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Internet of Things and Analytics for Agriculture, Volume 3

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Internet of Things and Analytics for Agriculture, Volume 3

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Preface

Edited book aims to bring together leading academicians, scientists, and researchers to exchange and share their experiences and research results on all aspects of Internet of Things analytics for agriculture. It also provides a premier interdisciplinary platform to present and discuss the most recent innovations, trends, and concerns as well as practical challenges encountered and solutions adopted in the fields. The book is organized into seventeen chapters.

Chapter "Functional Framework for IoT-Based Agricultural System" proposed IoT-based framework which consists of a coherent architectural viewpoint of the functional system. The proposed functional framework is useful in organic farming, monitoring of water, fertilizers, pesticides, crop yield and growth, etc. The framework provides timely valuable analysis-based help to enhance the agriculture production with quality of product and improve financial paradigm of farmers.

Chapter "A Review on Advances in IoT-Based Technologies for Smart Agricultural System" discusses the comprehensive review of available IoT solution in the areas of the agriculture which is presented. Some of the major targeted areas in the agriculture are selected, e.g., soil health monitoring, crop health monitoring, IoT-based smart irrigation, and real-time weather forecasting where automation can be implemented.

Chapter "Artificial Intelligence in Agri-Food Systems—An Introduction" gives an insight of the fundamentals of machine learning and deep learning with the emphasis on their application for AI implementation in the field of agri-food material handling. Popular ML algorithms, viz. support vector machine (SVM), K-nearest neighbor (KNN), artificial neural networks (ANN), decision trees, and convolutional neural networks (CNN), are discussed as feature description methods for classification and recognition, based on the product images.

Chapter "Intelligent Agro-Food Chain Supply" proposed IoT-based supply management system that could significantly contribute to improving the coordination of different strategic and operations units because of its remote operating ability. A strong coordination system among the different channels is the prime requirement of such a supply chain management system (SCMS). Coordination among the different channels can automatically improve the SCMS working efficiency in terms of operational and strategic decisions and timely delivery of goods on a priority basis.

Chapter "Machine Learning Approaches for Agro IoT Systems" analyzed the sensed data and machine learning approaches used in agro-IoT. Some of the machine learning algorithms are available for predicting the solution to the agriculture problems. ML algorithms learn from the given data and make the predictions precisely. A combination of optimized CNN model with deep learning neural network model provides promising results for IoT-based smart farming system.

Chapter "AI-Based Yield Prediction and Smart Irrigation" gives an insight about the current farming practices and several challenges that the farmers are currently facing. It also projects how to bridge the gap between these agricultural problems and challenges with the emergence of the IoT and AI technologies to sustain precision agriculture.

Chapter "IoT Enabled Technologies in Smart Farming and Challenges for Adoption" focused on how smart farming is digitally transforming using emerging technologies such as machine learning, IoT, computer vision, and unmanned aerial vehicles. Several key challenges for adopting smart farming are also discussed for providing sufficient information before actual implementation.

Chapter "IoT Based Agricultural Business Model for Estimating Crop Health Management to Reduce Farmer Distress Using SVM and Machine Learning" deals with the above-said drawback by implementing an agricultural business model which facilitates the farmers to know their crop and the market better. The farmers can grow and cultivate crops according to the market demands, thus leading to a good financial prospect and lesser loss.

Chapter "Rice and Potato Yield Prediction Using Artificial Intelligence Techniques" employed artificial intelligence (AI) techniques for rice and potato crop yield prediction model in the region of Tarakeswar block, Hooghly District, West Bengal, for rice and potato. The major variables used were climatic factors, static soil parameters, available soil nutrient, agricultural practice parameters, farm mechanization, terrain distribution, and socioeconomic condition. The analyzed datasets covered 2017–2018 seasons and were split into two parts with seventy percent data used for model training and the remaining thirty percent for validation.

Chapter "Socioeconomic Impact of IoT on Agriculture: A Comparative Study on India and China" objective entails the emergence of IoT and its widespread use has but provided for the evolution of state policies and strategies in India and China. The study undertakes comparative analysis, further utilizing mixed-method research, which utilizes both quantitative and qualitative approaches. Additionally, the chapter also deals with the huge impact of IoT on the development, growth, and other socioeconomic parameters of farming communities within India and China.

Chapter "The Impact of Irrigation on Generation of Marketable Surplus in the Bolpur Subdivision, West Bengal" addressed that the case study of Bolpur Subdivision is at the southeastern part of the Birbhum District, West Bengal, India.

Sources of irrigation of the study area are canal, submersible pump, tank and river lift irrigation. After consumption and keeping seed, farmers sold their excess production to the market.

Chapter "A Farmer-Friendly Connected IoT Platform for Predicting Crop Suitability Based on Farmland Assessment" proposed an economically innovative machine learning Internet of Things platform that can closely access and deliver the information pertaining to the attributes of the environment and soil. The proposed system was tested in real time at the local district of Karnataka state in India. The system accurately predicted crop cultivation in relevance to kharif and rabi seasons based on local environmental conditions gathered from the data made available by the Indian Council of Agricultural Research and also enhanced soil fertility by 33%.

Chapter "Smart Farming with IoT: A Case Study" discusses the brief about the different areas in which IoT can be applied in the agricultural field such as to know the weather conditions, to observe and monitor the field, and to analyze the crop health, planting, spraying the fertilizers, etc.

Chapter "Blockhain Solutions for Agro-Food Chain Systems" deals with the rapidly spreading blockchain, the opportunities it offers will be mentioned, and the studies using this technology in the field of agro-food will be examined. This study will focus on the challenges faced in this industry and the potential of blockchain technology in combination with advanced information and communication technology and the Internet of Things (IoT) devices to overcome these challenges.

Chapter "Efficiency and Reliability of IoT in Smart Agriculture" discusses the improvement of ICT in different areas for agricultural exploration. It is fundamental to increment the profitability of rural and cultivating processes to improve yields and cost adequacy with new innovation, for example, the Internet of Things (IoT). It can make rural and cultivating industry measures more proficient by decreasing human intercession through robotization.

Chapter "Architecture, Security Vulnerabilities, and the Proposed Countermeasures in Agriculture-Internet-of-Things (AIoT) Systems" aims to provide a survey of IoT systems, its enabling technologies, and communication technologies. Moreover, we provide insights into IoT-enabled agricultural applications along with its architecture and research challenges. Finally, we discussed the security and privacy issues that occur in agriculture IoT along with some cybersecurity attacks.

Chapter "Protocols, Solutions, and Testbeds for Cyber-Attack Prevention in Industrial SCADA Systems" investigated the security flaws and most significant protocols that could nullify the security loopholes. Further, the most suitable security recommendations are highlighted. Finally, the pre-mortem testbeds of cybersecurity dedicated for SCADA system have been clubbed together, which alerts the virtually developed SCADA system about possible threats before it is actually built on the real industrial ground.

We are sincerely thankful to Almighty to supporting and standing at all times with us, whether it is good or tough times and given ways to concede us. Starting from the call for chapters till the finalization of chapters, all the editors have given their contributions amicably, which is a positive sign of significant teamworks.

The editors are sincerely thankful to all the members of Springer especially Prof. Aninda Bose for providing constructive inputs and allowing an opportunity to edit this important book. We are equally thankful to a reviewer who hails from different places in and around the globe shared their support and stand firm toward the quality chapter submission.

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Raghvendra Kumar is working as Associate Professor in Computer Science and Engineering Department at GIET University, India. He received B.Tech., M.Tech., and Ph.D. in computer science and engineering, India, and Postdoc Fellow from Institute of Information Technology, Virtual Reality and Multimedia, Vietnam. He serves as Series Editor of Internet of Everything (IOE): Security and Privacy Paradigm, Green Engineering and Technology: Concepts and Applications, published by CRC Press, Taylor & Francis Group, USA, and Bio-Medical Engineering: Techniques and Applications, published by Apple Academic Press, CRC Press, Taylor & Francis Group, USA. He also serves as Acquisition Editor for computer science by Apple Academic Press, CRC Press, Taylor & Francis Group, USA. He has published number of research papers in international journal (SCI/SCIE/ESCI/Scopus) and conferences including IEEE and Springer as well as served as Organizing Chair (RICE-2019, 2020), Volume Editor (RICE-2018), Keynote Speaker, Session Chair, Co-chair, Publicity Chair, Publication Chair, Advisory Board, Technical Program Committee Members in many international and national conferences and serves as Guest Editors in many special issues from reputed journals (Indexed By: Scopus, ESCI, SCI). He also published 13 chapters in edited book published by IGI Global, Springer, and Elsevier. His research areas are computer networks, data mining, cloud computing and secure multiparty computations, theory of computer science and design of algorithms. He authored and edited 23 computer science books in the field of Internet of things, data mining, biomedical engineering, big data, robotics in IGI Global Publication, USA; IOS Press Netherland; Springer; Elsevier; and CRC Press, USA.

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Functional Framework for IoT-Based Agricultural System

**Manoj Kumar Sharma, Rajveer Singh Shekhawat,
and Ruchika Mehta**

Abstract In the present age of agriculture, governments are trying to increase yield production along with the improved financial health of the farmers. In continuation of the same, a visible technological advancement has taken place in agriculture. Internet of things (IoT) is one of the most revolutionary technologies which have been the game-changer in smart cities, transportation and its monitoring, new-age vehicles, healthcare, industry, security and agriculture, etc. IoT technology is mainly based on four factors: (1) high performance with reduced power requirement. (2) Sensors used to collect real-time data which stored on cloud-based storage for further analysis. (3) Big-data tools play very crucial role in analysis of captured data which is in different forms. (4) High-speed Internet connection plays very important role in IoT architectures. IoT has been the game-changer in the agriculture sector and is being used for various purposes (i.e. yield analysis, monitoring of water, soil, crop, etc., analyse the requirement of fertilizers and other gradients, pesticides requirement and many more). This chapter is presenting an IoT-based architecture modelling for the monitoring of various aspects related to agriculture (i.e. water requirements, soil health analysis, fertilizers and pesticides requirement) and a GPS-based monitoring system is also introduced. However, data will be collected from different sensor(s) and store on the cloud for further analysis. The proposed IoT-based framework consists of a coherent architectural viewpoint of the functional system. The proposed functional framework is useful in organic farming, monitoring of water, fertilizers, pesticides, crop yield and growth, etc. The framework provides timely valuable analysis-based help to enhance the agriculture production with quality of product and improve financial paradigm of farmers.

Keywords IoT · Food chain · Sensors · Wireless · Agro-products · Machine learning

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1 Introduction

Food is one of the basic necessities of life. Sixty percent of population in the entire world depends on farming for their food requirements. It is becoming very difficult to manage the food of the world population which is increasing rapidly. Because even today, most farmers give priority to traditional farming. Due to traditional practices in agriculture neither improvement in the quality of agricultural products nor production can be increased and similarly traditional practices in agriculture are responsible to an increasing shortage of food, as well as the economic condition of the farmer. In these days, the rapid growth of technology is increasing. The quality of the products as well as the production capacity can also be increased by increasing the use of new technology. As a result of which, along with the quality of food grains, economic growth of farmers can also be guaranteed. Also, the availability of food for everyone can also be ensured. The Internet of things (IoT) is a logical network of physical objects and devices. However, it has the information exchange capability without having any human intervention. IoT has been the integral part of all kinds of automations and drastically enhanced the productivity of the businesses. IoT network consists of sensors, robots, big-data tools for data analytics, machine learning and deep learning algorithms for data analysis and prediction, drones, some other electronic circuits, cloud storage, and processing mechanism, wireless networks, radio frequency identification (RFID), GPS, etc. IoT is one of the prominent technologies to enhance the agro-products quantitatively and qualitatively. The urbanization is increasing at the rapid speed and demand of agro-products is also rapidly increasing but the availability of labour is substantially decreasing for the agriculture operations. The IoT-controlled robots known as agribots are in high demand in the agriculture. They trained about the surroundings with the help of sensor and artificial intelligence technologies. Agribots are not substituting the labour cost but also increasing the yield productions and minimizing the wastage. The weeding robots are very helpful to identify the weeds in the crops with the help of image processing techniques and after identification easily weed out with the help of robotic arms. As we know, the excess use of the pesticides turning the fertile lands to the barren land and degrade the quality of the products which directly affect the human health. In this situation, removal of weeds with the help of agribots is not only saving health of the soil and crop but also saves the farmers hard money. GPS technology with the IoT control also helps the farmers to control their heavy farming equipment and machines like tractors to automatically ploughing the field from the remote place with high accuracy and the work progress also can be monitored through the mobile applications. Here, machine learning techniques also help the farmers to make their machines smarter. IoT-controlled agribots with the help of machine learning and image processing tools help the farmers in automatic harvesting of the crops (i.e. picking vegetables, fruits, etc.). Image processing and machine learning tools do not only help in the picking the fruits but also help in the identification of the ripe fruits and unripe fruits. Argibots not only help in the harvesting, ploughing and labour substitution but also help in the movement of heavy material, product, measuring the spacing between the plants at high accuracy, etc. IoT can control the drones also which can be equipped with the cameras and sensors, spraying chemical canes. With the help of such drones, farmer can monitor the growth of the crop, disease, pests and can automatically spray the pesticides in the specific area only, and this whole exercise can be done and monitored remotely; farmer needs not to come actually in the farms.

Another IoT-controlled technology which is very helpful and game-changing for the farmers is remote sensing. Sensors can be mounted in the different sectors of the field for different purposes (i.e. moisture sensors, heat sensors, health monitoring, pests' sensors, etc.) and data collected by the sensors stores on the cloud-based storage and big-data and machine learning tools uses analyse this high volume and versatile data for useful insights. Accordingly, farmer can monitor the crop in different stage and can take corrective actions. The monitoring with the help of remote sensing in agricultures is mainly for crop, weather, soil quality, irrigation and harvesting. An IoT-enabled agriculture framework is given in Fig. 1.

2 Scope of IoT in Agriculture

IoT is the new era of the future information communication technologies (ICT). IoT is a networking of devices (i.e. sensors, cameras, electronic devices, etc.). In an IoT network, devices are programmed to work together and crease an autonomous monitoring and control environment. Nowadays, IoT has been integral part of our daily life (controlling of TVs, air conditioner, refrigerator, washing machine,

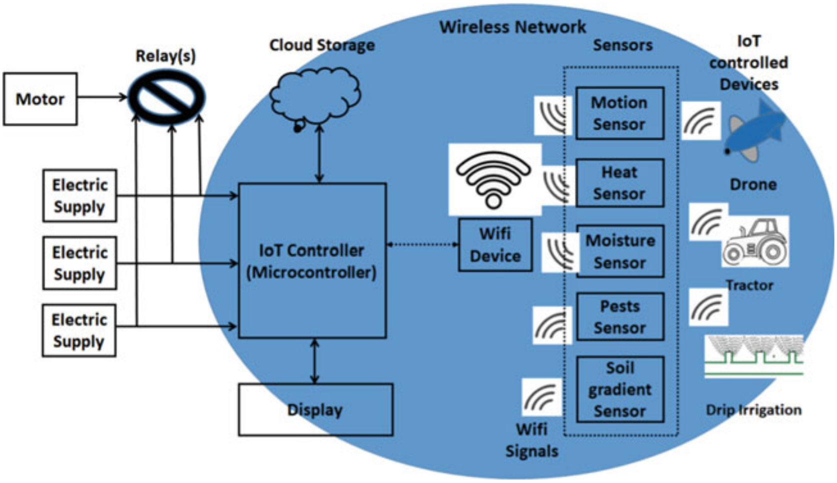

Fig. 1 IoT-enabled agriculture framework

electronic doors/locks, etc.). An IoT network is mainly depends on five components (i.e. sensors/electronic devices, cloud server, Internet, LAN and software application). Initially, IoT device(s) connects through the LAN and transmits data through cloud server, and from there, data reaches to software application through two-way communication.

(a) **IoT Devices**—are intelligent devices having wireless sensors and transmit data over the cloud server.
(b) **LAN**—network is used to capture data from the sensors and other devices.
(c) **Internet**—is helpful in the communication of servers and software applications.
(d) **Back End Services**—consist of end-user access, control, remote server(s), mobile apps. This service helps in the information exchange in between user application and devices.

IoT has a substantial impact on new-age agriculture technologies, monitoring, yield production, storage, transport and distribution, and it can moderate the production cost and minimize wastage of resources, agro-products and maximize the productivity of the farms. IoT is a hi-tech capital-intensive technology which helps the farmers to grow sustainable food with low cost and quality. In agriculture, IoT can help the farmers in many ways. Most importantly, it helps the farmers in (1) high-quality production with low cost. (2) It helps the farmers for storage, transportation and distribution of agro-products to consumer in time, with low cost and high gain.

2.1 Irrigation and Fertilizers

Right time irrigation of crops is very important for the health of the crop and qualitative and quantitative production of the yield. All crops and vegetations absorbs water content from the land water source or rainwater. However, surface water levels rest in deeper side of the earth and rainwater is available only for few months of the year, which demands for alternative irrigation methods. An alternative irrigation sources can be pounds, rivers and ground water. Each crop has its own life cycle, so the amount of water and number of times is varying and depends on some other factors (i.e. soil type, crop time, climate, amount of rainfall, way of cultivation, sunlight, life cycle). In agriculture, lack of information and knowledge about new tools and technologies is a biggest obstacle in the growth of this sector. Most of the farmers adopts agriculture practices as per their own understanding and knowledge transferred from their predecessors. The nature of the soil and its ingredients are not same through the globe. As per the region and climate, its nature also changes. The use of the fertilizers in quality, quality and type is also a challenging issue in the agriculture. In general, farmers are using their own knowledge for the farming and assessment of the fertilizer quantity and type is not possible without undersetting the soil requirements. Here also, IoT is very helpful. IoT-based sensor control mechanism can easily assess the nitrogen level of the soil, chemical composition of the soil along with the assessment of crop life cycle, type of the soil, its available ingredients and its actual requirement of the fertilizers. Excess use of fertilizers is not only giving financial burden to farmers but also destroying the soil health. An appropriate use of the fertilizer not only reduces the production cost but also helps to improve the soil and crop quality and health, which leads the increasing yield production.

2.2 Disease Control

According to some studies, around 15–20% of the crop destroyed by the pests and hundreds of pesticides are in use throughout the globe. The early detection of the pest can save this wastage of grains and can control the amount of pesticides used in the crops. One of the important mechanisms for early detection of the pests is image processing. Deep learning algorithms are capable enough to detect and prevent diseases and pests in the plants at their early age. The IoT-based machine learning solution can be provided to the farmers to remotely assess the amount of pesticides to be sprayed in the field to remove the present pest and minimize the chances of future pest attacks. AI-based algorithms can easily identify the faulty areas of the field and suitable pesticide and adequate amount can be sprayed in the target sector of the field. RADAR-based drones are very suitable solution to this problem because in the drawn we can have image processing units also which can assess the pests in the crop and can estimate adequate amount of pesticides to be sprayed in real time. RADAR-based drones are already having the longitudinal and latitudinal data of the field. This information helps the drone to target only the specified area. With the help of IoT-controlled application, we can assess the nitrogen, potassium and phosphorus value in the plants to monitor the plant health. Uncontrolled use of the pesticides has been a threat to the human health and has been cause of several critical illnesses. There is an international code of conduct which allows the judicious use of pesticides in crops. There are certain guidelines to assess the usages of pesticide in agriculture and food storage. The food safety and standard and health and family welfare of different governments are working over the standardization of the use of pesticides in the crops and foods. The geographical location of the cultivated land greatly affects food and supply chain logistics. The controlled use of the pesticides in the agriculture crops is mandatory to increase the fertility of the soil and quality of the crop which can save the bioorganisms lives in the field and is very useful for the crops also, and at the same time, it can prevent the harmful effects on human body. Nowadays, organic agriculture is another famous term which is frequently spreading in the agriculture business. It is the only mechanism which can sustain the health of crop, people, soil and ecosystem. In this, the use of synthetic pesticides is strictly prohibited. It develops useful agronomic practices like intercropping [1].

2.3 Precision Farming

Internet of things (IoT) is an appropriate and mostly usable technology in agriculture which transforms the traditional era of farming in to new era of precision farming. It uses the electronic devices and sensors, autonomous hardware and vehicles, robotics, etc. for the farm management [2, 3]. Smart irrigation and management of water resources is one of the key managements of precision agriculture. Optimized utilization of the water can enhance the productivity of the crop at low cost. Another key component of precision farming is monitoring the use of minimal fertilizers, identification of pest and use of pesticides. Monitoring is one of the active aspects in precision farming, and it can be done with the help of sensors and unmanned aerial vehicles. Precision farming is classifiable data collection, analysis, evaluation and implementation applications [2]. Use of multiview UAV systems in the agriculture monitoring can have a breakthrough in the agriculture. UAV can capture coloured imaged from different part of the field and later on these images can be analysed by the algorithmic systems and outcomes can help the farmers to take appropriate decision for irrigation as well as crop health. Nowadays, smart sensors are also integrated with the UAVs which helps mapping of grain volume during forage harvesting. With the help of IoT, UAV and sensor technology, the bottleneck in the breeding programs in farming can be mitigated in precision phenotyping and farming.

2.4 Crop Yield

IoT helps the farmers in growing quality agro-products with minimum cost. For the same, IoT can be used in the monitoring of the soil, crops, pesticides, temperature, light, moisture, humidity, etc. with the help of different sensors. It can help in assessment of irrigation requirement and its automation. With the help of IoT, physical assessment of the field conditions is not mandatory; farmers can monitor their field conditions remotely which is much comfortable to the farmers as compared to traditional agriculture. IoT has been the driving force behind the increasing agro-product production with quality and at low cost. The market cap of IoT devices and services in the market will be increasing up to 225 million dollars by 2024. Smart farming (application of ICT to agriculture) will enable growers and farmers to control every aspect of the production cycle reducing waste and enhancing productivity. There are certain IoT-based smart farming frameworks that are helping to revolutionize agro-production.

