser. In study [37], authors proposed IoT based solution for water quality monitoring system which monitored parameters such as temperature, turbidity, E coli. Fecal streptococci, dissolved oxygen and conductivity. Others concluded that the IoT based systems provide accurate and reliable monitoring of water quality. Authors in study [38] proposed a device for multi parameter monitoring and measuring which proved to be beneficial for the water quality management and early warning system for the same. Robotic devices are also being utilized for WQM which utilizes WSN along with robotic technology for monitoring the systems[39]. These comprise of both underwater vehicles[40] and on the surface vehicles [41], [42] for water quality monitoring. Fish robots are also being developed and tested utilizing IoT for WQM [43]. In study [44], Underwater robot platform was developed for WQM of deep water reservoirs. Proposed system utilizes sensors for measurement of WQ parameters such as turbidity and pH. System utilizes node MCU/Wi-Fi along with Arduino for control of actuators and communication.

Wildlife Animal Monitoring

Animal health monitoring for endangered species or farm animals is of vital importance for preservation of sustainable ecosystem and environment. IoT based solutions can be utilized for the Animal health monitoring, behavior, movement pattern of wild and endangered animals which can alert the Wildlife staff to take necessary actions for tracking and providing aid to the animals. Over the course of years different IoT based solutions have been developed for Animal monitoring that can be utilized for saving and assisting the animals in need. Some of the systems are listed as follows

RFID based tags have been used for animal tagging which helps in vaccination marking, contains data about the health, medicine, weight over the course of years etc. providing efficient over the time data[45]. System developed in [46] utilizes IoT, GPRS along with sensors for Animal Health monitoring. Different parameters of body such as temperature, heart rate and load cell are monitored and utilized for the same purposes. In study [45], WSN based system is proposed for the Animal health monitoring for stray animals in shelter that can be utilized for the animals which are in rehabilitation. In study [47], IoT based solution for Animal behavior pattern monitoring is presented which utilizes Accelerometers for identifying the bodily conditions of the animal by recognizing patterns of the animal if that's standing, grazing or sitting, historical data of which is utilized for disease estimation. In study [48], IoT, BLE and Lora Wan based network is developed for Sustainable Wildlife Monitoring System. Authors conclude that the potential of IoT for endangered species or wildlife monitoring are immense and proposed system can be utilized for the same. In study [49], IoT based Animal monitoring system is developed which utilizes UAV for the purpose. It monitors and detects the changes in the position of animals as well. In study [50], an IoT based solution for monitoring swamp deer and their migration and living patterns which gathered data about the herd along with the environment parameters. In research [51], IoT based solution for monitoring six horses was developed that tracked their speed along with location and provided data logs to the nodes.

Forest Monitoring

Forests are key source for providing oxygen, honey, wood, natural wild herbs and hold a vital ecosystem for many wildlife ranging from birds to land based predators and herbivores. They are a vital part of environment. With climate change on the rise and industry 4.0 in making, preservation and sustenance of the Forests is of vital importance. Incidents like wildfire breaking out due to lightning or other reasons can engulf a large chunk of forests, wildlife and nearby cities. Earlier detection of fire can lead to better rescue and fire control services which would result in reduced loss. Immense potential of IoT has resulted in development of different systems

for the monitoring of the Forest environment along with forest fire detection and illegal tree cutting detection which utilize different sensors[52]–[57].

Table 2: IoT applications for Sustainable Environment

Reference	Targeted Application	Description	Key Sensors Used
[29]	Air Quality Monitoring	WSN based solution proposed for Air Quality monitoring utilizing Zigbee and Sensors	Humidity Temperature
[30]	Air Quality Monitoring	IoT based solution proposed for Air Quality monitoring utilizing Sensors for orchard monitoring	Temperature Humidity Radiations
[31], [34], [32]	Air Quality Monitoring	AQM utilizing IoT and Sensors. Android Application developed provide remote access	Temperature Gases Particulate in air
[33]	Air Quality Monitoring	AQM utilizing Lora for the measurement and monitoring of the air quality parameters	CO_2 Temperature Particulate Materials Humidity Dust
[36]	Water Quality Monitoring	IoT based Water Quality monitoring system Proposed for the parameters measuring and remote access	Turbidity pH Conductivity Dissolved Oxygen Temperature
[37]	Water Quality Monitoring	IoT based WQM system proposed measuring parameters related to the health such as bacteria, E coli etc.	Temperature Turbidity E. coli. Fecal streptococci Dissolved oxygen Conductivity
[41], [42], [38]	Water Quality Monitoring	On surface vehicles based WQM systems utilizing IoT and Robotics	pH Turbidity Temperature Dissolved oxygen
[43]	Water Quality Monitoring	Fish (Dolphin) based robotic platform developed for WQ and Aquatic Life monitoring	pH Turbidity Dissolved oxygen Light
[44]	Water Quality Monitoring	Underwater Robot platform utilized for WQM using IoT and Sensors	pH Turbidity
[45]	Wildlife Animal Monitoring	IoT and RFID based system utilized for maintaining the data of animals	RFID
[46]	Wildlife Animal Monitoring	IoT based Animal health monitoring system utilizing GPRS and sensors to track the health of animal	Heart rate Temperature Load cell
[47]	Wildlife Animal Monitoring	IoT based animal behavior pattern monitoring for estimating actions such as standing, sitting, grazing etc. using previous data	Accelerometer
[49]	Wildlife Animal Monitoring	IoT based Wildlife herd monitoring in wild utilizing drone	BLE
[50]	Wildlife Animal Monitoring	IoT based Swamp deer herd monitoring for pattern	Location