2.5 Storage and Transportation

According to different research reports, 25–30% of the agro-products are in wastage due to inappropriate cold storage and supply chain. Thus, demand of the fresh agriculture products has substantially increased. However, traditional transportation and distribution system is not capable enough to supply fresh agro-products to consumers in time. However, with the help of IoT technology, we can achieve fresh food supply to consumers, intelligent production of fresh agro-products, monitoring the cold storage and supply logistics in storage and transmission [4].

2.6 Livestock Monitoring

Livestock monitoring is the monitoring of cattle behaviour. IoT-enabled systems help the farmers to monitor the cattle behaviour and other activities like milking time, amount, speed, amount of food needed and consumed by the cow, how and how much it walks, is there any change in walking and eating pattern, etc. In livestock monitoring ambient sensors are used to estimate the moisture, stress, temperature, and hazardous gas sensors are used to estimate the amount of formaldehyde, ammonia, hydrogen sulphide, methane [5]. A real-time monitoring of the livestock health (temperature, heart rumination, rhythm, etc.) is done with the help of ZigBee and BLE like cattle sensors [5].

2.7 Farm Machinery and Maintenance

Agriculture machinery can be remotely controlled, and their maintenance is also can be done remotely. The IoT-controlled robots knows as agribots are in high demand in the agriculture. They trained about the surroundings with the help of sensor and artificial intelligence technologies. Agribots are not substituting the labour cost but also increasing the yield productions and minimizing the wastage as explained in Section 1 introduction and in [6].

3 IoT Framework for Smart Agriculture

As we know, IoT is a logical network of physical objects and applications. In agriculture, IoT implements through the sensors, imaging tools, robots, data analytical tools like big-data, machine learning, drones, GPS, etc. Initially, farmer has to invest for the infrastructure and equipment's like sensors, bots, drones, highly skilled staff, electricity and Internet connectivity, installation and maintenance cost of the equipment's, efficient supply chain. A detailed standard IoT framework for the agriculture is given in Fig. 2.

3.1 Hardware Requirement

IoT-based agriculture applications are having a network of wireless sensors, wireless network, Internet technologies, cloud-based storage, GPS, relays, big-data and machine learning tools, etc.

3.1.1 Sensors

Sensor technology is the key component of the IoT-based applications. In the agriculture, IoT-based solutions capture different type of data related to the soil, fertilizer, crop growth and its health, pests, environmental, irrigation requirements, temperature, harvesting requirements and many more.

Some of the important sensors which used in the agriculture are explained as:

(1) **Airflow Sensor**: This types of sensors are used to measure the wind direction and its permeability.
(2) **Optical Sensors**: Optical sensors are used temperature to predict clay, water content in the soil, organic matter in the soil.
(3) **Electromagnetic Sensors**: These sensors are used to measure the organic matter, water content in the soil, salinity of soil, soil texture, etc.
(4) **Electrochemical Sensors**: These sensors are used to measure the pH and nutrients level of the soil.
(5) **Acoustic Sensors**: These sensors are helpful in the soil texture formative.

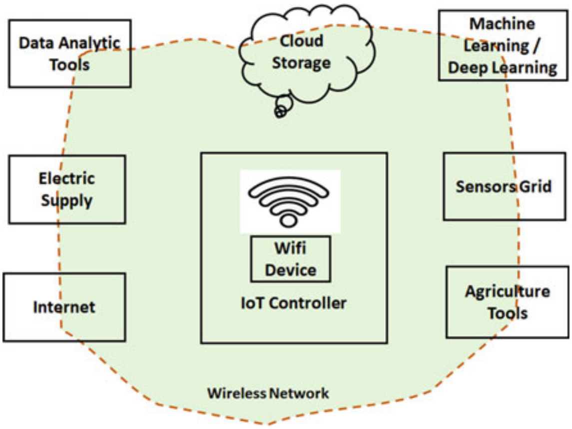

Fig. 2 Detailed IoT framework

(6) **Pest and Pesticide Sensor**: These are the sensors which used to monitor the pest in the crop and amount of pesticide is used in the crop.
(7) **Water Leak Detector**: These are the sensor which are very useful in the precision farming irrigation.
(8) **Rain Drop Sensors**: These sensors are helpful in the measure the amount of rain fail.
(9) **Water-Level Sensors**: These sensors are helpful to monitor the water level of the ponds uses for the irrigation purpose.
(10) **IPR Sensors**: These sensors are used to monitor animal intrusion.
(11) **IR Sensors**: These sensors are used to monitor the growth of the plants with the help of energy wavelength measuring.

3.1.2 GPS Module

GPS-based IoT applications used in the precision farming for the mapping, planning, soil health monitoring, yield mapping, crop scouting, machinery control and guidance regardless the physical presence of the farmer at the farm and odd environmental conditions like high temperature, rain, dust cloud, darkness, fog, etc. A GPS module uses obtained data from the sensors placed in different sectors of the field and drones. This high volume data sends to the cloud-based storage and monitoring system with the help of wireless sensor network. GPS module allows the farmer for pinpoint mapping of the pest, disease, weed in the crop. The collected data can be used with the drones to spray the pesticides in the pinpoint sections of the field with minimized chemical drift which ultimately benefited to the originality of the crop yield and environment. With the help of such GPS modules, the monitoring of the crop area is also possible by feeding the GPS map in the drone [7].

3.2 Relays

Basically, relay is a AC/DC switch which used to operate different electronic and electrical devices in the IoT-based agriculture architecture. Relays use solid-state, electromagnet principles to operate. They are mostly used when a low power signal is needed to operation a circuit. A contactor is a type of relay which used to control heavy motors and other electric devices. Electromechanical relays work as circuit breakers to detect faults and overload in the electric supplies. Relays are very useful in the radioactive safety-critical devices because of its high resistivity than semiconductors [8].

3.3 Software and Algorithms

Machine learning, big-data tools have been key components of the IoT-enabled agriculture applications. A wireless network is used to connect all the devices. This is very useful network for the peer-to-peer transmission of the data specially when Internet connectivity is not consistent. Various big-data tools are used in agriculture for the predictive insights of the agriculture operations (i.e. crop and yield health monitoring through the temperature data analysis, attack or possible attack of the pests in the field or in a specific area of the field and quantitative requirement of the pesticides in a specific area, irrigation requirement of the crop, etc.). Similarly, AI-enabled cameras, sensors and other operational devices can easily filter the data and other information in real time to take an appropriate decision in agriculture field as well as inventory monitoring and handling. With the help of machine learning algorithms, we can easily analyse different time stamp requirement of the agriculture. The health monitoring of the yield in the warehouses is very important and AI-enabled applications can easily handle this precious operation. Safety-critical operations also can monitor, controlled by the AI-enabled operations. AI and big-data tools are very important to improve the efficiency, accuracy, reduce production and other operational costs of the crop, etc.

3.3.1 ML-Based Image Processing Algorithms

Over the decades, machine learning algorithms are significantly contributing in agriculture. Prediction of the yield is one of the critical issues in precision farming. Yield prediction is based on various factors weather, soil, climate, seed quality and climate, etc. Long short-term memory, convolutional neural network, deep neural networks are the widely used deep learning solutions for agriculture products yield prediction and monitoring of the crops [9]. Machine learning algorithm can find the insight of the dataset and can predict the yield production. Some of the deep learning algorithms which are used in agriculture are:

(1) **Deep Neural Networks (DNN)**: In these algorithms, hidden layers are varying; otherwise, it is similar to artificial neural networks. In deep neural networks, most of the hidden layers are fully connected [9].
(2) **Convolutional Neural Network (CNN)**: As compared to other networks, it has less number of learning parameters. CNN network has convolutional layer which has feature maps and filters, and feature maps are the filter output. Pooling layer used to down sample the convolutional layer feature maps and minimize overfitting and generalized the feature representation. Fully connected is output layer in CNN [9].
(3) **Long Short-Term Memory (LSTM)**: This network works well with the sequential event prediction. So far, a number of LSTM architectures are presented (stacked LSTM, Encoder-Decoder-LSTM, CNN-LSTM, Vanilla-LSTM, Generative-LSTM and Bidirectional-LSTM [9]. Thus, multilayer perceptron

networks have some limitations like temporal structure, stateless, fixed sized input and output, messy scaling, etc. It is one kind of recurrent neural network, and it resolves all the limitations of multilayer perceptron networks.

(4) **3D-CNN**: In this, CNN model kernels travel through the depth, height and length and generate 3D activation map. The application of this network is in surveillance systems, medical where we capture video streaming [10].

(5) **Faster R-CNN**: It is a region-based CNN model and uses for object detection. So far, we have different variants of this family like faster, fast, mask convolutional network and R-CNN. A region proposal network is invoked in faster R-CNN network to interpret extended features to the [10].

(6) **Multitask Learning (MLT)**: In this model, a representation is shared among tasks to improve model performance. The application areas of this network are natural language processing, speech recognition and drug discovery, etc. [10].

(7) **Deep Recurrent Q-Network (DQN)**: DQN is the variation of reinforcement learning and deep learning. This algorithm is frequently uses with crop yield prediction [10].

3.4 Data Storage

The use of cloud-based services (i.e. storage, processing) is an essential port of any fruitful IoT-enabled agriculture application. In most of the village and farms, an uninterrupted high Internet connectivity is a myth. A peer-to-peer information exchange and decision are very important part of IoT-controlled agriculture applications. Different agriculture devices/sensors collect the required data and store it in the cloud storage. So the stored data can be accessed/analysed as and when required. A cloud-based data storage provides a kind of portability of storage, easy and efficient analysis of the data and in speculated time period. A big-data tools can find the insights of the data stored in the web. The use of cloud-based data storage and transmission provides a flexible, less time-consuming operations.

3.5 Methodology

As we know, IoT is a logical network of physical objects and applications. IoT works over the real-time data capturing, information exchanging, analysing and commanding, controlling to operations. Different sensors are uses to capture the real-time data (temperature, moisture, wind, irrigation requirement, crop health, yield production, pests, etc.). These sensors collect the data in time series manner and directly transmit to the local data storage through wireless network. Finally, data stores on cloud-based storage. From the cloud-based storage, different data analytic tools like big-data algorithms, machine learning algorithms, etc. analyse the data to discover the real insights of the data; on the basis of the insights, different operational activities are initiated like if there is a requirement of pesticides, if yes in which area? Only the required operation initiates in area-specific form. As per the moisture data of the soil, system automatically assesses the irrigation requirement of the crop and controls the water jets, motors in area-specific manner. Similarly, the health of the crop is also monitored by the IoT-based sensors and an auto-system takes required actions. With the help of IoT-controlled agriculture application even months before the harvesting of the crop, we can predict the possible yield production. After yield production, its storage and movement are also track and trace through the IoT-enabled sensors (i.e. GPS, temperature sensors, moisture sensors, etc.). After storage of the yield, the assessment of market demand and supply an automated IoT-controlled system can synchronize the supply of the agriculture yield to the consumer [11].

3.5.1 Architecture of Smart Agriculture Systems

Smart agriculture system builds with the help of intelligent technologies like IoT, big-data and machine learning algorithms for data analytics, GPS remote sensing, cloud computing for storage and analysis, sensors to capture data for different variables. There are two main components of the smart architecture: (1) data and (2) management.

In the farm architecture, various sensors are used to capture continuous data for different variables. The data remotely stores in the cloud storages and with the help of various data processing applications like data mining, video and image processing machine learning algorithms, decision support system, big-data tools, etc. The monitoring and mapping of the activities done through the data visualization tools where system monitors the environmental conditions, yield, temperature and sunlight, soil, etc. Finally, in the management, system manages the actuator, sensor, identification of the tools and devices, agent monitoring, vehicle control like UAV, finance services, etc. [12].

3.5.2 Sensor-Based Data Capturing

Different data variables responsible for the crop growth and production are acquired through the different sensors. Sensors have been integral part of the IoT-enabled agriculture operations. They can be mounted in or over the ground, UAV, trees and some other appropriate places. Sensors grid supports the remote sensing and monitoring of the agriculture requirements and functions. Different biophysical parameters of the agriculture can be assessing with the help of radar, satellite-based sensors. UAVs are another era of development and control of agriculture activities through IoT-controlled environment. UAVs can capture the aerial view of the crop and different variables can be captured with the help of GPS and cameras mounted on the UAV device.

3.5.3 Data Preparation and Feature Extraction

Traditionally, we irrigate the crops on the basis of farmer's knowledge and decent use of water for irrigation has been a great problem. Inefficient use of water for irrigation turns in less or more flooding of water, which results in reduced growth of crop and reduced availability of calcium to crop and crop rot and water wastage, respectively. IoT-based intelligent irrigation systems estimate the climate conditions and life cycle of the crop and then only finalize the irrigation plan. On the basis of such analysis, pump motor automatically operates when soil moisture reduced below welting point. In [13], Hargreaves et al. have proposed the smart irrigation method extra-terrestrial radiation and temperature. Different sensors, like heat sensor, moisture sensor, cameras, etc. collect the data. This data reaches to the data centre, where noises of the data filtered and applied with some smart algorithms to train the models. These trained models pretend the need of irrigation to the crops.

3.5.4 Classification and Quantification

Quantification of the feature is an important for the generation of adequate feature set and to understand the underlying phenomena. Thus, two machine learning features selection methods name RFs and BoRTs can be directly uses for the feature selection along with the feature quantification and classification of the data in different class using confusion matrix, decision-tree, k-NN, etc. Such tools work in both the forms, i.e. individual and sub-set evaluation [9].

4 Yield Prediction

Production of the agro-products is depending on various factors and integral aspects. Water is an integral aspect of the agriculture which directly affects the yield production. In the IoT system, different sensors are used to monitor the soil, crops, pesticides, temperature, light, moisture, humidity, etc. Readings from the different sensors are reached to microcontroller, which sends the information to cloud where it feeds to the analysing tools and visualize in required formats. Analysis of the sensors, data leads the identification of possible anomaly, if there exists, a quick response is initiated to resolve the issue, and further, it again assesses the percentage of anomaly resolver. On the basis of the assessment of such parameters, we can predict the possible production of the yield [14].

4.1 Hardware Requirement

Nowadays, a technological advancement has taken place in agro-products production. IoT is one of the important technology which is helping farmers in various means. However, various electronic devices like sensors have been integral part of today's farming.

4.1.1 Sensors

Sensors can be mounted at drones, robots, with the trees, weather stations and can be remotely controlled by mobile applications. A sensor-based data capturing is shown in Fig. 3.

There are some common sensors listed in Table 1 which are very common in agricultural.

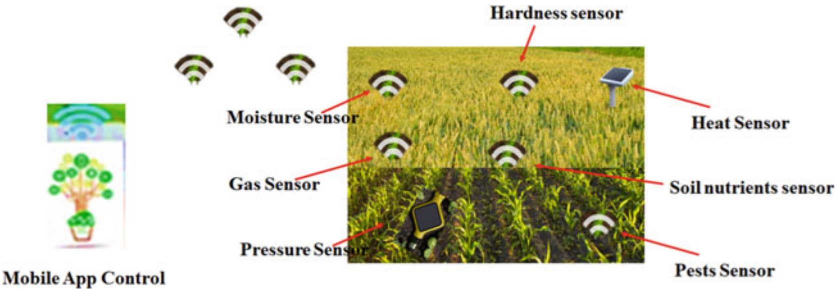

Fig. 3 Sensor-based data capturing

Table 1 List of agri-sensors [15]

S. No.	Agri-sensors	Functional implications
1.	Optical-sensor	Optical sensors are uses to sense soil properties (i.e. moisture, organic contents, clay, etc.) through light. Optical sensors can be mounted on robots, drown, etc.
2.	Location-sensor	Longitudinal–latitudinal–altitudinal position in a specific area can be determined with this sensor
3.	Air flow sensor	Permeability of the air is measured through this sensor, and these sensors can be used in both mobile and fixed places
4.	Mechanical-sensor	Mechanical resistance and soil compaction are measured with this sensor
5.	Electro chemical-sensor	Chemical components of the soil can be detected with the help of such sensors (pH level, nutrients in soil)
6.	Dielectric moisture sensor	Such sensors are uses to measure dielectric constant of the soil to assess the soil moisture

4.2 Software and Algorithms

Various advanced data analytics algorithms (i.e. machine learning, big-data, cloud computing) are the centre of gravity of the IoT-enabled agriculture applications. A wireless network is used to connect all the devices. This is very useful network for the peer-to-peer transmission of the data specially when Internet connectivity is not consistent. A detailed explanation of the machine learning-based algorithms is given in Sects. 3.3 and 3.3.1.

4.3 Predictive Models for Yield

It is very uncertain to predict the crop yield because of unreliable weather conditions. Thus, researchers are working over some sophisticated yield prediction models with the help of different technologies. Predictive models do analysis and observe the hidden patterns, and on the basis of such patterns, we try to gain insights that what will be the outcome of pattern extraction from the data (i.e. forecasting of consumer behaviour, price, yield, weather and demand). Machine learning is one of the key tools to develop such predictive models. On the basis of different models, it can be established that the climate change is impacting the yield production of different crops [16].

A parametric yield prediction model was presented by Jichong et al. [17]. In this model, OLS regression was used over the growing degree day (GDD) parameter which is about the time spend by plant in a specific temperature range. In this model, researchers explored different temperature bends and variation in plant growth. In [18], a crop yield assessment model was developed by dividing crop growth in four different segments specially in winter session. Initially, the Google Earth Engine was used to integrate data like soil, remote sensing data, climate data, etc., and interestingly model was able to predict one and half month before the harvesting time at national level and error rate was 0.75 only. However, various studies have established the superior performance of the support vector machine, Gaussian regression, random forest which are best performing in yield prediction [18]. In [19], crop yield prediction models were presented. This model is based on the crops of Andhra Pradesh's. A rainfall model was developed to predict the amount of rainfall during monsoon session. This model was based on modular neural network and with the help of support vector machine classification and amount of rainfall prediction the amount of yield prediction is predicted. In [19], an artificial neural network-based model was proposed for soybean and Maryland corn yield prediction in odd climate conditions. In this research, USDA NRCS soil rating and rainfall data were used. The learning rate of the proposed model was 0.90. According to this research, ANN network is best to predict soybean and corn yields in Maryland climate. In [20], a corn yield prediction model was proposed using long short-term memory (LSTM). The model was processing hourly weather parameters and predicting country-level time series-based corn yield prediction. In [21], wheat yield prediction model is proposed using multilayer online soil data. XY-fused network and counter-propagation ANN along Supervised Kohonen was used. The soil and crop parameters were used with the help of satellite imagery. According to this study, supervised Kohonen network is best performing in yield prediction. In [22], a field-scale maize yields prediction model that is proposed using time series weather inputs. In the proposed model, stochastic disaggregation, and nonlinear regression were used for different objectives. The predicted variance of yields was 28% to 33% during October to December. In [23], a crop predictive model for Indian climate is proposed. The proposed model was based on both linear and nonlinear models, and the crop prediction was done for two states of India (Telangana and Andhra Pradesh). A crop yield prediction system is given in Fig. 4.

4.4 Methodology

Prediction of the agriculture yields by accumulating and assessing different parameters (i.e. soil pH level, pesticides and pests, fertilizers, temperature, moisture, rainfall, wind). Different machine learning, deep learning and big-data tools are used to predict the crop yield.

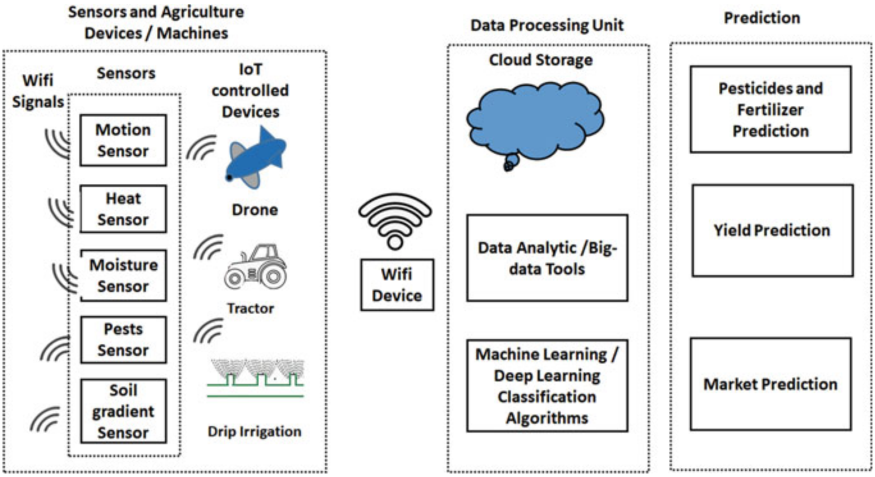

Fig. 4 Crop yield architecture

4.4.1 Architecture for Yield Prediction

An architecture of the crop yield prediction is shown in Fig. 3. This architecture of yield prediction of the crops consists of various essential parameters for crop yield outcomes classification. However, prediction models don't consider all the essential parameters for crop yield prediction which tends the degradation of the desired outcomes and efficiency, and it in result of inaccurate forecasting of the crop harvest. In traditional farming, harvest predictions are depending on farmer's knowledge about a specific crop and field. In machine learning-based predictive models, we use the existing data collected from previous knowledge and predict the harvest of the crop.

4.4.2 Sensor-Based Data Capturing

Nowadays, a technological advancement has taken place in agro-products production. IoT is one of the important technologies which is helping farmers in various means. However, various electronic devices like sensors have been integral part of today's farming. Such electrochemical sensors are used to acquire required data for precision farming (i.e. soil nutrients, pH, etc.). Sensors are used to assess soil health (chemical composition, ions, moisture, etc.). Farmers can easily monitor their farms and environmental conditions. Sensors can be mounted at drones, robots, with the trees, weather stations and can be remotely controlled by mobile applications. A brief description of the sensor is given in Sect. 4.1.1.

4.4.3 Data Preparation and Feature Extraction

Feature extraction and data preparation is the basic building block of classification. Data collection is the first step for the same followed by analysis of data and preparation. Preprocessing is the next level of data preparation which identifies the missing and inconsistent value from the dataset and filter them. Sometimes, we call this data de-noising process. In this step, we preserve the originality of data and eliminate random noises. There are different filters available to remove the noise (i.e. mean, min-max filter, Gaussian filter, etc.). In the next step, we perform feature extraction process which is most important step for data preparation. Basically, feature is a part of information which plays crucial role in classification. Feature extraction talks about the data form and each feature represented by a feature vector. In this step, we identify the most useful features (i.e. soil pH, humidity, amount of rainfall, temperature, etc.) for the training of the model. Finally, dataset splits in two training and testing datasets.

4.5 Yield Estimation

With the traditional multilayer perceptron algorithms, yield estimation is very limited. Some of the researchers are proposed yield estimation approaches. In [15], linear squared (LS)-SVM-based agro-yield estimator is proposed. It works will be complex datasets and can work with both classification and regression problems. In [24], a Spiking neural network (SNNs) is proposed for the estimation of crop yield with the help of image time series spatiotemporal analysis and having neuromorphic hardware with less power consumption. The proposed model is tested on winter wheat in China, and it is capable to predict yield six weeks earlier the harvest. Accuracy of the model is 95.64% and 0.236 error rate. In [25], a CNN model is proposed for the rice yield estimation using UAV sensed images. For the model, 160-hectare land was used with 800 management units. A fixed-wing unmanned aerial vehicle was used to click the images. In [26], a real-time yield estimation for vegetables and fruits was proposed using deep learning algorithms. The proposed model is robust enough for shadow, occlusion, etc. In [27], a synergistic metric approach was proposed for the yield estimation using EVI and VOD joint metric correlation. The proposed model combines both the time series in summarized statistic. The another machine learning-based estimation approach was also proposed using crop yield and indices relationship.

5 IoT-Based Irrigation Requirement

Water is very rare resource on the earth. The existing of all the living things depends on water. In the last few years, the water level in the geology has gone down sharply. Its main reason is excessive exploitation of water. Due to this, the entire earth is facing shortage of water. Farming is also not untouched by this. That is why, the need for new irrigation techniques is felt in agriculture, which can produce good quality crops in less water. Many times, more water is used in irrigation, which reduces the quality of the crop and also affects the fertility of the soil. The IoT-based smart solutions can help the farmer to irrigate the crops with decent amount of water. Such smart techniques save the wastage of water and minimize the irrigation cost also and increase crop productivity. In IoT-based smart irrigation system, different wireless sensors collect the data from the soil and predict the possible need of irrigation and can save 95% of water [28]. An IoT-based intelligent irrigation is shown in Fig. 5.

For the IoT-enabled smart irrigation system, various hardware like GPS, relay, wireless network, sensors, water leakage sensors, pressure sensors are needed which are explained in Sect. 3.1 hardware requirement for smart IoT-based agriculture architecture.

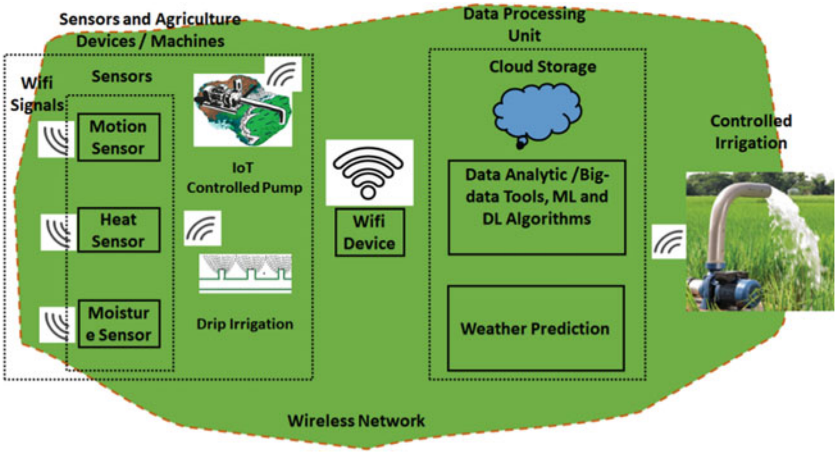

Fig. 5 IoT-based intelligent irrigation system

5.1 Methodology

An ultimate objective of the IoT-enabled irrigation is to optimize the use of water which helps to irrigate more agriculture area in the same amount of water which farmers simply use for small agri-field irrigation. A decent use of water for irrigation not only saves the water but also good for the crop health and yield production. If more and less quantity of water is used in irrigation, then there is also a problem of rotting or drying of the basal as well as the ripening of the crop at the right time, due to which both the quality and the quality of the yield are affected.

5.1.1 Sensor-Based Irrigation Requirements and Data Capturing

As the technology is improving, various classical and modern irrigation techniques are developed to determine moisture contents of the soil and predict irrigation requirements. The soil moisture sensors are very useful and complete IoT-based smart irrigation systems are depending on the data captures by such smart sensors. In the classical techniques, we include tensiometer methods, gypsum block, calcium carbide neutron, thermos gravimetric. However, modern moisture assessing techniques utilizes tensiometers, soil resistivity sensor, infrared moisture measuring, TDM and FDM capacitance techniques, micro-electro system, heat flux moisture sensors [29]. Real-time measurement of water contents using sensors can reduce the irrigation cost and save water. The use of sensors can be independent way or can be used according to the experiences. We distribute different sensors at different paces of the field. These sensors sense the temperature of air and soil, soil moisture and farm condition. The captured data collected at the base station for analysis, and on the basis of analysis, irrigation control station takes appropriate irrigation decisions [29].

5.1.2 Data Preparation and Feature Extraction

Traditionally, we irrigate the crops on the basis of farmer's knowledge and decent use of water for irrigation has been a great problem. Inefficient use of water for irrigation turns in less or more flooding of water, which results in reduced growth of crop and reduced availability of calcium to crop and crop rot and water wastage, respectively. IoT-based intelligent irrigation systems estimate the climate conditions and life cycle of the crop and then only finalize the irrigation plan. On the basis of such analysis, pump motor automatically operates when soil moisture reduced below welting point. In [13], Hargreaves et al. have proposed the smart irrigation method extra-terrestrial radiation and temperature. Different sensors, like heat sensor, moisture sensor, cameras, etc. collect the data. This data reaches to the data centre, where noises of the data filtered and applied with some smart algorithms to train the models. These trained models pretend the need of irrigation to the crops.

5.1.3 Sensor-Based Moisture Assessment

Accurate and timely information of the soil moisture plays important role in meteorological, water budding, agriculture, natural disasters prediction (i.e. droughts, flooding, erosions, dust storms), climate change. However, it is very expensive process due to repeated sampling requirement. Here, remote sensing is very important technology in timely collection of periodical information from a wide area. In remote sensing, intense vegetation, snow are the prime obstacles in assessing accurate moisture of the soil. We can assess accurate moisture information only when we have low soil cover. Sensors are the only solution which can work in both passive and active remote sensing technologies to accurately estimate soil moisture. So we keep the sensors around 5–10 cm deeper in the soil from the covered surface. There are some sensors which frequently used in the soil moisture measurements (i.e. resolution imaging spectroradiometer, microwave scanning radiometer, synthetic aperture radar, Pushbroom microwave radiometer, Earth Resources Satellites, land observing satellites, land surface temperature microwave imaging radiometer, electrically scanning microwave radiometer, thermal emission, etc.) [1]. Some of the moisture sensors are described below [15].

(1) **SM150-KIT**: It is a portable kit including SM150T sensor. It provides the organics and minerals of the soil.
(2) **ML3**: It is a ThetaProbe Sensor and has three rods around the central rod and creates cylindrical measurement zone of 60 mm * 30 mm diameter. It measures the soil temperature at high accuracy (i.e. ±1%).
(3) **WET-2**: It measures different soil properties like temperature, electrical conductivity and water content, roots nutrients, soil substrates calibration, crop growing condition, etc.
(4) **HH2**: It instantly assess the data from Delta-T moisture sensor and display water contents in the soil.

(5) **PR2**: It is known as profile probe to estimate soil moisture, with temperature sensitivity and low salinity.
(6) **EQ3**: It measures the soil moisture contents over 0 to −1000 kPa.

5.1.4 Irrigation Requirement Estimation

A time to time watering to the crops is the necessity of the crop growth and production of yield. All the vegetations absorbs water content from the land surface and rain fall. However, rainfall happened in certain months of the year, and for rest of the time, we need to irrigate crops with external source of water. Such external water supply sources can be pounds, rivers and ground water. However, quantity of water and number of irrigation are different for each crop. It depends on some factors like soil, crop time, climate, amount of rainfall, way of cultivation, sunlight, life cycle of crop because water requirement varies during the crop period. In most of the crops, we stop watering before the harvest. Sometimes, land becomes very dry and becomes very hard to crop to fertile. In such cases, paleo irrigation helps the crop to fertile and grew up. The watering process when crops are young is known as 'kor'. It is a single watering requirement and another watering pattern is time series basis. The 'delta' is another terms which describe the water depth water requirement for crop growth [30]. A certain requirement of watering can be estimated as:

$$\text{Per unit requirement of water} = \frac{\text{Volume of water supplied}}{\text{Irrigated land area}} \tag{1}$$

In most of the countries, the factors which affect the irrigation needs are temperature, sunshine, wind speed, humidity, etc.

6 IoT-Based Soil Health Monitoring

The base component of the agriculture is soil [31]. It contains required nutrients and some of its physical and chemical properties, i.e. pH, temperature and moisture certainly effect the crop yield. So monitoring of the soil health is very important factor which effect the crop growth and production. IoT-based soil health monitoring technology is helping the farmers to maximize the yield production, increase quality of yield, reduction of disease and pesticides, optimal utilization of resources. IoT-based sensors are capable enough to monitor temperature, moisture, radiations, oxygen level of soil, soil water potential, etc. This information reached back to cloud-based storage for further analysis, and outcomes can be used in optimal farming.

For the IoT-enabled soil health monitoring, various hardware devices and tools are needed (i.e GPS, relay, wireless network, sensors, water leakage sensors, pressure sensors). A detailed explanation of hardware and sensors is given in Sects. 3.1 and 3.1.1.

6.1 Methodology

An IoT-enabled system can monitor the soil health with the help of different sensors like temperature sensor to monitor soil moisture contents, pH value sensor for the soil, hardness sensor to monitor hardness of the soil, chemical and gradient monitoring, etc.

6.1.1 Sensors for Soil Health Monitoring

In smart agriculture, sensors play a vital role to assess the soil health, which can assess nutrients, temperature, oxygen level, sulphur, moisture and many more [31].

(1) **Soil Temperature**: Measurement of the soil temperature is very important because it affects the growth of roots, crop respiration, nitrogen mineralization, decomposition, etc. Soil temperature can be with the help of air temperature but use of buried in the soil and probe gives accurate reading of the temperature. As per the requirement and root structure, more than one probes installed at varying depths. Surface temperature of the soil can be measured with the help of IR technology-based sensors.

(2) **Soil Moisture**: Buried probes and electrodes can be used to monitor soil moisture. Soil moisture is very important component which is very useful in soil chemistry, ground water recharge and crop growth. It server nutrients to crop; it is essentially required for photosynthesis process, and yield production is highly effected with availability of water. It helps to regulate the soil temperature and measurement of conductivity of soil, volumetric water content, moisture and water potential in soil.

(3) **Solar Radiation**: Solar radiation plays important role in photosynthesis and plays crucial role in plant growth. It can be measured with sensors, which can measure active radiation, UV light, solar shortwaves.

(4) **Weather**: As weather plays important role in growth of crop and yield weather stations contain various sensor-based data (i.e. rainfall, air pressure, humidity, wind speed and direction, temperature, etc.).

(5) **NPK Soil Sensor**: NPK sensors can measure nitrogen, potassium, phosphorous, pH, temperature, EC and moisture.

6.1.2 Sensor-Based Data Accusation

Mounting of the sensors is very important to monitor different biophysical parameters to assess the soil health. Sensors can be mounted on UAVs, on trees, different parts of the agro-field. Some of the sensors-based monitoring in the IoT-enabled agriculture frame is discussed as:

i. **UAV Sensors**: UAV sensors are the optical sensors which use the light reflection to measure the variables of crop and soil. Cameras are used to capture the image data which further analyses through the photogrammetric process. A soil colour, vegetation, temperature, moisture contents, height of the crop, leaf status of the crop are some of the variables measured by UAV sensors. In the UAV sensors category, thermal sensor, hyperspectral sensor, multispectral, sensor, GPS and light sensor used.
ii. **Ground Sensors**: Sensors can be mounted in different locations of the field which called weather stations. From these stations, we can measure solar radiation, atmospheric pressure, rainfall, wind direction and speed, moisture level in air, etc. variables.
iii. **Electrochemical Sensors**: These are the sensors which are helpful in the assessment of pH and nutrients of the soil. Different magnitude value sensors are available for the measuring the membrane potential, conductance difference, impedance change, etc. [32].

6.1.3 Sensor-Based Fertilizer Requirement

Till today, agriculture is not profitable as compared to other businesses. Most of the farmers are doing their crop production with the help of their own understanding and knowledge. A different kind of soil present in the world, and each crop needs certain type of soil composition for efficient growth of crop and yield production. As on today, different IoT-based technologies have been developed to assess the soil health and recommend fertilizers in quantity and quality as per the soil health and crop requirement. Excess use of fertilizers is not only giving financial burden to farmers but also destroying the soil health. However, various sensors are available to measure the nitrogen level available in the soil, chemical composition of the soil along with the assessment of crop life cycle we assess the real need of fertilizers in terms of quality and quantity both, which helps to improve the soil quality and crop growth and yield production at minimized fertilizer cost [33].

6.1.4 IoT-Based Pesticides Monitoring

Food is the basic need of living things, and most of the food requirements of humans satisfies with the help of fruits, vegetables, grain, etc. These crops satisfy the hunger and give energy to human body. It fulfils the need of nutrition like fibre, minerals, folic acid, niacin, thiamine, vitamins, pyridoxine, etc. According to different studies, insecticides waste the 30–40% crops and yield. Farmers use pesticides to protect the crops from insecticides. The excess use of pesticides contaminates the yield with toxic chemicals, which increase the health risk of the consumers, and consumers are simply not able to identify such toxic chemicals. However, IoT-based monitoring system can assess both excess and moderate use of pesticides in the crop. Such technological tools work with antigen-specific antibody immune response system. There are some other methods to detect the pesticides in the crops through water sample analysis, gas and liquid chromatography, analysis of soil chemical composition.

Chromatography-based pesticides detection technology is used to detect organophosphorus pesticides. GC-MS-based technique is not able to the pesticides which have thermal instabilities and polarities. So a liquid chromatography-mass spectrometry technique is capable enough to detect such type of pesticides.

There are some IoT technology-based sensors as given below [1]:

i. **Gas Sensor (MQ135)**: with this type of sensors, we can assess the presence and intensity of atmospheric gases and can pretend the amount of pesticides in the crop.
ii. **Moisture Sensor (DHT11)**: with moisture sensor, we can assess the amount of moisture in the yield. The reduction of moisture in the yield is the cause of high amount of pesticides.
iii. **Temperature Sensor**: toxicity of the grain and fruits is significantly affected by temperature. Just by measuring the temperature of the fruit, we can say that the fruit is not eatable and presence of pesticides increase the temperature of the fruit.
iv. **pH Sensor**: with the help of pH sensors, we can identify the amount of pesticides available in the fruit or grain.

6.1.5 Image-Based Pesticides Requirement Analysis

According to some studies, around 15–20% of the crop destroyed by the pests and hundreds of pesticides are in use throughout the globe. An image-based detection of the pests and their possible attack helps the farmers to take preventive measure in advance. A camera and machine learning-enabled UAV can easily identify the pests and their possible attack in any section of the agriculture field. These aerial devices can automatically spray the pesticides in those specific areas only. A detail explanation of the pesticides and disease control is given in Sect. 2.2.

7 Outcomes of the Framework

Outcomes of the IoT-based agro-products supply chain management system are encouraging enough. It can change the entire agriculture beliefs and practices. With the help of wireless sensor network, Internet, Big-data tools, artificial intelligence techniques, it is not only saving the time and money of the farmers by taking smart decisions and optimal use of the tools and infrastructure available with the farmer. It contributes in increasing yield productions and quality of the crop and its yield. It helps in the storage and transportation of the agro-products and delivery of the quality fresh agro-products to the end user. A complete and efficient supply chain for the agriculture products is possible with the help of IoT-enabled technologies in the agriculture. As the scarcity of water for agricultural use is increasing, the size of barren farming is increasing. With the help of Internet of things-enabled technology, crops grown in less water can be easily selected, due to which not only water is saved, but good quality crops can also be produced, which is also necessary to improve the economic condition of the farmer. With the help of Internet of things technology, it also limits the identification and elimination of weeds in agricultural areas and excessive use of pesticides, which not only improves soil and crop quality, as well as avoidance of many critical diseases occurring in the human body. With the help of UAV and GIS-based technologies, the preidentification of the pest in a specific area and monitoring of the growth and health of the crop can be easily identified. The automation of the agro-tools helps the farmers in reducing labour cost and error-free activities, which definitely leads the efficacy and accuracy of the events but also increase the quality of soil, crop and crop production. After, harvesting the crop storage and transportation is another challenge in the agriculture, with the help of IoT-enabled services in the cold storage and transport vehicles; the monitoring of the yield in both qualitatively and quantitatively has been very easy which serves as a waste minimizer in agriculture products. With the help of IoT-enabled services, the demand and supply of the agro-products can be easily predicted and synchronized. This synchronization controls the price hike of the agro-products in shortage and price drop of the agro-products in case of excessive production. The wireless sensors and peer-to-peer communication ensures the information exchange in remote areas where Internet connectivity is not predictable. With the help of this system, we can minimize the wastage of the agro-products which leads the low cost purchase to the consumer and high profit to the farmers.

8 Summary

IoT-enabled agriculture mechanism is a revolutionary framework to uplift the traditional agriculture practices and management with minimization of the wastage of agro-products and operational cost. A quality fresh food can be supply as per the consumer demand at speculated time and low cost. IoT-enabled agriculture framework not only helps the farmers in the minimization of the wastage of agro-products and operational cost but also helps in quality seeds selection to the harvesting, storage, transportation, distribution, ownership, decision taking capabilities and responsibilities, etc. Various IoT-controlled sensors are used to assess different stages of the crop and yield in field as well as storage and their requirements. The agriculture tools and machines can be remotely controlled to reduce the labour cost of the farmer and sensor-based technologies can help in optimal use of such machineries. The hassles transportation and delivery of the agro-products to the cold storage and consumers are also ensured with the GPS and wireless sensor. The AI-based monitoring system is to help the operational activities with minimum human error with great efficiency and accuracy. With the help of peer-to-peer communication, this system can ensure the timely information exchange among different nodes even in the remote areas. The decentralized operations are the another level of technological and operational freedom in the agriculture activities which enhance the system productivity by taking run time decision and actions even than the central unit is not responsive because of Internet connectivity. An auto-approval process helps the stockholders to take independent decisions when they are not connected with other nodes. Finally, the increasing use of IoT technologies in the agriculture sector is not only increasing the yield production of the crops but also decreasing the excessive of fertilizers, pesticides, which are making lure barren and harming the human body. The use of IoT is a win–win solution to all the stockholders, government, market consumers, etc.

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A Review on Advances in IoT-Based Technologies for Smart Agricultural System

Amit Kumar Pandey and Arpita Mukherjee

Abstract Agriculture has a critical role in the overall development of a country. The demand for food is increasing day by day in the terms of quality and quantity, but the significant growth in crop production is comparatively less. Conventional agricultural process faces many difficulties such as dependence on the human power, weather dependency, lack of knowledge and lack of technology. The solution to this problem is the technology-based agricultural industry. The usages of information and communication technologies (ICT) can be a suitable solution for these problems. In Internet of things (IoT)-based system, the physical objects, e.g. sensor nodes, actuators work collaboratively to build a technology-driven system based on information to maximize the crop productivity. In this paper, a comprehensive review of available IoT solution in the areas of the agriculture is presented. Some of the major targeted areas in the agriculture are selected, e.g. soil health monitoring, crop health monitoring, IoT-based smart irrigation and real-time weather forecasting where automation can be implemented. Here, the overall idea along with the state of the art work in these targeted areas has been provided. The IoT-based crop and soil monitoring, automated irrigation system along with real-time weather forecasting can help to reduce wastage by the effective usage of fertilizer, pesticides and water, thereby increasing crop yield. An IoT architecture in smart agricultural model and a schematic model of IoT-based automated smart agricultural system comprising subsystems like soil health monitoring, crop health monitoring, IoT-based smart irrigation and real-time weather forecasting have been presented. The information obtained from these subsystems can be integrated using artificial intelligent (AI) algorithm, and accordingly, the alert can be sent to the farmer's mobile.

Keywords Smart agriculture · IoT · Smart irrigation · Soil monitoring · Crop monitoring · Real-time weather forecasting

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1 Introduction

Agriculture is the key source of food and considered as the basis of the human being's life. Agricultural growth is one of the major factors in the economic growth of the any developing countries like India, Nepal, Pakistan, Srilanka, etc. The researcher has found that the agricultural production is not increasing as compared to the growth of population [1]. The main reason for this hampered production of agriculture is that most of the farmers are using the traditional method of agriculture as by planting the same crops for centuries, but over the periods, soil conditions, weather patterns and epidemics of pests and diseases have changed accordingly. The forecast of the estimated world population is 9.8 billion by 2050, which is 25% more than the current population [2]. By keeping in view this figure, we need to produce more crop, not only for food, but also equally for the industrial crop like cotton, rubber, etc. The rapid increase in global population and high demand of quality products intensify the modernization and automation of agricultural practices which provide high efficiency and precision in the use of water and other resources like pesticides, fertilizers, etc. Today's farm activity is static and manual, which need to be more dynamic and intelligent. It is only possible by automatic farm activities by using information and communication technology, which is presently a key factor in the human's daily life.