		notice and related data acquisition	
[51]	Wildlife Animal Monitoring	IoT based horse herd monitoring for the speed, location and other parameters	Accelerometer GPS
[58]	Forest Monitoring	Forestry monitoring system proposed which utilizes drone and LoraWan for data acquisition and monitoring	Humidity Temperature Light
[54]	Forest Fire Detection and Monitoring	IoT and sensor nodes based system proposed which utilizes DL along with sensors for the change in environment to predict biomass fire	Humidity Pressure CO CO_2 Smoke
[55]	Forest Fire Detection, Monitoring	IoT and Image processing based forest fire detection and monitoring system proposed. System incorporates with the trespassing detection as well.	Temperature Smoke Fire Sensor Ultrasonic Rain Sensor
[56]	Forest Fire Detection	Forest Fire monitoring system prosed based on MCU and sensors for detection of change in temperature and smoke	Smoke Temperature
[52]	Forest illegal tree cutting	IoT and CNN based system proposed utilizing Audio detection and cloud processing for detection of axe noise to alert the relevant person for illegal tree chopping	Audio

Smart Agriculture

Agriculture is one of the major resource of food production and crop production providing raw material which is utilized for consumption and production of by products such as clothes, paper, oil etc. So for efficient economy of the agrarian countries, plant yield is of vital importance[59], [60]. IoT has a lot of potential that can be utilized in Agriculture for efficient irrigation, control and monitoring that would assist the farmers in getting the best out of the practices. Over the course of years IoT has found its applications in sub domains of agriculture some of them are listed below.

Irrigation system

Water for growth of plants is necessary. However, poor means and planning for irrigation of plants can result in loss of water which could be evaded by smart irrigation. Smart irrigation system provides data about environment and the soil along with moister level in soil, which can be used for making decision related to irrigation and control of water. Over the course of years, different irrigation systems have been developed using IoT which have proved their worth for smart system and saving water. Some of those systems are reviewed as follows.

In study [61], a smart irrigation system is developed which provides remote access to the user and provides the data such as environmental parameters, soil and moisture which can be accessed via android application. Irrigation can also be controlled using the application. System utilizes zigbee along with cloud computing for the task. In study [62], IoT based smart irrigation system is developed which utilizes sensors for soil moisture monitoring and makes the decisions for irrigation. Information about the soil and irrigation can be accessed via webpage by the farmer who utilizes this for monitoring.

In study [63], WSN along with Zigbee is used for creating a smart irrigation which monitors the pH, humidity, air temperature and soil moisture which can be controlled using fan, water pump and alerted using buzzer. WSN and Zigbee is used in study [64] for smart irrigation system which monitors and communicates the changes in the pH, humidity, air temperature via GPRS and can be accessed via webpage. In study [65], an IoT based framework is proposed which utilizes different sensors such as pH and humidity along with temperature sensors that are used for smart irrigation.

Soil Monitoring

Soil nature and composition is of vital importance for plant growth thus it plays an important part in agriculture. Conventional method of soil composition involves lab tests which require time and effort in collecting the soil sample, drawbacks of which are necessity of lab environment and small sample size. IoT has assisted in this matter by proving its potential for soil monitoring using sensors that measure different parameters which indicate the viable conditions for plantations. Some of the implementations in this regard are reviewed below.