The Internet of things (IoT), artificial intelligence (AI), cloud computing and edge computing are taking important roles to enhance the productivity of agricultural land in a precise manner. Technologies such as IoT-based monitoring of crops and soil, analysis of data through artificial intelligence for taking appropriate decision, automated irrigation system and weather monitoring and forecasting are in huge demand to improve the crop quality and detect the diseases in pests and plants resulting in enhancing crop productivity with a considerable decrease in farmers' dependency on human labours. The crop field can be monitored with the help of IoT devices and sensors. The edge computing collects sensor data from the crop field and sends it to the cloud where the data are processed and analysed to take a correct measure based on the analysis. So, there will be increased in production of crop, and it will also reduce the usage of water, fertilizer and pesticides in the field crop.

Agriculture is also a data-intensive industry which needs to collect and evaluate the information from the huge numbers of devices (e.g. sensors, automatic farm machineries and smart agribots) to make the production more efficient and keep appropriate information for future use [3]. This kind of the IoT-based agricultural system can be used to make farm activities automatic. The main applications, services delivered and sensors used in IoT-based smart agriculture are given in Table 1.

In this paper, we have presented a systematic review of advances in IoT-based technologies for smart agricultural system which consist of reviews on different submodules of the system, e.g. soil health monitoring, crop health monitoring, weather forecasting and smart irrigation along with the architecture of the whole

Table 1 IoT-based smart agriculture

Applications	Services	Sensors
• Soil condition monitoring • Crop health monitoring • Weather monitoring • Disease and pest control monitoring	• Automatic irrigation • Fertilizer control • Pesticides control • Soil preparation • Field crop management • Message services	• Temperature sensor • Humidity sensor • NPK sensor • Camera • GPS • Acoustic sensor

system. The chapter has been organized as follows. The IoT focused areas of agriculture like soil health monitoring in Sect. 2, smart irrigation in Sect. 3, crop health monitoring in Sect. 4, real-time weather forecasting in Sect. 5, Internet of things architecture in smart agriculture in Sect. 6, and schematic of IoT-based smart agricultural system has been discussed in Sect. 7. Further, in Sect. 8, the conclusion part is discussed.

2 Soil Health Monitoring

Soil is important natural resources which are present around us just like air and water. It is the habitats not only for human beings but the plant and animal also. It is called the stomach of plants, and its health is the most important part of the agricultural process, so various critical decisions are needed to take at different stages of the farming. The soil parameters which play critical role in the development of crops are soil moisture, soil temperature, soil nutrients and soil structure. The only way to know these parameters is soil monitoring. It provides a better farm management with a major benefit to the farmers by increased crop yield, reduced operating costs and providing environmental risk management.

Traditionally, soil was being monitored by directly going out in the field and physically handling the soil, taking samples and comparing it with the previous results from the soil information banks. However, most of the farmers do not have the means to know the appropriate pH level, sufficient water content, temperature of the soil, soil genesis type and soil nutrient availability according to the crop at the time of sowing. They face difficulties to maintain these parameters at the desirable levels. But in the today’s context, the soil is being tested using various sensors, e.g. pH sensor, temperature sensor, humidity sensor, NPK sensor, etc. It provides unparalleled and instantaneous information about what is going below the surface of the soil.

One reason for the reduced growth and yield of the plants is water stress. Farmers have to maintain a gentle water level in the root zone to get effective crop production. In [4] soil water deficit index (SWDI) is calculated by the use SMOS L2 in total span of one year in 2014. The other factor which is critical to analyse is the soil nutrient. Agrocares has developed a soil testing tool kit, LabinBox, which provides a complete solution for the soil nutrient testing. A farmer who does not have any lab experience can also analyse the nutrient level of his field without visiting any lab [5]. Presently in India, chemical technology is being used to analyse the nutrient level by providing the Soil Health Card (Mrida Card) to the farmers by confined laboratories [6]. But these are the very long process to get the information. IoT can solve this problem and help the farmers to control their crops remotely and take an appropriate instant action according the data provided by the sensors. By embedding IoT sensors in the agricultural field, farmers can monitor the moisture content of the soil and understand its chemical composition on a real-time basis. These devices are configured to notify the farmers automatically when the field data like moisture level and nutrient level reach undesirable values. By monitoring this data, they can restore these levels to their requisite level.

In the paper [7], the author presents an IoT-based wireless sensor network (WSN) system to estimate phosphorus level in soil using artificial neural network. To monitor the nutrient level in the soil, author of the paper [8] proposes an NPK testing kit with its IoT interface to provide the real-time sensor data directly to the farmers. It also integrates a cloud-based approach to assist farmers about their crops and field fertility. Author of [9] suggested a methodology to monitor the real-time data, by the help of sensors, of physical parameters of the field and its future prediction using MATLAB. This sensor's data are further mitigated to the cloud with the help of IoT-based technology.

To maximize the farm products and reduce the farmer's drudgery and unnecessary engagement in the farm field, some startup has provided a big hand towards making farming easy. A startup called PEAT GmbH, Berlin based, has developed deep learning-based application, plantix, to identify the potential defects and nutrient deficiencies in the soil [10].

The schematic of cloud-based soil monitoring system is shown in Fig. 1. Different types of sensors are used to evaluate the condition of the agricultural field. The temperature and humidity sensors are used to monitor the air temperature and humidity of the agricultural field. The soil moisture sensor measures the water content of the soil. Soil PH, NPK and EC sensors are used to measure the soil PH level, soil nutrient value (sodium, phosphorous and potassium) and electric conductivity of the soil, respectively. There parameters are used to evaluate the condition of the soil for any particular crop. The rain sensors are used to detect the real-time raining in the agricultural field. All these sensor data along with the weather station data are sent to the cloud. These data are processed and analysed with the artificial intelligent algorithm in the cloud to make a decision regarding the proper usage of fertilizer, pesticides and irrigation in the agricultural field. The decision/alert is sent to the farmers mobile to take appropriate decision. The data are also stored in the cloud for the future reference and taking appropriate action. In the next section, some more details about the IoT-based automatic irrigation system are discussed.

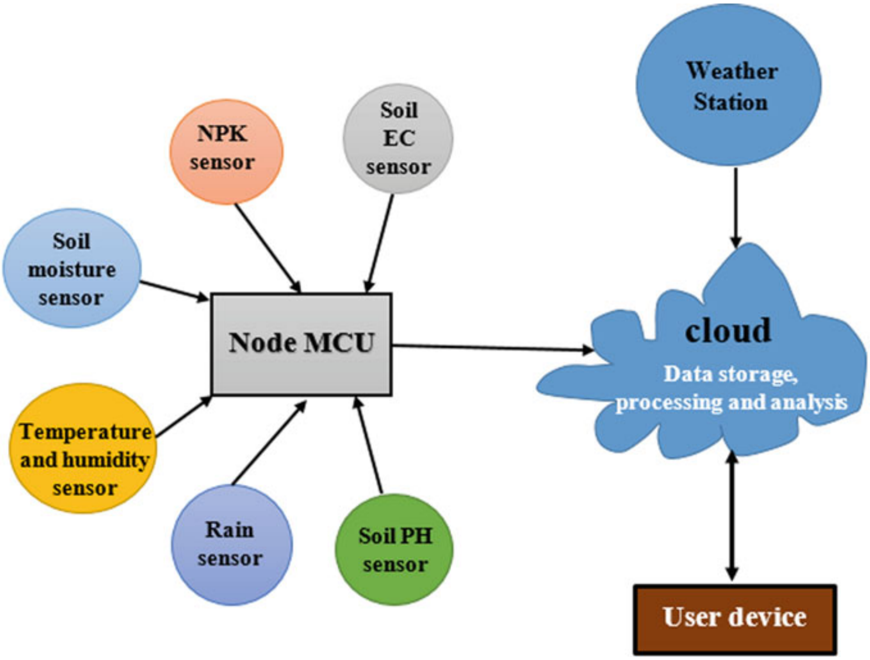

Fig. 1 Schematic of cloud-based soil monitoring

3 Smart Irrigation

Irrigation is the most important part of the farming. From sowing to harvesting, it plays a critical role in crop growth. Farmers mostly depend on the rainfall for water supply for field. But if rainfall does not happen, then they need to depend on the available water resources. According to [11], the agriculture accounts for 83% of total water consumption in India. This high water consumption is due to the unplanned use of water for irrigation and unawareness about the monitoring system. In upcoming years, this demand is going to high because of the high demand of food and a rapidly growing population. Farmers are using traditional methods for irrigating the field such as overhead sprinkler, flood type irrigation and so on. But they result in a lot of wastage of water. This wastage of water can cause a lot of problems like desertification, soil salinity, water accumulation, etc. 169 countries were affected by desertification during 2010 to 2020 as per United Nations Convention to Combat Desertification (UNCCD) [12]. By 2030, the half population of the world will be affected by desertification. There is an urgent need to develop systems that prevent wastage of water without hampering the farm productivity. There are so many controlled irrigation methods that have been adopted for watering the field, like a sprinkler system, drip irrigation system, but these are also not more effective. The accurate estimation of the water demand of crops is not a simple task because of a lot of factors like crop type, soil type, irrigation method, soil moisture retention, precipitation, etc. For that purpose, farmers have to visit their field periodically to monitor these things. To fulfil the demand of water for agriculture precisely and minimize the human intervention in the field, we need to adopt emerging IoT technologies for fully automatic irrigation or smart irrigation system. Author [13] proposed a GSM-based remotely controlled technology for irrigation. It will take the reading from the sensors and automatically irrigate the field, according to the humidity and temperature reading. A Bluetooth module is also implanted to exchange the information. In the [14], it is mentioned about the automatic rain gun irrigation system which is developed by the use of microcontrollers. In the same manner, author of [15] proposed a switch ON/OFF system using the Arduino board and ATmega328P microcontroller. It also integrates a GSM-GPRS SIM900A, SIM with 3G data pack to provide the IoT features to the system. There is a prominent example of variable rate technology (VRI) by crop metrics [16] to improve the water use efficiency. In the [17], smart irrigation techniques have been proposed. Sensors are placed in the field to monitor the data and the tank water level, and information will be sent through the mobile data communication network. The Web server uses intelligent software to analyse the data and acts according to those data. Water management system has been proposed by [18] to continuously monitor the water level in the tank and provides accurate amount of water to the plants. A smart irrigation technology based on IoT using Raspberry Pi is proposed in [19] to control the water motor automatically. A wireless sensor network (WSN) has been proposed in [20] for smart irrigation system. Data from different sensors, placed in the field, are received by ATmega318 microcontroller, sent to the Raspberry Pi to take the required decision and further transferred to the farmers. In the [21], a model was proposed for automatic control of the drip irrigation system. The flow diagram of the automated irrigation system is shown in Fig. 2. The pump will be automatically operated as per the condition of the soil. The soil condition will be evaluated with the help of the moisture/humidity sensors and temperature sensors. A probable diagram of the smart drip irrigation system is also shown in Fig. 3. Here, we can see that the water flow of the pump is controlled by the cloud-based control system as per the condition of the soil and weather. The moisture content of the soil and air can be evaluated with the help of soil moisture sensor and humidity sensor, respectively. Also the real-time rain and weather condition can be measured by rain sensor and weather station data in the agricultural field. All the sensor data are sent to the cloud for processing and analysing to take an appropriate decision regarding irrigation depending on the condition of the soil and weather, and accordingly, the pump is activated through cloud control system. The farmer can get the update about the agricultural field condition through their smart phone or laptop; similarly, the health of the crop can also be monitored which has been discussed in the next section.

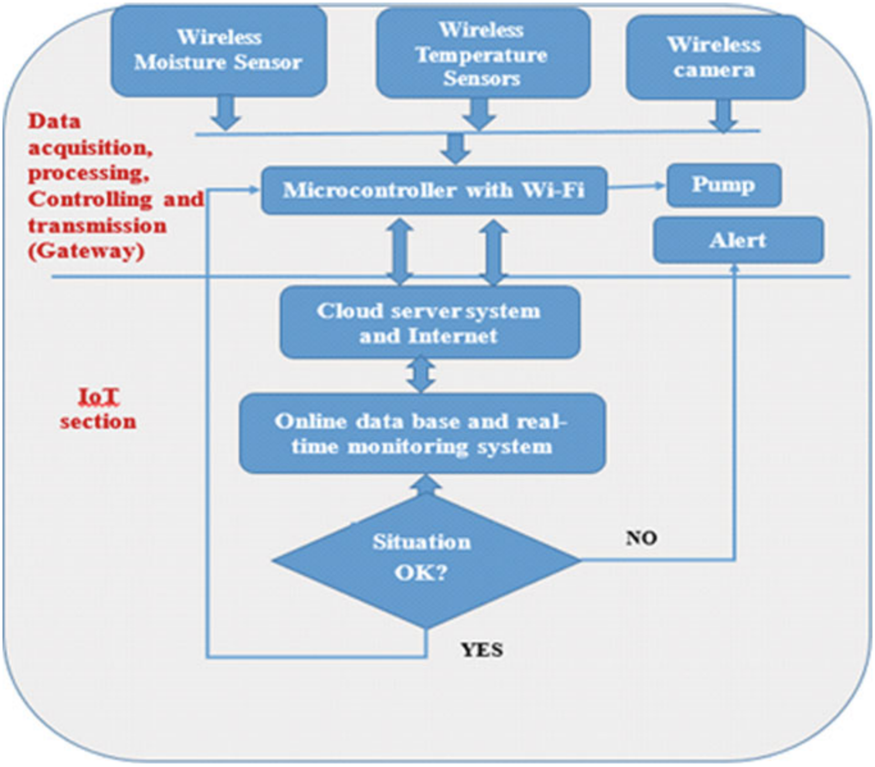

Fig. 2 Flow diagram of the automated irrigation system

4 Crop Health Monitoring

To fulfil the demand of the hour to increase the production of agriculture, crop health is one of the most important things. It is necessary to monitor the crop health from sowing to harvesting. Every crop goes several growing stages such as seedling, tillering, heading, ripening and so on. Each stage has own specific requirements like water, nutrient, temperature, solar radiation to grow them. Traditionally, this work is done manually. To detect the disease, deficiency of nutrient, insect attack detection is crucial, time-consuming and labour-intensive job. The accuracy is also very low by manually monitoring the crop's health. This will create a trouble to take appropriate measure which genuinely impacts the plant's yield and also affect the quality. For this type of difficulty, we need to have a technology-based crop health monitoring system which will improve efficiency, accuracy, decision-making capability, etc. As IoT becomes more effective in agriculture, it can be also integrated to crop monitoring. IoT-based technology consists of sensors, camera module, microcontrollers, SD card, WI-FI module, image processing devices, etc., to monitor the crop health, could make an exceptional impact.

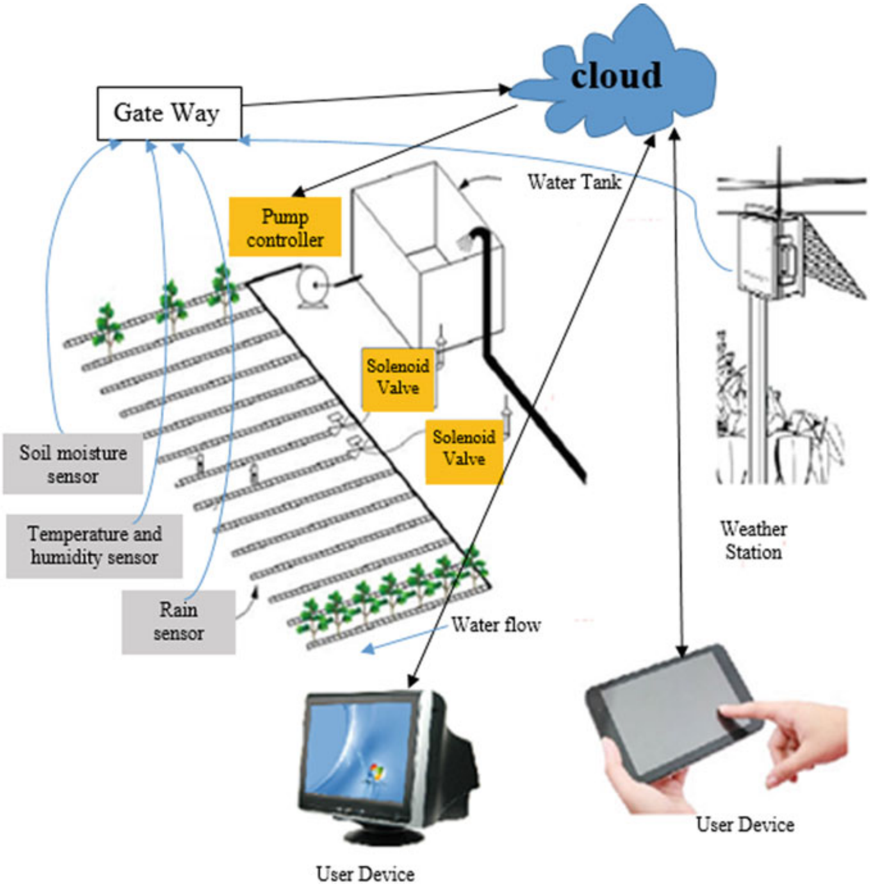

Fig. 3 Smart drip irrigation system

SkySquirrel Technologies Inc. is a company which developed a drone-based technology to monitor the crop, which helps farmers to improve their crop yield and reduce the cost.

In [22], the wireless sensor network and drone technology are used to develop a crop health monitoring system. Paper [23] discussed about the insect detection in plant. The paper [24], presented a technology to detect the disease by image processing technique and an IoT platform is used to communicate with farmers. In [25], author has proposed a system that receives images of plant, and after image processing is done, the crop growth is analysed. An automated crop system monitoring is developed in [26] for monitoring the cotton crop. It will provide the real-time data with deployed WSN about the health status of the crop. It provides preventive actions to reduce the losses due to disease and attack of insects or pests. Paper [27] represents IoT-based disease recognition in the leaf of apple and cucumber plant with an accuracy of 91%. Authors of [28] designed and implemented an approach to monitor the crop health in real-time basis. It uses motes to detect the wetness of the leaves of the targeted plants. In [29], authors have concentrated on the crop monitoring. Temperature and rainfall information is sent to the farmers. In [30], it is proposed that sensor data will be sent to the cloud platform and processing will be done. The outcome of that process will help to do the required action and send an alert to the farmers. In [31], author proposed a system to use the BeagleBone to process the information received from the different sensors and provide an accurate information to the farmers related to crop growth.

For monitoring the crop health, drones are also used which are equipped with the camera. For this purpose, in [32], a rover which is fixed with a camera developed to capture the condition of the crop for disease identification. Further, these data are processed by an algorithm to take the suitable action.

The schematic diagram of crop health monitoring is shown in Fig. 4. The decision regarding the management of the crop is taken by analysing several data obtained from different sources using artificial intelligence and machine learning algorithm. Multiple data are analysed, e.g. soil monitoring sensor data to evaluate the condition of the soil, which is one of the important factors on which the crop health depends. Also, the crop health can be monitored using the images taken by drone, satellite images, sensors mounted on the tractor, etc. These all data are sent to the cloud for further analysis. Also, GPS data of the agricultural field are used for field mapping which help area-wise monitoring and management of the crop.

5 Real-Time Weather Forecasting

In today's world, it is seen that the weather and the condition of the climate is changing day by day. This creates a very uncertain and unpredictable effect on the agriculture. Farming is totally dependent on the weather from timely sowing the seed to timely harvesting the crops. The factors like temperature, humidity, moisture and precipitation keep changing rapidly. Farmers and agriculture fields are continuously being affected by these changes and struggling to cope with these parameters. So, it is an essential need to have real-time weather data, which can inform the farmers in advance to take the appropriate decision at the right time and provide a solution to save their crop.

Weather forecasting is a prediction of the future weather condition at the present time [33]. In today's context, weather forecasting is becoming a part and parcel, but the most challenging task is to provide real-time data with a great accuracy. To fulfil this requirement, a lot of weather station has been installed at various locations. Here, we can monitor the parameters which are relevant to us. But the main problem is to transform these data personally to the farmers, which will help them to take the important decisions.

To overcome these hindrances, we need to implement the IoT in one more dimension of the agriculture which is called real-time weather forecasting. In [34], a

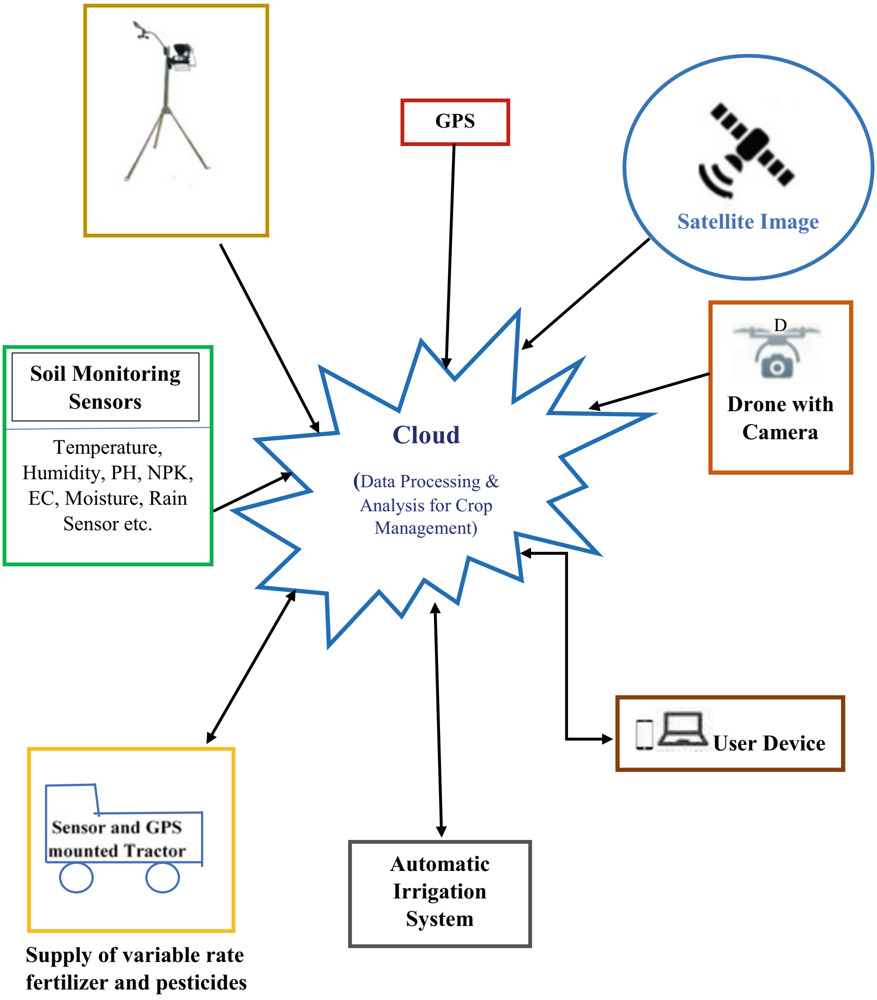

Fig. 4 Schematic diagram of crop health monitoring

low-cost weather forecasting system has been proposed which can be accessible from anywhere from the cloud database management system and will display the result on the OLED display. It comprises an Arduino platform with ESP8266-EX to retrieve the data from the cloud. A small-scale intelligent weather station is discussed in [35] to deliver the real-time data of the surrounding environment. It comprises a wind direction sensor, wind speed sensor and temperature sensor with the Dragon12-plus2 board to display the data LCD. In [36], author has proposed a system which is based on the micro-electro-mechanical system and wireless sensor network technologies for monitoring the environmental parameters. Another use of IoT is proposed in [37] which uses webpage based on LPC1768 to display the environmental data, and GSM network is used to inform the farmers about these parameters. To use the wireless technology in [38], it has proposed a system to collect the weather data and upload it to the online platform. In [39] a low powered and low cost weather station has been developed for the indoor environment using low powered wireless sensors. It uses low-powered wire sensors and SoC-contained GPRS module SIM800L. Gajbhiye and Dongre [40] propose a system which retrieves the data from the sensors and sends to a central server, which is microcontroller, and further, these data are uploaded to the Internet through Wi-Fi connectivity. A system in [41] uses ZigBee/IEEE802.15.4 equipped with wireless sensor networks to provide accurate and automatic information to the farmers about the real-time weather data by GSM SMS technology. A Raspberry Pi-based system is developed in [42], based on IoT, to provide the information about the PM2.5, PM10, temperature, humidity and air quality. A weather monitoring system is developed in [43] which uses the Node MCU to monitor the parameters like temperature, humidity and soil moisture trough the sensors. A higher resilience-based system is developed in [44] to monitor the weather parameters like temperature, humidity and rainfall using microcontroller on a real-time basis. In [45], a data logger-based weather monitoring system is proposed using a microcontroller to monitor the temperature, humidity, as well as CO with the suitable sensors. Some parameters like weather, temperature, humidity and rainfall are also affected by pollution. In [46], a system which is the coordination of Arduino and Raspberry Pi is developed to monitor the pollution-related parameters like carbon monoxide using pollution sensors. In [47], an IoT based integrated information system architecture is developed for environmental monitoring and management.

6 Internet of Things Architecture in Smart Agriculture

Internet of things (IoT)-based technology is the interconnected physical device which communicates with each other by the means of Internet which includes microcontroller, microprocessor, actuators and sensors. The rapid emergence of IoT-based technologies reformed almost every industry, including agriculture also, making them statistical to quantitative approach. IoT monitoring and automation of agricultural farm is replacing physical presence of human being and providing more benefits to the agricultural industry. It enables farmers to remotely monitor the farm activities by knowing the sensor values, which monitors the environmental factor, moisture content, temperature, soil health, transportation, animal monitoring, pest control and supply chain management, making the farmer’s work much easier to concentrate on the other farm activities. The objective of IoT in agriculture is to connect different agriculture-related things over the networks as shown in Fig. 5, where the different activities and conditions are monitored by interaction between the four layers.

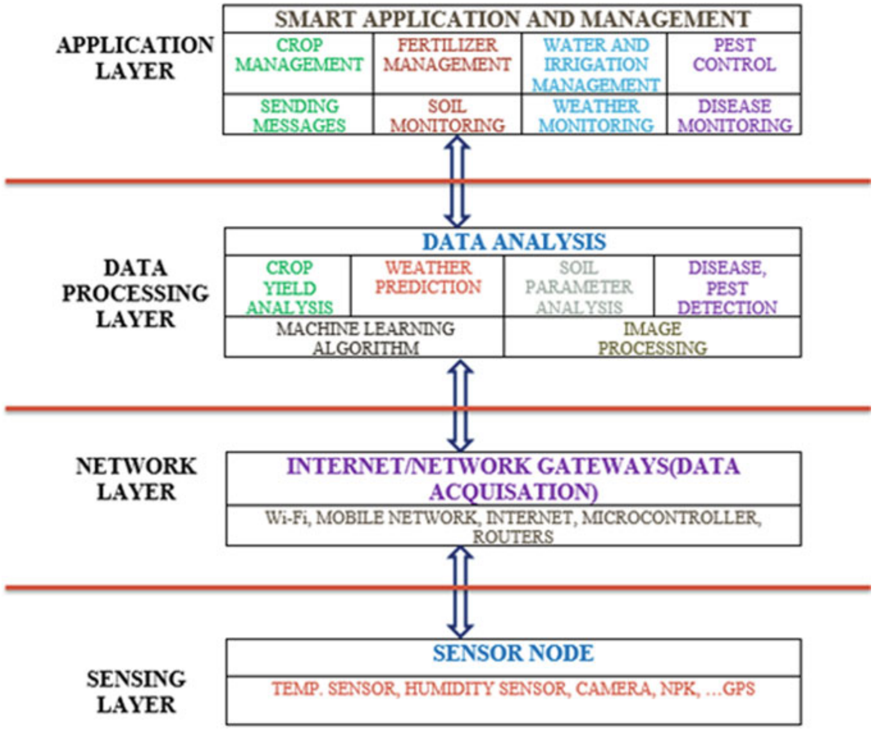

Fig. 5 IoT layer architecture in agriculture

Sensing Layer: The function of sensing layer is to sense the agricultural field for monitoring the conditions of the field and crop with the help of WSN node which consists of different sensors, e.g. temperature sensor, humidity sensor, NPK sensor, camera, GPS, etc., and radio-frequency identification tagged device.

Network Layer: This layer connects the different network together like sensor network and mobile network. This layer aggregates and shares all the information related to agricultural field, crop condition and also solves the problem of heterogeneous network issues, i.e. wireless and mobile.

Data Processing Layer: The function of this layer is to address the issues related to data storage, data processing, in-depth analysis of data and data management. The data are stored in the cloud for analysis and detailed insight in future also. Here, different artificial intelligence and machine learning algorithms can be used based on the sensor's dataset as well as data from other sources. This layer analyses the data, evaluates the condition, e.g. crop yield analysis, weather prediction, soil parameter analysis, disease and pest detection, etc., and takes decision related to management of these agricultural processes.

Application Layer: The user interacts with the help of this application layer. It delivers application-specific services to the user. This layer manages all application process based on information obtained from data processing layer. It involves sending messages, activating alarms, fertilizer management, water and irrigation management, pest control, crop management, etc., in smart agricultural system.

7 Schematic of IoT-Based Smart Agricultural System

The schematic block diagram of an IoT-based sensor network system for real-time agricultural field monitoring and management is shown in Fig. 6. The first unit consists of sensor network of several sensors node, which collects the information about conditions of agricultural field and crop, e.g. temperature, humidity, soil nutrients, crop condition, image, etc., using different types of sensors and performs some local processing. The acquired sensor data are then sent to the base station, i.e. the second unit where some initial data processing is performed. Then, the processed sensor data are uploaded to the cloud server through gateway for further analysis. These multi-sensor cloud data can be accessed by the user, and data analysis is performed using different intelligent and machine learning algorithm to evaluate the condition of agricultural field and crop and generate intelligent decision. As per the analysis of data acquired from different sensors as well as other sources, the alert is sent to the farmer regarding management of different agricultural process, e.g. fertilizer management, water and irrigation management, pest control, crop management, etc.

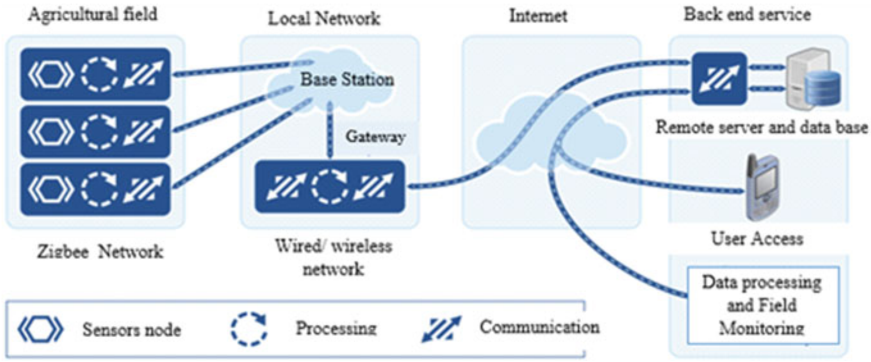

Fig. 6 System architecture for IoT-based wireless sensor network system

8 Conclusion

Recent research in the IoT has enabled it not to be limited in specific domains. Nowadays, IoT has become more versatile and dynamic to several fields like industry, medical, information system and also plays an important role in the agriculture. The agriculture enabled by IoT and modern technologies has worked as the bridge to maintain the gap between the production and quality. The proper use of advanced technology will expedite the growth in agricultural field and also will help the farmers different issues related to the agriculture. This review paper has provided an overall idea and state of art work regarding the application of the IoT in some core areas of agriculture, e.g. soil health monitoring, crop health monitoring, real-time weather forecasting and smart irrigation. It also discusses about the importance of IoT in the agriculture in the context of the present scenario. Instead of monitoring the crop health and soil health by human intervention, an IoT-enabled agricultural field can provide accurate information to the farmers anywhere in the world. Traditionally, irrigation is one of the most important tasks of farming, but nowadays, an IoT-enabled irrigation system can provide remote access to the farmers without going into the field. Continued and rapid development of the information technology in agriculture is an opportunity for business professional to explore and provide an easily accessible and reliable system for smart agriculture.

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Artificial Intelligence in Agri-Food Systems—An Introduction

Ninja Begum and Manuj Kumar Hazarika

Abstract Artificial intelligence (AI) is a replacement to human intelligence with expanded capabilities that has empowered the industries to handle and drive more complex systems. In agri-food industrial systems, an artificial intelligent system would drive a system towards the set objectives based on the information and knowledge gathered from the consumers, farmers, machines, and domain experts. Machine learning (ML) is the preferred tool to process the knowledge and information for identifying some underlying rules and patterns to support the implementation of the AI based solution. ML-based AI is preferred, because the heterogeneity in consumer preference, biological variability of material characteristics, and unpredictable system behavior presents a highly complex system to be handled by the rule based expert systems. This chapter gives an insight of the fundamentals of machine learning and deep learning with the emphasis on their application for AI implementation in the field of agri-food material handling. Popular ML algorithms viz., support vector machine (SVM), K-nearest neighbor (KNN), artificial neural networks (ANN), decision trees, and convolutional neural networks (CNN) are discussed as feature description methods for classification and recognition, based on the product images. Works from different researchers are cited to demonstrate the potential application of these techniques for solving real-life complex problems.

Keywords Artificial intelligence · Agri-food system · Machine learning · Deep learning · Material handling

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1 Introduction

Artificial intelligence (AI) is making machines intelligent in order to replace manual worker for automated decision making and operation. To overcome difficulties of manual tasks viz., being tedious, time-consuming, and labor extensive, mechanized process operations were adopted at the beginning of the industrial revolution, which has been continuously developed and now reaching another level with the integration of intelligence to the machine operated tasks. In the present age of advanced technologies, it has become necessary to analyze and direct complex tasks and systems for maximization of gain. Intelligent machines, with adequate training, are utilized to solve or optimize such tasks within shorter times [1]. Intelligence in machines is stimulated by adequate training with algorithms to mimic the human brain in information processing and making decisions, and thereby, making the machines capable of carrying out tasks similar to the human brain [2]. To work on AI algorithms, machines have to deal with numerous data [3] primarily on the system being analyzed. When a system is represented with a larger pool of data, it is expected to provide more accurate results [4].

Agri-food system is requiring to adopt advanced technologies in its pursuit to feed nearly 10 billion population by 2050. Also, automation is very much essential with the increasing demand to overcome the drawbacks of the traditional techniques used [5]. AI is already adopted in various aspects of agri-food systems. At the food production front, AI is being used for crop health monitoring, irrigation scheduling, weed detection, harvest scheduling. AI based machines are used to carry out operations at larger scale with better efficiencies. AI is also being used in handling of agricultural produces, with the goal of preventing loss and meeting the consumer acceptability. Effective implementation of an agri-food system encompasses relating the information from consumer to the post-harvest handling of produces including processing for value addition, as well as with the farm practices at the production stage. In terms of data to be handled, it involves information from consumer, information and knowledge of processing including supply chain and post-harvest handling, information on production practices at the farm. The rule based expert system that was taken as an option for having a system view of the agri-food practices is having a limited capability to handle such a complex system. These complexities are also the result of the variable nature of consumer demand, biological variation in product characteristics, dependence on uncontrolled factors, etc. Machine learning (ML) based AI has the capability to handle large data, extract rules or patterns of its own, make decisions based on the derived rules or patterns, and actuate. Hence, ML-based AI is gaining more acceptability in handling the complex problems of agri-food systems.

AI techniques are also used for tasks like quality assessment of food products, automatic sorting and grading of foods, recipe recognition, and dietary assessment. AI leads to non-destructive techniques and has the ability to assess and transmit large data in a few seconds without much human intervention. Overall, AI has gained recognition because of its ability to learn and interpret from data provided [6]. A brief discussion on ML-based AI for handling agri-food systems is presented in next sections.

2 Artificial Intelligence

2.1 Functioning of a Human Brain

Artificial intelligence attempts to make machines mimic the human. The human intelligence is characterized by its ability to—*Think*, *Learn*, *Act*, and *Decide*. Functioning of human brain is at the root of human intelligence. The human brain consists of a hundred billion nerve cells/neurons connected in layers that pass on the information and perform calculations [7] as shown in Fig. 1a.

A nerve cell or neuron consists of dendrites, a cell body, an axon, and synapses as shown in Fig. 1b. The dendrites collect signals and transmit information to the cell body/soma and axon. At the same time, the synapses[1] forward information to the next neuron. The transmission of information happens when synapses release neurotransmitters, resulting in communication between neurons [8]. One of the fundamental steps in artificial intelligence has been to process information in a way similar to human brain, and the technique has been known as artificial neural network (ANN).

2.2 Artificial Neural Network and Its Functioning

The artificial neural network (ANN) architecture is the base model of artificial intelligence. The ANN architecture is comprised of several layers—an input layer where the data are provided, hidden layers where classification tasks are done, and the output layers predict the output. ANN is the architecture that processes information [9], and is accountable for AI to attain such an outstanding advancement. The ANN models resemble the human brain's nervous systems functioning as shown in Fig. 2. According to Haykin [10], ANN is the interconnection of artificial neurons that mimic the human brain functionally and performs desired tasks. For an ANN to predict future data, it has to be trained once [11]. Once trained, the ANN model can predict similar patterns. The accuracy of ANN goes on increasing with the addition of more and more data. Just as the human brain, ANN consists of several layers for processing information. Each layer of the neural network consists of an arbitrary number of nodes, and the nodes function independently of each other. Each layer has a particular node termed the bias node. The bias nodes are

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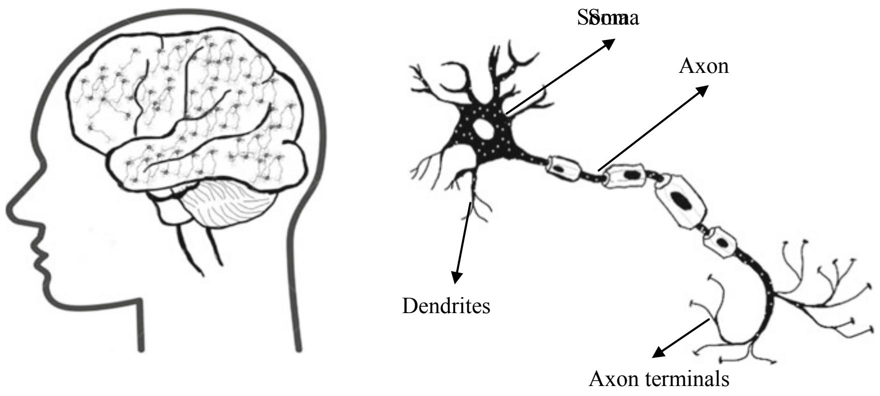
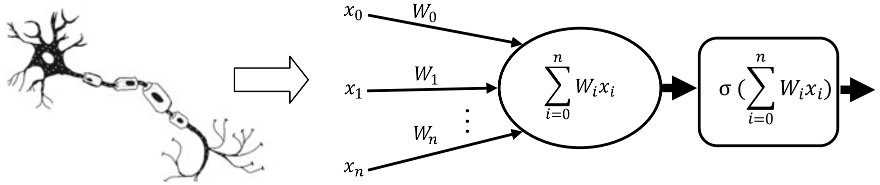
[1] Synapses are small gaps between neurons.

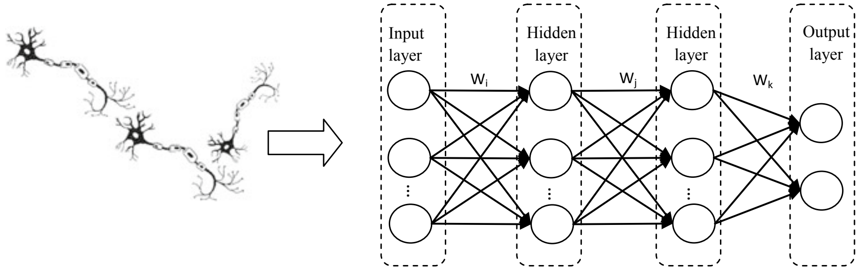


(a) Human brain (b) Nerve Cell or Neuron

Fig. 1 The pictorial representation of the human brain and a nerve cell or neuron



(a) Human neuron (b) Artificial neuron



(c) Biological network (d) Artificial Neural network

Fig. 2 Analogy between human neural network and artificial neural network

normally initialized to one. The bias provides a constant value to each node, but this constant value can be learned during training. Considering the line equation, $y = mx + c$, where '*m*' is the co-efficient of '*x*' and '*c*' is the slope. An analogy can be drawn between the bias node and the slope '*c*'. Nodes other than the bias node take the output of the previous layer nodes and produce an output. ANN as a classifier is used to train the network with input data such that it learns pattern in the data corresponding to each class. The trained ANN then helps in predicting the class of new data values.

3 Machine Learning and Deep Learning for AI Application

Artificial intelligence is a broad topic and covers wide variety of techniques. This chapter focuses machine learning and deep learning techniques as AI tools. Although there is a tendency to use machine learning as synonym for artificial intelligence, it is basically a subset of artificial intelligence. Similarly, deep learning is a subset of machine learning.

3.1 Machine Learning

Machine learning (ML) is one of the aspects of AI, which gives the computing machines the ability to learn patterns in data without being explicitly programmed for each task. It is the technique that employs algorithms to parse, learn from past data and predict for unseen data. It is used to train computers to utilize data to solve a specified problem. During training, ML requires a large number of datasets which are available from different sources. With the growing demand for machine learning and availability of datasets, large number of machine learning algorithms has evolved [12]. These algorithms are basically used to build models based on the trained data values and is further used for prediction. Image processing tools that allow farm manager to detect plant disease, fruit maturity, etc., are practical applications of ML. Mathematicians and data scientists have also involved themselves in solving a wide range of food related problems through the implementation of ML techniques. ML involves facilitating the machines to acquire knowledge from data provided to it. As numerous data is available on agri-food systems from various sources, ML techniques can be used effectively used in these systems to find the accurate prediction and help in decision making.

Machine Learning Practices. Machine learning is an attempt to make machines act like human by making them learn from data that comes its way. Based on the learning problems, as shown in Fig. 3, machine learning can be broadly categorized into—

i. Supervised
ii. Unsupervised
iii. Reinforcement

In supervised learning, the machine is trained under the guidance of an expert. The expert guides the machine to learn features from the input data to identify new information. In doing so, the entire dataset is divided into two class-training and testing. From the training dataset, the classifier learns and from testing dataset accuracy of the classifier is predicted as shown in Fig. 4. Once it is done new data can be used to predict the future information using supervised learning classifiers such as ANN, KNN, SVM, Decision Tree, etc. In unsupervised learning (also

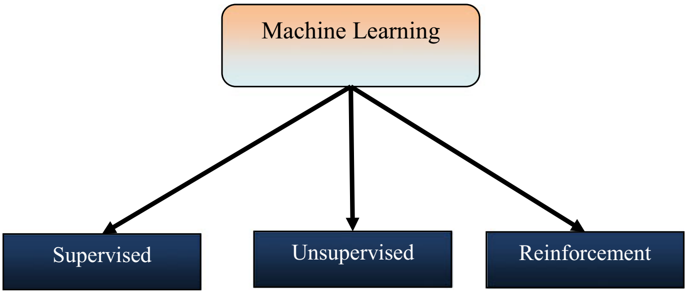


Fig. 3 Different categories of machine learning techniques

known as ‘self-learning’), features from the input data are learnt without the help of an expert. The dataset is carefully figured out finding out hidden patterns and making predictions of output as shown in Fig. 5. Unsupervised learning algorithms include k-means clustering, KNN, anomaly detection, PCA, neural networks, etc. Reinforced learning is completely an unseen scenario where the computer is allowed to make prediction on the provided inputs learning mechanism of reinforcement learning involves rewarding a correct decision and panelizing a wrong decision.