In studies [66], [67] soil moisture and temperature are monitored using WSN in farmland. Systems are based on Zigbee GPRS and internet and can be accessed by web application. In study [68], agriculture monitoring system is developed which monitors soil parameters for smart agriculture. System utilizes Zigbee, IoT and Wi-Fi for the communication. In study [69], Soil monitoring is used for detection of water leakages around the pipeline utilizing soil moisture sensor and IoT. In study [70], authors propose a system which monitors and reports the soil parameters such as moisture, NPK values and pH using IoT system for agricultural purposes. In study [71], authors presented IoT based solution for soil acidity and moisture monitoring which can be utilized for the agricultural purposes. System proposed in study [72] presents a soil health monitoring system for agricultural purposes which provides the data about the soil health.

Fertilizers and Pesticides Control

IoT solutions have been utilized for pest control, to improve nutrient usage, efficiency, crop quality and yield. In study, WSN based system was developed for microenvironment greenhouse which used sensors for collection of plant data for taking appropriate actions for pest control, fertilization and irrigation. Systems like [73]–[75] have been developed which utilize IoT for Pest control for smart agriculture systems and application of drones for pesticide spraying. Systems like [76] have been developed for fertilizer and pest control by spraying utilizing IoT based unmanned aerial vehicle capable to fly above crops. IoT based robots [77] are developed for indoor farming which utilize IoT and sensors along with actuators for fertilizer distribution and pest control.

Logistics in Agriculture

Logistics in agriculture involve phases from production to commerce and transportation. Conventional methods or steps are laborious and cost time and amount in the agriculture. IoT has proved its worth in logistics from production to commerce and delivery of these agricultural produce. Different systems have been developed for efficient execution of these phases and data generation to improve future practices. System developed in [78] targets the production phase in which apple orchard was monitored and controlled for better production as agriculture management system was developed which would alert the user for abnormal weather conditions, pesticides etc. for better produce reducing labor cost. Similar systems are proposed in studies which monitor parameters to increase yield and crops.

System developed in [79] supports tracking and tracing of whole production procedure involved for the agricultural produce. Information system is also presented in the framework which presents the managing control and locate the business data for agricultural purposes. Framework allowed the consumers to ask queries for ensuring the quality of the produce received. System developed [80] in targeted the logistics section of transport and commercialization of the agricultural produce. Case study involved transportation of melons from one country to other involving the travel time of forty-six days. WSN nodes measured environment parameters along with travel conditions such as shocks for data production and monitoring of the transportation quality to maintain the Quality of the delivered produce.

Cattle Farming:

Cattle farming is an associated part of agriculture where farmers use cattle for getting milk, butter, yoghurt and related dairy products along with meat. For better yield from cattle farms, health and ambient environment for the cattle is of vital importance. Cattle health has few indicators which are utilized to judge and check for the state of health. Body temperature, movement patterns and related are utilized to check if the cattle is sick or not. IoT has revolutionized the concept of cattle farming by use of RFID tags for maintain the cattle age and related data of vaccination. IoT based cattle health monitoring systems have been developed by researchers which monitor temperature of the cattle and utilize accelerometer for the movement tracking of the cow state for itss health alerts as cows tend to eat less or move slim to none when they are sick. Automated ventilation and heating systems for the cattle farms by the use of sensors and IoT are developed and utilized to provide appropriate weather conditions along with the cattle health monitoring to get better yield[47], [81]–[84].

V. METHODS AND DISCUSSIONS

In the 21st century, there have been countless advances in technology. There is a coherent theme running through this progression. The Aim of the literature review is to identify and evaluate evidence for support and profits of IoT in Sustainable Environment and smart agriculture. IoT is believed to have great future potential, especially when addressing issues in a more cost-effective manner than traditional service delivery methods. We used the SLR criteria for the evaluation of eminence of retrieved studies. Four hundred and sixty three papers were downloaded and checked based on the search keywords from the repositories. Out of these, 193 were duplicates which were excluded. Remaining papers were studied and out of these 81 papers were selected for the study. Table 4 provides details about the implemented studies which were reviewed and included in study. Again some roles of IoT were so versatile that they were implemented and utilized in more than one roles (Soil monitoring in Irrigation system).

Studies selected for the review had their developments from four continents and number of inclusions from Asian countries was greater than any other. In studies related to IoT applications in Sustainable Environment, Water and Air quality monitoring had more concentration. IoT has its applications in wildlife management and preservation with actual studies implemented and tested in different environment and parameters. For water quality monitoring, universal parameters were temperature, turbidity and pH while particular parameters involved conductivity, dissolved oxygen, E coli and fecal solvents. In Air quality monitoring, parameters such as temperature, humidity and particulate materials were universal and gas concentrations, CO and CO_2 concertation monitoring was in particular parameters. In wildlife monitoring, applications showed great potential for monitoring the movement and related parameters of endangered species for preservation and providing veterinary first aid to the animals at earlies for sustainable ecosystem.