Machine Learning Algorithms. Machine learning is implementable through a wide number of algorithms. Such algorithms are programmed to analyze the input in order to predict the output. Here, a brief discussion is done on the algorithms that are mostly used for predicting food images. The most widely used ones are—

(a) Support Vector Machine (SVM)
(b) K-Nearest Neighbor (KNN)
(c) Decision Trees
(d) Artificial Neural Network (ANN)

SVM is one of the widely used methods for classification and regression. All data points contained in a data set are used to generate a hyper plane, such that the whole data points are divided into separate classes. A hyper plane acts as a decision boundary for the different classes. However, there may be more than one hyper plane in a classification problem. Which one to be chosen? The algorithm chooses the hyper plane that maximizes its distance from the boundary data points of each class. The data points from each class closest to the hyper plane are called support vectors, and the distance between the hyper plane and a data point is called margin. The SVM algorithm finds a hyper plane that maximizes the margin. Later, new input data points are classified into one of the classes based on the decision boundary created by the hyper plane. Figure 6a gives a graphical representation of the working of SVM algorithm.

Another prominent machine learning technique is K-nearest neighbor (KNN) [11]. The algorithm used in KNN is simple and based on the assumption that object

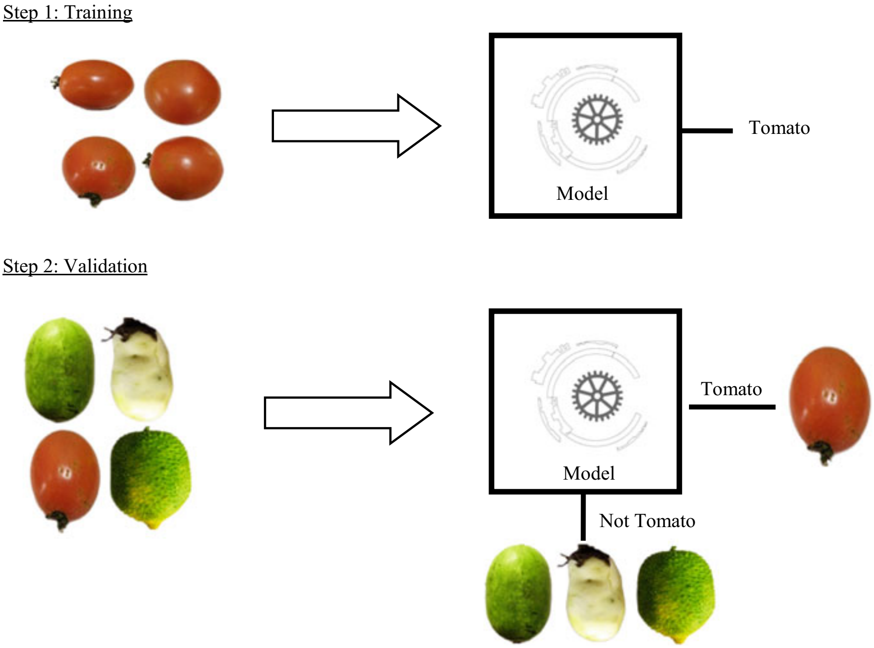


Fig. 4 Pictorial representation of supervised learning

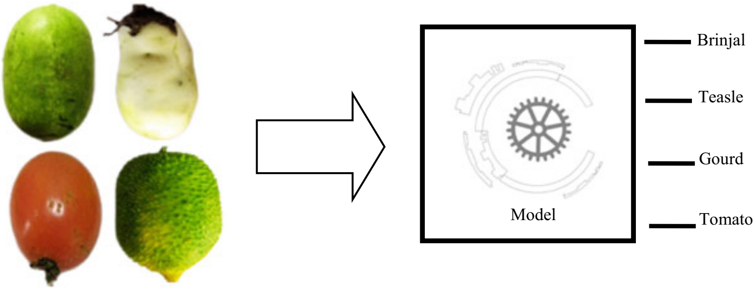
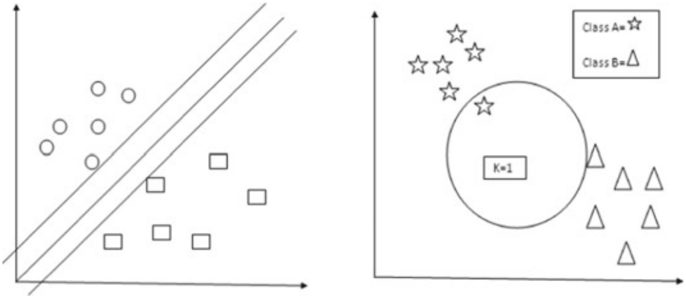


Fig. 5 Pictorial representation of unsupervised learning

in close proximity are similar. The closeness between two data point is calculated based on the Euclidean distance. Mathematically, Euclidean distance is calculated as—

$$\text{Distance}(x, y) = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2}$$



(a) SVM (b) KNN

Fig. 6 Insight into the classification mechanism used in SVM and KNN

The KNN algorithm predicts the class for new input data points based on its neighborhood information (closest data points). The numbers neighbor data points needed to predict the class for a data point needs to be supplied to the algorithm. For image classification, during training the extracted feature vectors from the training images are labeled based on its class and stored. Then in the testing phase, a new input image is classified by finding *K* feature vectors that are closes to the input image's feature vector. Out of the *K* feature vectors, the maximum number of feature vectors that belong to a particular class is assigned as the class of the input image. Figure 6b gives a graphical representation of the working of KNN algorithm.

Decision tree is a powerful supervised learning model having capability to learn with high accuracy from categorical data. The algorithm basically prepares a simple tree-like structure which is then used for classification or regression. In the training/learning phase, the goal of the algorithm is to learn simple decision rules on the feature sets. These simple decision rules are the test condition in the internal nodes of the tree. The child nodes or the leaf nodes in the tree represent the class labels. A branch in the tree is set of decision rules to predict a class outcome. In order to predict a class label, the algorithm starts at the root node and test the decision rule. Based on the decision outcome, the algorithm follows the branch which satisfies the decision rules and jumps through the internal nodes and finally reaches the class label. The class label is provided as the predicted class for the input data. A simple decision tree structure to predict tomatoes based on color and shape features is represented in Fig. 7.

As elaborated in Sect. 2.2, the functioning of human brain has inspired development of ANN, and it is a supervised learning model. Interconnection of artificial neural neurons forms an ANN. The neurons in an ANN are also termed as nodes, and the nodes are organized in layers; more complex network, more number of layers. This is the reason why sometimes ANNs are also called as multi layer perceptrons (MLP). Each neuron in a layer performs a simple operation on the input value and produces an output. The output is then given to an activation function to decide where the neuron fires or not. When the output of the neuron in a layer is

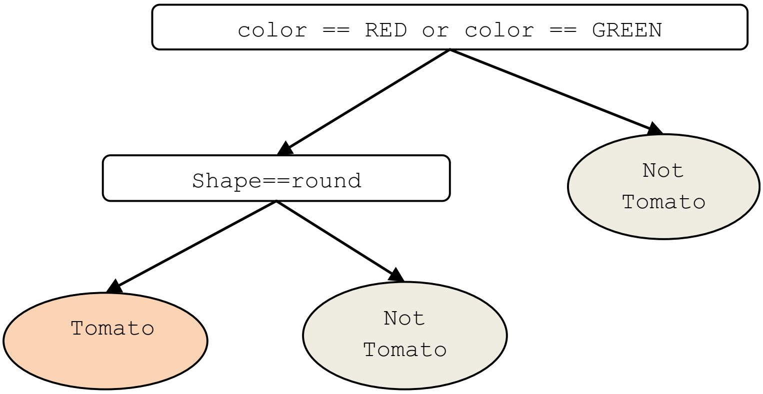


Fig. 7 A simple decision tree structure

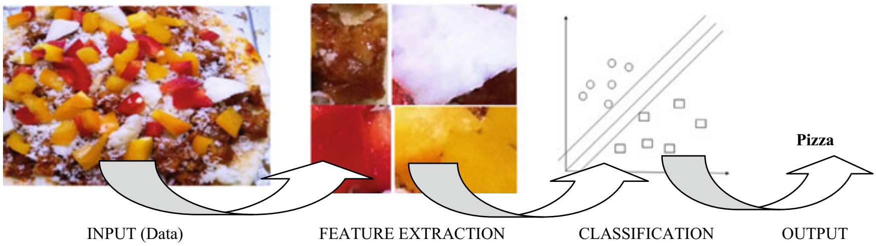


Fig. 8 Classification steps using machine learning

given as input to the neuron of the next layer and the connections do not form any cycles, then the ANN is called as feed-forward neural network. In order to train an ANN, back propagation technique is used as the standard. This technique uses a loss function to calculate the error and back propagates the error rates to adjust the weight in each layer. A trained ANN is then used to predict the class of the given input data point for a classification problem. The applications of these algorithms in the field of food identification are highlighted in subsequent sections.

Food Image Classification Using ML. Most of the ML-based food identification based on image recognition and classification. As illustrated in Fig. 8, the series, of steps undertaken to perform the classification tasks [13], is discussed below.

i. *Preprocessing*—This step involves improving the image data (features) by eliminating unwanted elements present enhancing the targeted features. Three major steps include: (a) Image conversion from RGB to HSV, (b) Image noise removal, and (c) Image crop.

ii. *Detection of an Object*—Detection includes segmentation of the image and identification of the segments of interest. Segmentation of the image is separating a digital image into smaller sections. This is done to separate the background for accurate evaluation.
iii. *Feature Extraction and Training*—Feature extraction is identifying the most captivating patterns of the input image. For each class of image, a unique feature is extracted which distinguishes one image from the other. Feature characteristics mostly color, size, shape, texture are fed to the classifier to enlarge the rate of recognition.
iv. *Classification of the Object*—In this step, different classification techniques are used to categorize detected objects into predefined classes. Most common classification techniques are SVM, Decision tree, kNN, ANN.

ML Applications in the Field of Food. Some of the contributions of researchers in the agri-food systems are highlighted in Table 1. In these works, supervised and unsupervised learning are used in food prediction.

3.2 Deep Learning (DL)

Deep learning (DL) is an advanced subset of ML and is an upgradation of ANN [22]. A DL architecture is composed of sophisticated, multi-level deep neural networks (DNNs). These architectures are different from the architectures discussed in Sect. 3.1, in the way that it can perform tasks such as feature extraction/detection automatically from training data provided.

Deep Learning Categories. Recurrent neural network (RNN) and convolutional neural network (CNN) are the two broad categories of deep learning. In a RNN, a recursive way is employed in using output of a given step as the input of the next step. RNN architectures are sequential hence its applicability is more in extracting features out of time series data, text data, audio data, etc. Mostly, preferred RNN models are LSTM, GRU, and bidirectional RNN.

Convolutional Neural Networks (CNN): CNN is another sub category of deep learning which is widely explored in classification of visual data. CNN architectures are hierarchical comprising of different layers. The input layer is followed by convolutional layers, pooling layer and fully connected layer. In the CNN architecture, convolutional layers and pooling layers are responsible for extracting hidden characteristics out of image pixels while the fully connected layer is responsible for classification [23]. CNN shows excellent performance in dealing with large corpus of data and makes classification automatically. CNN models find its application predominantly in image classification, detection, and segmentation [24].

Input to a CNN is a tensor represented as a 3D matrix with 2 spatial dimensions (height and width) and a channel dimension. The input passes through several layers undergoes automatic feature extraction and classification in the layers resulting in the desired output.

Table 1 This table presents the various research works conducted in classification of food images

Fruits	Feature	Category	Classifier	Reference
Plum, potato, cashew, onion, orange, kiwi, apple, watermelon, pear and peach	Texture features	Classification	SVM	[14]
Tomatoes	Color and size features	Quality evaluation	ANN	[15]
Apple, mango, sweet lemon, chikoo and orange	Color and texture features	Identification/ classification	ANN	[16]
Lemon	Color and size	Sorting/grading		[17]
Tomato	Surface defects-color and texture features	Sorting/grading	SVM classifier	[18]
Batuan fruit	Size, shape, color, texture features are extracted	Grading	ANN, SVM, KNN	[19]
Tea	Color, texture, wavelet-based features	Quality	Fuzzified decision tree	[20]
Indian food	Color and shape features	Recognition and classification	kNN and SVM	[21]

Convolutional Layers: As the name goes, this layer combines two functions resulting in a third function. The input is an image of $m \times n$ pixel. Each pixel in RGB image contains three color channels. Pre-defined sized kernels/filters are slide over the input. Feature from image is extracted by convolving a filter kernel, and the result obtained is a feature vector. This can be explained mathematically as-multiplying each image pixel by corresponding filter kernel.

Rectified Linear Unit (ReLU): This activation function activates a node if the input is above zero, else the node is considered as zero. By using an activation function it is decided whether a neuron should be activated or not. The output matrix obtained out of the convolution layer passes through the ReLU function wherein every negative value is removed and replaced with zero. This helps avoiding a zero sum.

Pooling Layer: In the pooling layer, *max pooling* or *average pooling* is done. Max pooling retains the maximum value within a certain filtered region, while in average pooling, and the average value is retained. Convolution and pooling layers are repeated until dimensionality of the network is reduced. The output of the pooling layer is then fed to the fully connected layer as input.

Fully Connected Layer: The actual classification takes place in the fully connected layer together with an activation function known as softmax activation.

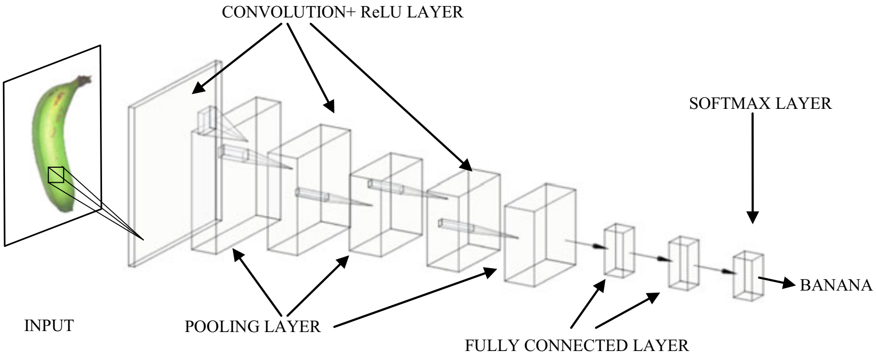


Fig. 9 A typical CNN architecture

A softmax function is used on the output of the fully connected layer to distribute the prediction probability between 0 and 1 among the classes.

In addition to the above functions, some more operations can be incorporated to enhance the performance of CNN. Such techniques include batch normalization, batch standardization and dropout. *Batch normalization* standardizes the inputs in a mini-batch by calculating the mean and standard deviation of each input variable thus rescaling the values to [0,1]. While *batch standardization* rescales the value to zero mean and standard deviation of 1 (unit variance). Dropout is a technique of dropping out some neurons reducing overfitting issues improving generalization error. Also, CNNs accuracy can be modified by adjusting number of hyper-parameters such as batch size, epoch, learning rate, etc. Epoch is the number of iteration and batch size is number of samples used in each iteration. Learning rate controls the speed of learning by setting a step size in each iteration of optimizing the loss function. Figure 9 is a pictorial representation of CNN architecture.

Commonly Used Deep Learning Tools. There are some already available toolkits and libraries which helps a researcher to smoothly execute the deep learning operations. Selection of the appropriate tool depends on the expertise of the researcher on that tool. Here, a discussion is made on the commonly available toolkits namely TensorFlow, Theano, PyTorch, Pylearn2, Keras, Caffe, TFLearn, etc. Theano is an open source deep learning tool written in Python using Python's Numpy library to perform complex mathematical operations. In the year 2007, Theano was developed at the University of Montreal [25]. TensorFlow is one of the mostly preferred open source deep learning tools written with a Python API over a C/C++ engine that makes it work faster. Google built TF in 2015 aiming to replace Theano [26]. TF is considered as one of the most efficient libraries with many industrial applications. PyTorch is a deep learning library written in Python, C++, and CUDA. It was developed by Facebook AI Research and accelerates the journey from prototyping and product deploying. Pylearn2 is another deep learning library developed by LISA at University of Montreal is built on top of theano. Keras is a deep learning library that uses either TensorFlow or Theano as backend.

Table 2 Various applications of deep learning in food

Commodity	Category	Dataset	Classifier	Ref.
Food items	Classification	Food mages from datasets Food-101 and Caltech-256	CNN classifier	[28]
Vegetables	Classification	Popular dataset ImageNet used	Pre-trained CNN architecture-AlexNet, ANN, and SVM	[29]
Fruits	Classification	Fruit-360	CNNclassifier Tensorflow framework	[30]
Food and drinks	Classification	Food images crawled from google	Popular CNN architectures-AlexNet, GoogLeNet, NutriNet, and ResNet were used	[31]

Created by Francois Chollet, in 2015, Keras is bestowed with an intuitive API written in Python. Developed by Berkeley Vision and Learning Center (BVLC) in 2017, Caffe is considered a mature deep learning tool. It is written in C++, while its interface in coded in python [27]. TFLearn is another deep learning library built on top of TF written in python.

Application of Deep Learning in Food. Researchers are successful in solving a wide variety of problems in field of food technology using deep learning. Works of different researchers presented in Table 2 deal mostly with classification and identification.

Food Datasets. Performance of a deep learning model depends on the images in the dataset. There exists some popular food datasets that are available for performing food product classification. Those benchmark datasets include UNICT-FD889, Food 101, UEC FOOD 100 and UEC FOOD 256, Food-5K and Food-11. UNICT-FD889 is the first dataset of food image containing of 3583 images of 889 different plates of Italian food [29]. The images in this dataset are captured multiple times using a smart phone with photometric and geometric variation [32]. Food 101 consists of 101,000 real-world images of 101 food categories of American Fast Food. The images of this dataset are crawled from internet and used to train different classifiers [33]. UEC FOOD 256 is updation of UEC FOOD 100, both consisting of photos popular foods in Japan. These two datasets are prepared by capturing images using a mobile camera. The only difference is the number of food items in each dataset. UEC FOOD 100 consists of 100 different kinds of food items, while UEC FOOD 256 consists of 256 different kinds of food items. The demarcation of the food item in each image is done by a rectangular [34]. Food-5K is a combination of food and non-food images. This dataset consists of 5000 images gathered from publicly available datasets out of which 2500 images are only food images [35]. Food-11 dataset is prepared using food images of other datasets. It consists of 11 different categories of food items consumed on regular basis. This dataset has a total of 16,643 images [35]. Again there exists few dataset that is confined to only fruits and vegetables. Two such datasets are Fruits 360 and FruitVeg-81. Fruit 360 is a huge dataset consisting of 90,483 images of 131 classes of fruit and vegetables. Each image in the dataset is of size 100 × 100 pixel [30]. FruitVeg-81 contains 15,737 fruits and vegetable images of 81 fine classes. Furthermore, there are some datasets that are limited to the cuisines of a particular region. Such datasets are Indian Food Dataset, Chinese Food Net, Turkish foods-15, Pakistani Food Dataset, THFood-50 and so on. The Indian food dataset consists of 5000 images of 50 different varieties of food download from the web. The Chinese Food net consists of 192,000 images of 208 different Chinese dishes. Similarly, the other food net consists of ample of images of their respective cuisine. There are some datasets that consist of images of food collected from internet sources such as Instagram, Facebook, etc., those are Food 50, Food 101, Instagram 800k, FoodX-251, Vireo Food 172, and many more. Food 50 is the other name used for the THFood-50 which is based on 15,770 images of 50 categories Thai foods collected from the internet. Instagram 800k is a dataset prepared from 808,964 images of 43 categories collected from Social Media. FoodX-251, a dataset of 158k fine-grained food images of 251 categories, extracted from the web. VireoFood-172 is a dataset containing of 110,241 food images of 172 categories that are crawled from Google search engine and Baidu. Comparison of different food datasets is drawn in Table 3.

Pre-trained Models and Transfer Learning. CNN architecture is an organization of stack of complex layers that automatically transforms input to output. Pre-trained models are those deep learning architectures that are trained on large datasets to solve specified problems. Pre-trained models differ from one another in the arrangement of the layers, and the way weights are optimized during training. The most popular CNN architectures based on spatial exploitation are LeNet, AlexNet, VGG, GoogLeNet, etc. *LeNet* is the first pre-trained CNN model proposed by LeCuN in 1998. This net is comprised of 7 layers-five alternating layers of convolutional and pooling, followed by two fully connected layers. LeNet is the simplest of all and is used for black and white object recognition. This net was most specific to hand written digit recognition. *AlexNet* outperforms other architectures by successfully classifying big dataset. Krizhevsky et al. in 2012 introduced Alex Net by making the architecture deeper with 5 convolutions, 3 fully connected, max pooling, and dropout layers. This enhancement in layers makes the architecture capable of classifying wide variety of objects. *Visual Geometry Group (VGG)* is similar to AlexNet but its feature extraction capability is more as it supports up to 19 convolution layers. VGG successfully classified images and solved many localized problems. Google Net won the image classification challenge at ILSVRC 2014. The *Google Net* architecture objective was to decrease error rate with high accuracy as compared to AlexNet and VGG. CNN architectures based on depth in number of layers are ResNet, Inception V3 and Inception V4. *ResNet* consists of 152-deep layers and is 8 times deeper than AlexNet and VGG. *Inception V3* architectures make use of factorization and reduce the problem of overfitting. *Inception-v4* is advanced form of Inception-v1 or Google Net. Compared to Inception V1 to Inception-v3, this net is simpler and uniform with more inception modules. CNN architecture based on multipath is DenseNet. In terms of accuracy,

Table 3 Comparison of different food datasets

Dataset	No of classes	Total no of images	Category	Year
UNICT-FD889	889	3583	Italian food	2014
Food 101	101	101,000	American fast food	2015
UEC FOOD 100	100	14,361	Japanese food	2012
UEC FOOD 256	256	28,375	Japanese food	2014
Food-5K	2	5000		2016
Food 11	11	16,643	All categories of food	2016
Fruit 360	131	90,483	Fruit	2018
Fruit Veg 81	81	15,630	Fruit and vegetable images	2017
Indian Food Dataset	50	5000	Indian foods	2017
Chinese Food Net	208	192,000	Chinese dishes	2012
Turkish Foods 15	15	7500	Turkish dishes	2017
Pakistani Food Dataset	100	4928	Pakistani dishes	2020
TH Food 50	50	700	Thai foods	2017
Instagram 800K	43	808,964	All kinds of food	2016
Food X-251	251	158,000	All kinds of food	2019
Vireo Food 172	172	110,241	Chinese food	2016

DenseNet and ResNet are similar, but the difference lies in the number of parameters and FLOPs, which is almost half in case DenseNet. CNN architecture based on width is Xception. Xception architecture is designed by making the inception block wider. Compared to inception models, xception model has 71 deep layers that works on large datasets which comprised of 350M images with 17,000 classes. Table 4 gives a comparative view of the different CNN architectures. In transfer learning, these existing pre-trained architectures are used for solving similar classification problems. Transfer learning is advantageous over deep learning in the way that the tedious task of data collection is not required.