From studies related to Agriculture, it was discovered that higher chunk of the studies was focused on monitoring based systems however some of the applications involved control of parameters for the environment in greenhouse based systems. There were worthy implementations observed in logistics sector of agriculture that involved commerce along with the transportation of the yield and production. Data acquired by sensors would prove to be beneficial for the future transportation preparations. Actuators, pumps and valves along with drones/robotics were widely used for irrigation, fertilization, pest control and monitoring of the crops.

Table 3. IoT roles studied.

Application	Roles	Percent
Sustainable Environment	Water Quality Monitoring	15
	Air Quality Monitoring	16
	Wildlife Monitoring	12
	Forest Monitoring	10
Smart Agriculture	Irrigation system	14
	Soil Monitoring	12
	Fertilizers and Pesticides Control	10
	Logistics in Agriculture	8
	Cattle Farming	5

for math, etc.

VI. IoT Architecture

Implementations in the retrieved studies showed the potentials along with the architectures proposed for these IoT applications for large scale implementations. Certain sustainable environment and agriculture applications require instantaneous decision making for prompt response and alert system such as fire breaking out in the forest, endangered species health alert in case of critical conditions and prompt AQ alerts requiring low latency and real time response. Cloud computing ads delay and increases latency due to data uploading to cloud and processing at the end of cloud. For overcoming the latency issues, Fog computing can be utilized which brings the storage and computation closer to the sensor node reducing the delays and latency for computing. Some of the existing applications for the sustainable environment and agriculture applications are utilizing cloud computing for analysis of data and decision making. Over the course of years, more solutions suggest utilizing fog computing for the critical and fast decision requiring applications such as forest monitoring and related. Some of the architectures being utilized are discussed.

In study, author proposed cloud computing based architecture for IoT based agriculture applications to monitor and compute the data where data was uploaded to the server, analyzed and processed for making decisions[85]. It utilized sensing layer for data collection, which was uploaded to server and processed and decisions were made based on the computing. In study[86], authors reviewed cloud computing based architectures and proposed a multi-layer solution where cloud is only utilized to share the data with the user for monitoring agriculture environment and applications.

In study [52], cloud was being utilized for the detection of the sound of axe to identify and illegal chopping of tree. Sound anomaly was uploaded to the cloud, processed and utilized for identifying the chopping. In study[55], a combination of fog and cloud computing was being utilized where sensor data was being processed and images were taken for the processing to detect fire in forests. In study[34], fog based solution was utilized for AQM and server was utilized to share the data with the user to monitor real-time air quality. Similar systems were utilized for the AQM and WQM in which fog computing along with sensor layers were used for collection and processing of data and results were sent and simulated of the environment applications[31], [87].

Here we propose Fog based architecture which comprises of three layers as Sensing layer, Fog layer and Cloud Layer as shown in figure 2. This architecture incorporates for the applications requiring immediate response and alert system for taking action such as fire detection, endangered animals health monitoring, illegal tree cutting and wood theft etc. and the applications not requiring urgent response such as WQM etc. Sensing Layer contains different sensors for monitoring and data collection. This sensors acquire the data and send them to the hardware or application node consisting of controllers, Arduino, Node MCU etc. which transfer it to the immediate next layer which is Fog layer.

The fog layer consists of storage servers where collected data is processed, filtered and analyzed based on the application. It also consist of local gateway. Privacy and security features can also be implemented at the gateway. After processing, transformation and filtering of the data, it is shifted to the upper gateway which forwards the data to the cloud layer. It is assumed that the communication is carried out using secured channels in the network. At cloud layer, data can be stored and utilized for displaying purposes at the user end to show the real time parameters.

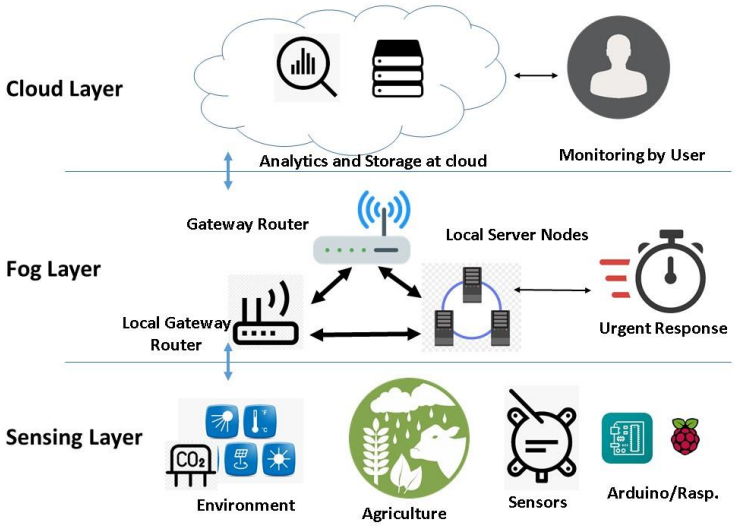

Figure 2: Proposed IoT Architecture for Agriculture and Sustainable Environment

Use of IoT for smart agriculture and environment applications is still in adoption stage. Challenges involved in the IoT for these domains still need to be addressed by the researcher. Some of these challenges and limitations are discussed in next section.