4 AI Application in Food

This section discusses the applications of AI in food. Figure 10 shows some of the application of artificial intelligence in food. Below are the different areas of food technology where artificial intelligence is used:

- *Dietary Supplement*: Artificial intelligence has made things like recipe recognition [36] and dietary assessment [37] possible. AI helps us telling how much calorie is contained in the food to be eaten [38].

Table 4 Comparison of different CNN architecture

Architecture	No of parameters	Dataset	No of layers	Developer/year
LeNet	60K	MNIST	7	Yann LeCun et al./1998
AlexNet	61M	ImageNet	8	Alex Krizhevsky et al./2012
VGG	138M	ImageNet	19	Simonyan and Zisserman/2014
GoogLeNet	4M	ImageNet	22	Google/2014
ResNet	25M	ImageNet, CIFAR	152	Kaiming He/2015
Inception V3	23.6M	ImageNet	48	Szegedy et al./2016
Inception V4	35M	ImageNet	27	Szegedy et al./2016
DenseNet	–	CIFAR	264	Huang et al./2017
Xception	22.8M	ImageNet	71	Chollet/2017

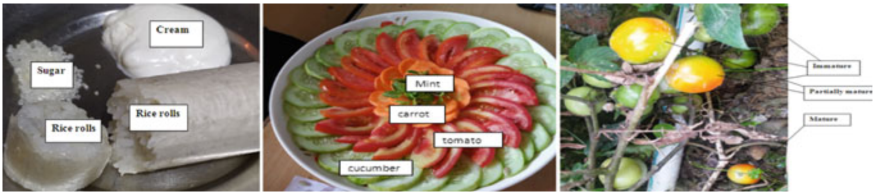


Fig. 10 Image classification using AI

- *Food Grading/Sorting*: sorting and grading in an integral part during food processing in identifying the presence of foreign materials as well as damaged or defect products [39].
- *Food Safety*: AI aids to food safety by recognizing unwanted or foreign materials that comes its way during processing [40].
- *Food Quality*: AI ensures food quality by detecting defects which is important during inspection, marketing, and packaging [41].

Artificial intelligence conjugated IoT devices has made remarkable contribution in industries. The amalgamation of the Internet of things and industrial automation has led to profound convenience in sterilization, food drying, extrusion, etc. Hence, IoT enabled AI devices are a new dimension of using image processing and machine learning in food processing industries. These devices are potential innovations to food industries for its growth and development.

5 Conclusion

The central focus of this chapter is to highlight the possibilities that the AI offers in applying system approach to agri-food systems. The process of development and the forms of models that would yield from ML or DL implementation in agri-food system are not significantly different from those for other systems. However, the information and knowledge fed to the system as input data will help to characterize the individual systems and its features. Thus, the tools available for ML implementation in any platform remain valid for analysis of agri-food systems. This offers the opportunity to garner benefit from developments in other disciplines. Use of pre-trained NETs or solutions with the provision for customization of parameters for few layers, as available in transfer learning is worthy of exploration. Similarly making use of archived data sets, as was highlighted with food image data sets, also offers benefits to agri-food discipline. Overall, this chapter covers the basics of artificial intelligence alongside shallow to machine learning and deep learning. Works of different researchers using different machine learning algorithms that find its application in food are discussed. Advantages of machine learning and deep learning techniques have been summarized citing its applications in the field of food. Hence, it can be said that machine learning and deep learning techniques have the potential to become a mainstream tool in image analyses and making prediction from data. AI offers opportunities to researchers and industries to take the understanding about agri-food systems to a next higher level.

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Intelligent Agro-Food Chain Supply

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Abstract Technology can play a vital role to boost the qualitative and quantitative productions of agri-products and can ensure timely delivery to the end-user. However, a strong supply chain management system is not only needed for the fast delivery of the products but also very important to increase the financial activities and profit of all, like the producer, supplier and end-user. Most of the countries, especially developing countries, are facing the lack of effective supply chain management for agriculture supplies, which is increasing the rot of agri-products, increasing wastage of products, infiltration of the products price, shortage of agri-products, and theft of the products at distribution. It tends the financial loss to everyone like farmers, suppliers and end-users. Most importantly we are not able to satisfy the hunger of the people in time, even though we have sufficient production of agri-products. However, with the development of an effective and efficient supply chain management system, we can overcome all the said issues and the agriculture sector can be more competitive. The proposed IoT-based supply management system could significantly contribute to improving the coordination of different strategic and operations units because of its remote operating ability. A strong coordination system among the different channels is the prime requirement of such a supply chain management system (SCMS). Coordination among the different channels can automatically improve the SCMS working efficiency in terms of operational and strategic decisions and timely delivery of goods on a priority basis. The proposed chapter is presenting the IoT and cloud-based logistic support supply chain system for agriculture products.

Keywords Agro-products · SCMS · Coordinated system · Timely delivery · Prevention-of-grain-rot · Cloud storage

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1 Introduction

Food is the first essential requirement of any living organism. Farming is the primary unit for the supply of food for any living organism, and it is a difficult task to feed the fast-growing population of the world with a balanced diet. However, from the decade's governments are trying to increase yield production. However, various researchers and agriculture research laboratories are working over different areas of agriculture to increase yield production. Thus, researchers have developed high-quality seeds to increase yield production. They have developed different scientific techniques to irrigate crops with less water and identified the soil quality-based crops, etc.

Even though such efforts have been fruitful to increase the production rate of the agricultural products, still a large segment of the population is starving for the food. This starvation for the food cannot be overcome by increasing yield production only, because this is not because of less food, but it is because of the wastage of food. Most of the time we are not able to supply the agro-products to the end-user in time, which results in hungry belly and grain rot. However, these are not only the consequences, it leads degradation of economic growth of any country, financial weakness of the farmers. So, alongside the increase of yield production, we have to work over some other areas for improvement like supply chain management of agro-products.

Agro-Products Supply Chain Management (APSCM) activities start from the farms and reach to the food supply to the end-user [1]. An efficient APSCM starts with the processing of agro-products, priority-based delivery and distribution (through transportation), recording keeping and analysis of data, and finally handover the product to end-user [2, 3]. However, with the help of efficient APSCM an improved quality of processed foods can be available to the end-users just by processing quality row grains [4].

Recently world is facing the COVID-19 pandemic, which forced the most of the human population has imprisoned in their homes [5] and they are facing a severe shortage of food, and it is because of improper food supply chain management system. At the same time, it has badly affected the farmers in price fall of their crops due to inappropriate storage and transportation. Even though the production of the crops was as it is. All these lead to a need of robust and efficient supply management system for the priority-based delivery of agro-products. Internet of things is popular enough since 2009 and ultimate objective of this emerging technology was to associate all devices and services to the web. IoT is rapidly changing and positively impacting our lives in all means like health care, business, household services, agriculture, production, law enforcement, vehicles and big machineries. However, its predicted market worth by 2021 will be around $20T. IoT-based solution can improve the agro-products supply chain management system substantially. IoT is mainly about the automation of the devices. It consists of cloud computing, big data tools for analysis of sensor data, data mining, etc. IoT is very powerful and flexible automation system over the existing systems.

1.1 Food Clusters (Metropolitan Agriculture)

Nowadays, the urbanization of the population is at its utmost speed of the human history. Almost 65% population is living in cities, and by 2030, it will be increasing up to 73% and this rapid growth of urbanization is centred in Asia and Africa [6]. The growth of unban middle class is a centre of gravity of explosive urbanization, and it has impacted the food consumption patterns in quantity and quality both. A traditional agriculture is not able to fulfil such changing demand pattern and demands for a new form of agriculture, which can substantially map up the increasing demand pattern. The new model is based on land-independent agriculture because near the cities agricultural land sizes are substantially decreasing but this evolving model is resolving this issue with its high productivity and quality food. These food clusters are innovatively developing the logistic network in terms of consolidation centres which have their efficient product-based supply chain management system. Such supply storage and supply chain management systems are managed and functioned through the technology like IoT. These centres are not only developing supply chain and storage but also training the farmers to grow quality products at low cost [6]. IFFCO Greenport Nellore Project, India is one of the examples of urban agriculture clusters. This Special Economic Kisan Zone is situated near the Nellore Andhra Pradesh of India. The agriculture cluster has large number of dairy production around 10,000 cows, 400 greenhouses, sheep and goat production and around 300 processing, storage and transportation units. This park is generating large-scale employment of around 30,000 thousand of direct/indirect employees [6]. In the south-east Netherland, mixed urban agriculture farms are being established. This farm is basically based on poultry products and pig breeding. In this park, there will be a bio-energy plant to fulfil the energy requirements and utilize the waste [6].

1.2 Food Waste

However, 35–40% of the agro-products rot during the storage and transportation and do not reach to consumers in time. Such wastage of agro-products imposes the cost of billion dollars. Therefore, it is highly demanded to have consumer-driven sustainable storage and supply chain management system to reduce such wastage of food and remaining unavoidable waste can be converted into bio-energy or compost [6], which can further use in fields.

1.3 Information Management

Accurate, well in time information processing and delivery has been a game-changer factor in agro-food market. Increasing middle-class urban population is focusing on food quality, safety and sustainability. There must be research-based knowledge management agro-models for multidisciplinary processes with close cooperation of government agencies and business partners. Such models can apply both fundamental and applied knowledge to achieve desired goals (i.e. sustainable business goals, coherent embedded agro-framework, automated monitoring and control). However, the performance of the food supply chain is totally based on the real-time information process and distribution and association between supply chain management and transportation actors of the chain.

2 IoT in Agriculture

IoT is the networking of the electronic devices, machineries, sensors, cameras, GPS devices, etc. In the IoT networking devices are programmed to work in association and exchange information to create an autonomous environment where system itself can take appropriate decisions on the basis of data analytics done by big-data tools and machine learning algorithms. IoT-controlled environment can be automatically and manually controlled through the mobile application and real-time monitoring of the activity logs can be monitor. In our daily life, IoT has been established well in terms of television operating control, air-conditioner remote control, electronic doors, camera-based security and event monitoring. IoT has been very important in controlled entry in the secure campuses by checking the authenticity of the person. It has intrinsic role in the automation of agriculture practices. IoT mainly consists of sensors, cloud storage and analysis, interment, electronic devices, Wi-Fi network, big-data tools, machine learning algorithms. All the devices are connected through the wireless network for information exchange and operational synchronization. A simple IoT framework is given in Fig. 1.

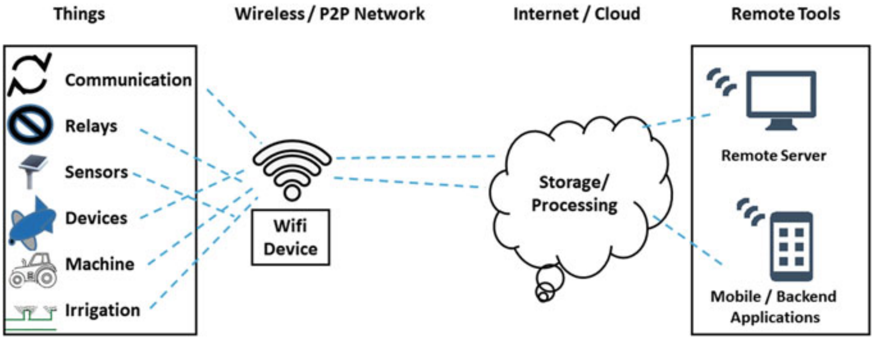

Fig. 1 IoT framework

i. **IoT Devices**—it is intelligent electronic sensors and other devices which capture the information and exchange it through cloud-based wireless communication.
ii. **Wireless Network**—wireless network is very important in the IoT framework to remotely operate and monitor the network.
iii. **Internet**—it is one of the key components in the IoT framework which helps to connect the devices and exchange information among them, monitoring and control of the devices are also remotely possible through the Internet.
iv. **Cloud Server**—cloud servers are very important to store data remotely and process it remotely through big-data tools and other machine learning algorithms.
v. **Back End Services**—these services consist of user remote control through mobile application. It helps the user to monitor the activities and decision taken by the system automatically or in controlled manner. It helps the user to monitor the health of the devices connected to the network and also helps in information exchange.

IoT is significantly influencing the design and development of new agriculture technologies for the monitoring of the crop growth and health, pests, pesticides, conservation of water, irrigation, harvesting, storage, tracing and tracking of the agro-products transportation, monitoring of the freshness of the products. IoT helps in the controlling and operational activities in the farming through tractors (auto-controlled), pumps, drip irrigation, harvesting, spraying the pesticides and fertilizers. IoT helps in the minimization of the resource and product wastage and misuse and enhances the productivity of the crops and yield at low cost.

2.1 Agriculture Production

IoT frameworks enhance the agriculture practices with the precision monitoring and decision to ensure the production of qualitative and quantitative agriculture products at moderate cost and labour. The precision monitoring and precision decision of the IoT framework are taken with the help data analytics taken out by the big-data tools and machine learning algorithms from the high volume data captures through the sensor, cameras like soil health data, soil gradients information, water contents in soil, temperature monitoring, pests and pesticides monitoring, sunlight monitoring, crop growth and health monitoring, yield production prediction through machine learning algorithms, image-based monitoring through camera modules, etc. However, it has made it myth that the time-to-time physical assessment of the agricultural lands and crops is necessary to take appropriate actions to ensure capacity full production of the agriculture products. Now farmers can control their agro-machineries like tractors for ploughing the agricultural land. With the help of IoT-based control and monitoring farmer can remotely control the tractor to plough the field automatically. Similarly, the irrigation pump control is also done remotely. However, the organic farming also can promote with the help of IoT-enabled frameworks in agriculture.

2.2 Storage and Transportation

Various researchers are working over different agriculture tools and technologies, and they found that around 30% of the agro-products wastes because of the shortage cold storage and inappropriate monitoring of the products at cold storage and agro-products supply chains. However, we are living in the technological age and consumers are aware enough to their health, which increases the qualitative fresh agriculture products demands in the market. Traditional supply chain management is not capable enough to ensure the quality and fresh product deliver to end-user. IoT is one of the technologies which helps the supply chains to main the quality and freshness of the agro-products during production, storage, transportation and delivery to consumer [7].

2.3 Agriculture Production Frameworks

IoT-enabled agriculture frameworks are the new era of technological advancement in farming, and it has been the driving technology to increase the agro-products production with ensured quality and optimal utilization of the available resources at low production and labour cost. The design and development of the low-cost reliable technologies for the monitoring, growing, harvesting, storage, transportation and delivery of the agro-products are the primary focus of the agriculture industry. According to the researchers [7], IoT service market has a rapid growth and by 2024 its worth will be around 225 million dollars. Smart and intelligent farming technologies enable the grower and distributer to both automate and optimize the complete supply chain management system to ensure the enhancing productivity of the products [7].

2.4 Precision Farming

Precision farming is the optimum utilization of the available resources (seeds, water, land area, etc.) to increase the qualitative and quantitative production of the agro-products. IoT is one of the important and reliable technologies which can significantly contribute in the precision farming. In IoT framework, we place different sensors at different places of the field. Along with the sensors, it uses other electronic devices like Wi-Fi device, automated machineries, IoT water pumps, robots [8, 9]. Optimum utilization of the fertilizers, pests, pesticides, water, land area, seeds is the basic requirement of the precision farming. UAV and sensor-based monitoring are two prime monitoring mechanisms in IoT which works with agriculture practices. Precision farming is classifiable data collection, analysis, evaluation and implementation applications [8]. Use of multi-view UAV systems in the agriculture monitoring can have a breakthrough in the agriculture. UAV can capture coloured imaged from different parts of the field, and later on this image can be analysed by the algorithmic systems and outcomes can help the farmers to take appropriate decision for irrigation as well as crop health. Nowadays, smart sensors are also integrated with the UAVs which helps mapping of grain volume during forage harvesting [9].

2.5 Livestock Monitoring

Live monitoring of the activities and operations always helps to save the damages and improve the quality of the products and minimize cost. IoT is one of the best live monitoring technologies working with agriculture products supply chain. It uses the electronic wireless sensors, camera modules to monitor the agro-products health, stock, location, movement, etc., in real time and remotely. Livestock monitoring of the agro-products helps both the grower and businessman to synchronize the demand and supply of the products and ensure the freshness and quality of the products [10].

3 IoT in Supply Chain of Agriculture Products

From the last two decades, a rapid digitation of agriculture sector has taken place. It is especially in remote sensing, precision farming, MIS for farm management, robots, supply chain management, decision support system. Newer technologies like AI, robotics, blockchain, big data, IoT and cloud computing are playing a vital role in the integrated autonomous system of the isolated agriculture developments. A sustainable and resilient agro-products supply chain is highly demanded. Such design is complex enough because of the risk involved and uncertainty in demand, supply production, social impacts, climate, etc. However, worldwide agriculture is one of the political and as well as economical important fields. Agriculture sector is not important because of the food requirements of the growing population but it contributes more in the economic growth of the countries and employment creation. An IoT-based agro-products supply chain system is sturdily pressured to handle the uncertainties and risks involved in the agriculture. IoT-based supply chain management allows the supply chain managers to assess the real-time flow of the agro-products and helps to assess the risks and develop contingency plan to overcome the problems. A very basic principle of effective supply chain is the resilience in operations, logistics and reaction time of the control units. These days, we are in advancing technological age and data have been the lifeblood to any IoT-based automation even in the agriculture field. The real-time exploration of the data insights plays an important role and makes the systems able to take intelligent decisions by own at great efficiency, agility, flexibility and sustainability. IoT-based agro-products supply chain consists of insights identification of the data, products and data storage, cold storage management, transfer and transportation of the agro-products, perform analytics on the stored data and marking. However, integration of the technologies brings a real potential of the supply chain management and improve the efficiency of various supply chain operations, i.e. (adaptive learning, in time decision, prediction of demand and production, data analysis, controlled logistics, monitoring, sensing, etc.) [11]. An efficient handling of these operations helps in the detection of the problems, changing market dimensions followed by appropriate decisions. An integration of the various tools, sensors and technologies, data analysis models and real-time information transmission predicts the suitability of the decision at an appropriate time. IoT-enabled system has an extensive impact on operations, economy, environment, society, business and technology [11].

i. **Technological Inference:** IoT-enabled agro-products supply chain management is based on battery-based wireless sensor network. A wireless network provides the peer-to-peer connectivity to the local nodes. It enables the data collection and analysis from different remote sectors. With the help of peer-to-peer connection between local nodes, it can resolve the issue of inconsistent Internet connectivity. The decision power distribution in decentralized way helps in the governance- and ownership-related issues. The cloud-based data storage, analysis and local authentication and authorization process provide the data security.
ii. **Functional Inference:** In IoT-based supply chain, a sensor-based monitoring and data collection happen. With the help of sensors, various factors which impact the yield production and its quality (i.e. moisture, temperature, diseases, pests, irrigation requirement, fertilizer requirement, harvesting time, climate change) can be monitored and can be automatically managed and controlled.
iii. **Social Inference:** IoT-based controlled and monitored in time, fresh food supply gives a satisfaction and belief the customer in the quality and safety of the product. As on today consumers are aware enough about the quality of the products and their own health a product quality certification system can help to earn the confidence of the consumer in the supply chain and its product quality.
iv. **Economic Inference:** An IoT-based supply chain for agro-products, ensure the lower operational cost and increase its efficiency, a battery-based low-power consuming sensors, wireless technology, peer-to-peer information exchange helps in reduced cost operations. The local data transmission and cloud-based storage and AI-based analysis of the data help to increase yield production, yield quality, health of products and consumers.

v. **Environmental Inference:** IoT-based supply chain management helps the farmers to have controlled cultivation. It helps in adopting newer technologies as per the climate and soil health and helps in crop management. With the help of sensor technology, it helps the farmers in assessing the irrigation requirement of the crop. The sensor-based monitoring and machine learning-based prediction help the farmers to estimate the cost of the production and minimize the wastage of resources and yield.

vi. **Business Inference:** An IoT-based supply chain management not only help the farmers in producing high quality and quantity agro-products but also helps in increase their earning with the help of controlled monitoring and use of sensors.

4 Existing supply chain system for Agriculture products

In the last three–four decades, biodiversity has significantly reduced and as per the study in [12] by 2050, 70% of the biodiversity will be reduced at our earth, and interestingly, it is happening because of our own activities and so-called economic growth of the countries. Thus, agriculture is one of the sectors which can slow down the speed of biodiversity reduction by quantifying the excess use of fertilizers, pesticides in the crop and polluting the fields, area even the water, and there many insects and animals have their shelters [11]. Increasing use of technology like IoT, robotics, sensors, machine learning, etc., can easily address the agriculture issues and can optimize the growing process with less resources and optimum use of chemicals. In [13], digital techniques are explained to exploit the geometric features of the crops. In few decades, we are using light sensors, digital photographic, ultrasound, LIDAR, stereo vision, X-ray tomography, GPS, GIS, DBMS, AI, machine learning, etc., in the agriculture operations (irrigation, pesticides, crop training, temperature measuring, health of the crop and product) and supply chain management. In [14], integrated models for the agriculture supply chain management are explored and found that the existing technologies are not capable enough to potentially manage the agro-products supply chain especially with complex weather and other environmental situations. In [15], authors studied the ICT implications in the agriculture, which is still a medium level of information dissemination in agriculture activities and food supply chain. In [16], third-party logistic services-based agriculture supply chain management has been proposed. This research has enhanced the concept of activities outsourcing for IoT-controlled agro-products supply chain. In [17], a data-driven IoT-controlled supply chain performance measure framework has been developed. According to research, responsiveness and flexibility are the key factor for any IoT-based agro-products supply chain management. In [18], blockchain-based agro-products supply chain management is proposed. In this framework compliance, trust, pricing of the product, tracking—tracking of the product, coordination, control are the key factors which are making the proposed framework stunning. In [19], IoT-based agriculture supply chain technologies are explained in contact of developing countries and they have identified total six IoT-based technologies.