VII. Limitations and Challenges

After reviewing and analyzing the papers that were selected for SLR, following summarizes the insights that contribute for adoption of IoT at larger scale in reviewed fields and applications.

Standardization

Standardization would assist to increase the compatibility of IoT devices resulting in better security across IoT devices and all vendors from the base to the cloud computing and interfaces at end users.

Better Power Management:

Major drawback for IoT based solution deployment is the issue of Power for nodes. An efficient power management system or techniques that would lower the power consumption by introducing the low power sensors along with energy harvesting methods and secondary source of energy which would increase the endurances of IoT solutions.

Security

One of the major established challenge in IoT applications is of security problem. Few implementations address it by use of incorporated strategies for mitigation. It is evident that there is a need of IoT based solutions in Environment and related applications for utilization of proper end to end security of information and integrity of the devices that are deployed in the field.

Modular Hardware and software for Design:

Utilizing Modular hardware and software for the design of IoT applications in fields of environment, healthcare, assistive technology and related reviewed fields providing the users with the option to modify it according to their need and increased degree of reuse.

Unit Cost Reduction

With the advent in technology cost of embedded systems and platforms is decreasing rapidly with the increased options, however cost of precise and accurate sensors and actuators is still on the high end. For IoT to prevail our lives due to its immense applications, cost of the IoT nodes needs to be decreased for hardware, internet access and the data roaming.

Scalability considerations at early stage

Data synchronization, management and reliability becomes critical with increasing number of deployments. So scalability should be considered at early stage.

Robustness for field deployments

Sensors and structures used for the deployment should be rugged enough to handles the humidity, temperature and weather condition changes at times for climate variability across the globe.

User Oriented Design

Design of the commercial IoT solutions should be user centered and management, usage and deployment of the nodes for the non-expert should be easy and straight forward. Hardware should require minimal to none human intervention for maintenance during its life span and it should be intelligent enough to automatically correct its fault and in the network.

IoT Ecosystem

It should contribute to already existing Ecosystem as literature availability apart from prototypes is very low for the mature IoT solutions.

Adoption of better software Practices

With the increase of scalability of IoT solutions, time required for data sorting, analysis, code refinement and additions of new features would be really cluttered so well documented and designed software is of vital importance.

Sustainable Environment Practices

For IoT based solutions, recycling strategies should be vital considerations for the product life to reduce the impact on the environment. This should be considered even if the smallest realization of IoT adoption predictions.

VIII. Conclusion

IoT is revolutionizing the industries of agriculture and sustainable environment due to its immense potential. A lot of work is being done in this field. In this paper, IoT evolution over the course of years discussed. We provided review of IoT technologies for Sustainable environment and Agriculture applications. Considerable focus was on the sensors due to their key role in sensing and enabling IoT as surrounding perceiver for making decisions. Some of the key applications of IoT in Sustainable Environment, Water and Air quality monitoring, Wildlife monitoring and forest monitoring are reviewed. Key sensors utilized for the applications were pH, turbidity, conductivity, dissolvent, particulate materials, gas sensor, temperature, humidity, fire, smoke sensor and accelerometer.

In agriculture, IoT showed great potential for applications in irrigation, pest and fertilizer control, soil monitoring, logistics and cattle farming. Key sensors utilized for the purpose were NHK sensor, soil moisture, temperature sensor, radiation, and humidity and pressure sensors. Finally some of the important challenges reviewed for IoT applications were discussed and solutions were suggested for the same.

Studies reviewed in this paper provide a concise and compact view of proposed solutions for Agriculture, and Sustainable environment during the last 10 years. IoT has proved its worth in these fields and how it is revolutionizing them. It was observed that most of the studies involved utilization of different sensors along with WSN and fog nodes. However it is safe to say that future developments in IoT would need to utilize cloud computing and newer ways of connectivity for getting full benefits from fully connected ecosystem with the increase of the sensors. IoT Architecture is proposed for the applications in these fields. And limitations & challenges are also discussed. One of the major concerns in IoT is of security. In future, Comprehensive review for security in IoT sustainable environment and smart agriculture will be conducted.

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