5 Industry 4.0 for Agricultural Processes

Industry 4.0 [11] has emerged to provide new tools and techniques in the agriculture so the emerging demand of the agriculture quality products can be fulfilled. Some of them are explained as:

5.1 Big Data in Agriculture

In [20, 21], big data has been used for the grapes agriculture which is able to integrate and explore the services, analyse the sensors data, derive insights of the data. Big data tools, clustering techniques, data transformation algorithms and data storage management are very important and useful in agro-products supply chain management. An integration of big-data technology in agro-products supply chain extends the farmers knowledge by adopting ICT-based facility. There are certain number of big-data repositories (NASA Earth Exchange, Satellite Imagery Google, National Climate Data Center) available to exploit tools in agro-product supply chain.

5.2 IoT in Agriculture

IoT-enabled agro-products supply chain management is based on battery-based wireless sensor network. A wireless network provides the peer-to-peer connectivity to the local nodes. It enables the data collection and analysis from different remote sectors. With the help of peer-to-peer connection between local nodes, it can resolve the issue of inconsistent Internet connectivity. The decision power distribution in decentralized way helps in the governance- and ownership-related issues. The cloud-based data storage, analysis and local authentication and authorization process provide the data security. Now multiple IoT platforms can be integrated for large-scale information exchange and control the heterogeneous components and sensors.

5.3 Knowledge Model in Agriculture

Multi-sources of database repositories need to be shared with everyone as a service so the decision-making can be expedited in the agriculture sector. In recent research knowledge creation from the data and engineering techniques to build new agriculture models for resource optimization and allocation, technological advancement in agriculture, risk assessment module, decision influencing parameters, quantification of the decisions, etc. [22, 23].

5.4 AI in Agriculture

AI has been the key driver for IoT-based agriculture applications and modules. It is serving as a knowledge models creator, service provider, enhances decision modules in agro-products supply chain applications. AI is contributing to precision farming as pattern classifier, pest identification, quantification of pesticides and fertilizers, identification of quality seeds, assessment of soil health, resolve irrigation issues, land allocation, robotic control and evaluation of the system performance [24].

5.5 Smart Farming

An agriculture 4.0 and agri-food 4.0 are having the concept of smart farming by the integration of the new technologies in farming. Such smart farming focuses on the carbon emission control, conservation of soil, water saving, etc. As on today, we know water is very precious and groundwater level is going deeper to deeper and various parts of the world have been converted into water dissert. Similarly, excessive use of chemical fertilizers is ending the fertility of the land and making it barren. On the other hand, carbon emission is destroying our atmosphere and it is badly impacting the agriculture production and its quality. Smart farming is to adopt best agriculture practices to increase the quality of production and improve the supply chain management system.

5.6 Precision Agriculture

With the help of robotics and other tools and techniques, it is very important to increase the precision farming culture in the agriculture. So quality of agriculture practices and applications can enhance. From few years, robots have been integral part of farming technologies for precision farming with the help of sensor technology, camera and localization technologies to improve the operational behaviour of agriculture practices.

6 Challenges for IoT in Supply Chain

IoT is an emerging technology in the agriculture operations and food supply chain management. With the help IoT-controlled tools and technologies, real-time management and assessment of the logistics and products are possible, which is increasing the quality of the products and financial grace of the stockholders [25]. However, some burning challenges also need to take care while using the IoT technology in farming. Some of them are explained as:

6.1 Functional Challenges

IoT has some functional challenges in the agriculture as we know sensor technology that has been integral part of IoT for the data capturing (temperature, moisture, pests, irrigation, tracking, tracing, diseases, etc.) from different places for different purposes. Sensors data can be tempered due to different environmental and technical issues, and quality insurance of sensors data has been big challenge in the use of IoT in agriculture [11].

6.2 Organizational Challenges

Agriculture sector is heterogeneous in nature, and a single solution cannot work well to enhance the agro-production quantitatively and qualitatively both. A capital investment is little higher and not bearable to small-scale farmers so borrowing-based technologies like cloud need to be involved in this solution. However, we are using cloud computing for data storage and processing-related services, which have limited use in agriculture.

6.3 Social Challenges

Farmers use their own understanding and knowledge whichever transfer from their parents for farming practices. So, the lack of technological skills the social acceptance of the new technologies has been a big challenge. The complexity of the data collection and processing tools like sensors, images, big data has increased this challenge. In the remote rural areas, Internet connectivity is another challenges and IoT tools cannot work properly either for data collection and processing. Data governance, security and privacy are some other challenges in the use of IoT in agriculture.

7 Role of Big Data Analytics in Supply Chain

Big-data tools play a key role in the agro-products supply chain management. It is ranging from the minimization of delivery time to the minimum communication gaps. In the IoT technology, a large amount of sensor participates in the data collection. A high volume of heterogeneous nature data is collected and processed through big-data tools only. Various deep learning-based algorithms work over the big data to enhance prescriptive and predictive capabilities of big-data analytics [11]. An integration of big-data technology in agro-products supply chain extends the farmers knowledge by adopting ICT-based facility. There are certain number of big-data repositories (NASA Earth Exchange, Satellite Imagery google, National Climate Data Center) available to exploit tools in agro-product supply chain.

7.1 Functional Impact of the Big-Data Analytics Agriculture

In the agricultural practices, big-data descriptive analytics help to understand the process and find the insights of the data for analysis of risk involved in agro-products production and supply, feature clustering, patterns identification. In the next step, the impacts of the descriptive analytics are analysed in the predictive analytics like prediction of demand and supply of the products, yield prediction, weather prediction, price prediction, etc. Perspective analytics help in firm decisions and their impact analysis (risk assessment and management, information and operational distribution, capability of real-time decision, planning for planting, irrigation, harvesting, etc.). The use of big-data tools in agriculture enhances the economic dimensions. With the help of real insights of the data and optimized decisions, economic paradigm of the agriculture sections also can improve and stockholders can have more profit in less investment. The qualitative and quantitative improvements in the crop yield are possible with the help of big-data analytics which can make it a profitable business. Moderated use of chemicals, pesticides and minimized carbon emission can help to improve the quality of soil, crop and environmental conditions also. With the help of big-data analytics, timely delivery of the fresh agro-products enhances the demand of the products and preserves the quality and minimize the wastage of agro-products. Real-time decision and tools/applications integration ability enhance the cheaper production and their delivery. The use of big-data analytics in agriculture is impacting the business also. It brings all the stockholders closer to each other and development of new supply chain mechanism and target the consumers' demands with real-time analysis of data. Big data has the ability to solve the new and existing problems and creates the value by providing real low-cost understanding of the problem. Apart from the positive impacts of the use of big data in supply chain management, it has some organizational, social and technological challenges. Decentralization of the data and operations, control the operational activities where number of actors involved, data privacy and security, authentication, authorization and ownership are some basic organizational challenges of big data. Another lack of awareness and knowledge socially, it is very challenging to make the stockholders understand the value of such technologies and encourage them to exchange information. Ethical implications are also a big issue in the use of big-data tools in agro-products supply chain management. Technologically, the synchronization of the varieties of sensors, applications, tools, mobile tools is very challenging. Especially when we have limited Internet connectivity in the remote rural areas. There, information exchange, processing and ownership are the major technological issues [11].

8 AI and IoT Combo for Agri-Product Supply Chain Management

Agriculture and food are an important to human lives and for business sector also. A simple IoT-based supply chain network is shown in Fig. 2. One of the challenging issues is to deal with uncertainty in demand and supply. To handle the highly unpredictable production of the agro-products in quality and quality, a flexible and adoptable logistics are highly recommended for supply chain management. There must be a priority-based cold storage and transportation facility to deliver the fresh agro-products in time to consumers. According to the global demand, we have to ensure the year-round availability of the seasonable crops and foods also.

Nowadays, consumers are aware enough towards their health and they try to ensure to use the agro-products which were grown in healthy environment and demands for the growing, storage and supply environment. Thus, to ensure uninterrupted supply flow and converging processes an advanced intelligence tracking and tracking logistics are needed and to ensure the quality of the products a continuous quality tracking process is also required. Now we are living in the global trade age, and a small farmer also can work with small and multinational companies. This relationship between farmers and retail and storage section demands for a flexible and adoptable supply chain logistics which can protect interest of all the stockholders [26].

8.1 Characteristics of Agro-Products Supply Chain Networks [26, 27]

Various departments and organizations are responsible for the production and distribution of the agro-products. There are two types of agro-products supply which are needed (1) raw products production and distribution and (2) processed agro-products production and distribution.

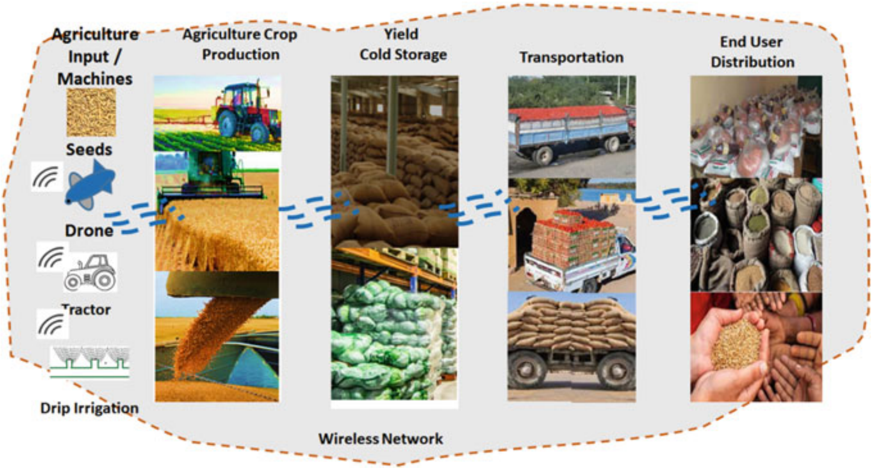

Fig. 2 IoT supply chain network

i. **Raw Products Production and Distribution:** For raw agro-products supply chain management, a number of different nodes (i.e. farmer, auctioneers, wholesalers, retailers, specialized traders, exporters and importers) are needed. At all level of supply chain (production, transportation, storage and packaging), freshness and hygiene of the products must be preserved.
ii. **Agro-Processed Product Supply Chain:** In another form of supply chain where raw agro-products use to produce consumer products (fruits juice, snacks, canned food products, sweets, fast foods, etc.). It is necessary to insure the quality and hygiene of processed agro-products so the self-life of the processed products can increase.

In both supply chain management systems, different person and institutions involve and they know the fact that the original quality of the product can be compromised with only single inadequate action taken by someone and this is the real challenge of any agro-product supply chain management system.

9 IoT-based Supply Chain Management System (SCMS) Architecture

Supply chain management system for the agro-products is a relationship between yield production and supply of the products directly from the farms to the end-user by meeting the changing consumer demands (i.e. price, quality, quantity, etc.). In the IoT-based agro-products, supply chain different sensors (i.e. temperature, moisture, RFID, GPS, etc.) are used for the logistics. Thus, temperature and moisture sensors can be used to assess the quality of the product and RFID and GPS sensors can be used to track the transportation of the goods and in some other communication requirements. The sensors are integrated with global control unit which consistently monitor the product status and analyse the deviation in expected and real parameters and take an appropriate action accordingly. At the next level of supply chain management system, telematics sensors are used in IoT-based agro-products supply chain to react on the small change in parametric states (light, ethylene concentration, temperature, etc.). An observation of these sensors integrates with other parametric values (i.e. speed, location, change in forecasting, etc.) to react accurately. To handle the sudden changes in interrelationship of the partners, a decentralized authentication–authorization and revocation system works and avoids the governance-related complicacies with the assurance of data privacy. In the tracking and tracing of the services and goods, RFID- and GPS-based technologies are integrated with IoT-based solutions. However, tracking and tracing systems must be capable enough to track and track through the different level of the system in centralized way to compile all the data received from all the food chain actors. A hierarchy model manages the different logistic operations to avoid the complicacies of centralized system. This is achieved by making all the individual entities capable enough to independently process the data, take appropriate decision and communicate the same to other units also. Different intelligent systems work at different levels to take such decision and synchronize them in food supply. In business intelligence, IoT-based agro-product supply chain management system analyses the information related to the competitors and can suggest corrective measure to meet the need of advancement in supply chain. An integrated supply chain management system architecture is shown in Fig. 2.

The design of the IoT-based agro-product supply chain has been designed in 11 different functional blocks.

(1) In the first module, a peer-to-peer supply chain communication has been established so the different actors of IoT-based agro-products supply chain management can easily join and leave the network. This network has one a hybrid control unit. So some of the functionalities can happen directly with intervening by central process system (i.e. communication through the chain, routing, prioritization of the goods, storage, etc.).

(2) In the second module, an asynchronous transportation mechanism is established to work efficiently even in the rural areas where network coverage may not efficient. So the communication can take place in asynchronous manner with waiting for other responses.

(3) In the third module, mobile-centric services are established to the dependency on the network connectivity which can be eliminated and a consistent user support can be provided. This is possible by migrating the services to consumer-centric devices with the assurance of quality of service in real time.

(4) In the fourth section of the design, a decentralized and distributed cloud-based storage of the information is provided so the applications and users can fetch the real-time information about the progress of different functions and state of

goods. This allows an efficient exploitation of the services even some of the resources are down.

(5) In the fifth section of the design, a decentralized and distributed cloud-based storage for updating the logistic information is available. This helps the product-related real-time information for timely delivery to end-user.

(6) In the sixth section of the design, an entity authentication mechanism is designed to keep the real-time record of the products and agents along with a distributed security mechanism. This helps the local network logistics to work well even the Internet connectivity with the main servers is not available.

(7) In the seventh section of the design, an auto-system is designed which helps the agent to add and disconnect from the network without affecting the functionality of other agents. So the product flow and ownership-related issues can be automatically resolved.

(8) In the eighth section of the design, uniquely identification mechanism of the logistic objects has been developed using SGLN and GRI.

(9) In the ninth section of the design, a virtual identity section for the objects has been installed. This facility helps to avoid the use of active digital objects for virtual entities.

(10) In the tenth section of the design, it has been installed to allow a secure human intervention in the supply chain management. This scheme is used for the certification process in decentralized manner for the remote agents.

(11) In the eleventh section of the design, ftp and http interfaces are established for secure information exchange.

9.1 Hardware and Software

In the IoT-based agro-product supply chain management the use of sensors, GPS and wireless sensor networks, we can achieve the desired goals. The optical sensors and heat sensors with camera module are used to observe the food state as we human visualize it. The monitoring of the agro-products safety can be done with the help of AI-enabled applications. With the help of IoT-controlled AI-enabled applications, we can ensure the food hygiene.

9.1.1 Sensors

During the transportation and storage of the agro-products, various IoT-controlled sensor units are used to collect the different information from designated places automatically and send the information to the information processing unit. An IoT-enabled sensor network is given in Fig. 3.

Some measure sensor activities take place in agro-product supply chain management are explained as:

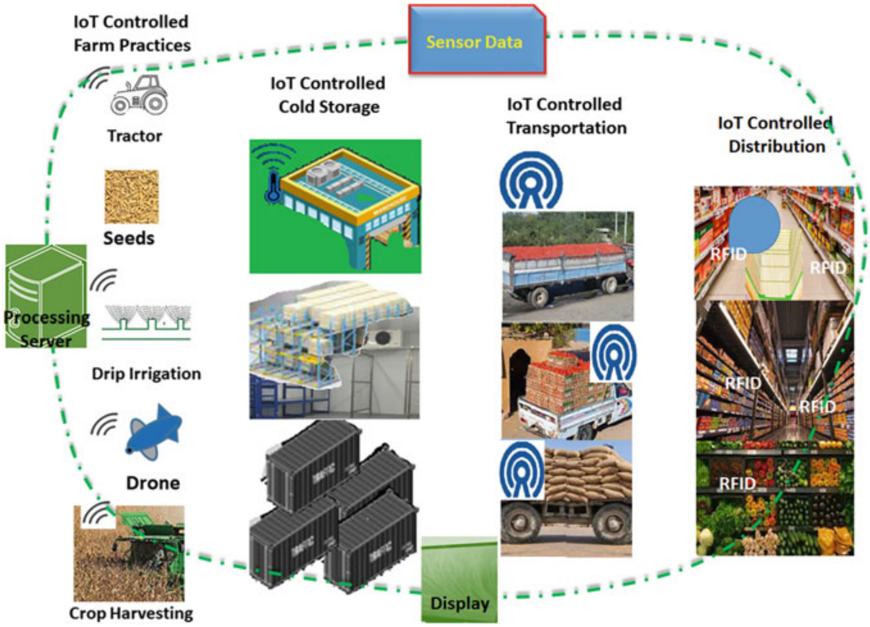

Fig. 3 IoT-enabled sensor network

(1) Temperature and moisture sensors used to detect heat and moisture levels of the food through which we can assess the freshness of the food.
(2) Various wireless sensor networks are used in agro-product supply chain management. It consists of radio frequency, sensors, power supply, micro-controllers, etc. Such wireless units having some special properties like auto-healing, diagnosing, configuring of themselves. These capabilities make the users in remote areas also. These sensors having the microelectromechanical and can be integrated at sensor node at small in size, low energy requirements and at low cost. MEMS-based temperature sensors, pressure sensors, humidity sensors are used for the vibration measurement, acceleration, velocity, position and proximity.
(3) Radio frequency identification (RFID) is the radio frequency-based tracking sensors which use to track the goods state and stock and their movement during their transportation.
(4) Electronic product codes, RFID tags are uses for the tracing and tracking of the transport vehicle during supply.

9.1.2 GPS Module

With the help of GPS models, we can trace and track the transport vehicles and other-related activities like air quality, behaviour, vibration and location.

9.1.3 Relays

The relays are used to enhance the communication range in wireless sensor network especially in remote areas so the supply chain of the agro-products in the remote areas where quality Internet connectivity is unpredictable [28]. In the multihop relays, data transmits through number of intermediate nodes. This relay is reliable enough to ensure in time delivery of the information from one node to another at great reliability and low cost.

9.1.4 Software and Algorithms Required for IoT-Based Agro-Product Supply Chain

IoT-controlled machine learning algorithms have been key components of any supply chain management system. Some of the deep learning algorithms which have been integral part of the agro-product supply are explained in Section 1. With the help of AI applications, the hygiene of the products and hygienic behaviour of the agents can be ensured. If there is any violation of the hygiene process, it can be easy captured by IA-based algorithms and camera module. AI-enabled applications play an important role in an efficient inventory monitoring and handling. Machine learning is very helpful to analyse the varying eating and purchasing habits of the consumers and the supply chain can fulfil the dynamic demands of the consumer. Warehouse is the integral part of agro-products supply chain, and the machine learning-based application is very helpful to address the various warehouse-related issues like maintaining the stock of the grains and other agro-products and monitoring the health of the stored products by measuring the temperature, moisture, gas, etc. Apart from the warehouse, safety of the data and products is critical and essential issue which need to be addressed in right direction. Machine learning and AI-based application have been very useful to ensure the safety of the products as well as the person which are involved in the supply chain. The operational cost of the process can be minimized with the help of AI-based solutions by reducing the errors, incidents and increase in time process completion.

9.1.5 Data Storage

IoT-controlled agro-products supply chain consists of various sensors, which capture raw data from different events. However, data can be remotely stored and managed in the cloud. A large amount of data acquiesces through sensors and stores in cloud for further processing and analytics. In cloud, big-data tools efficiently manage such volume of data and identifies its insights for an appropriate decision for customer satisfaction and business expansion. Machine learning algorithms can create the predictive analytics using the sensors data.

9.2 Risk Management

Agro-products supply chain risk analysis and management are highly recommended for the successful implementation and execution of supply chain. A secure information exchange has been a challenge in the IoT-based systems. Cyber-physical attacks can theft the information and can disturb the supply chain. In [26], US 'National Institute of Standards and Technology' has presented a list of comprehensive list of security risks in agro-products supply chain. However, IoT-based agro-products supply chain is a diverse framework. Any actor who is not willing to supply the system or will to drip the information can inject viruses and malicious applications. In [27], a cyber-secure IoT-based supply chain risk management framework is proposed. In the research, three different algorithms, i.e. machine learning algorithm, distributed system coordination and cryptographic hardware monitoring, are used to assess the abnormal behaviour of the system. Another kind of risk involves in supply chain is to balance demand–supply and storage and to overcome such risks we need to do some alternative arrangements. Ownership and decision power are one another risk in the IoT-based supply chain especially in remote rural areas where Internet connectivity is not up to date and decentralization is the simplest method to overcome such risks. Unavailability of the trained and skilled persons to handle and monitor the IoT-connected devices is another level of risk in the system, which can lead to the failure of the system or inaccurate data collection.

A robust structuring of the risk assessment and evaluation plays an important role in the IoT-based supply chain risk minimization. The IoT-based supply chain risk can be mitigated by observing IoT ecosystem critical points, and there we can identify different devices participating in the system and their functionalities. Proper designation and placement of the sensitive algorithms, codes, and data in the system also can help to improve the supply chain risk. There must be some contingency plans in the agro-products supply chain (i.e. alternate source of products, alternative storage arrangement, alternative for managing teams, it should be distributed in nature). Legal risks can be handled by a designated team only. Decentralization is a good option to minimize the ownership and decision-taking risks especially in remote areas.

9.3 Collaboration and Governance

IoT-based supply chain is a heterogeneous structure of various electronic tools and techniques, data analysis tools and algorithms. So real-time tracking and tracking of the products and events are little hard when number of objects and actors are involved in the process. An interoperability and collaboration expedite the acceptability of IoT-based supply chain by automatic information exchange among logistics and actors. In [28], a IoT-based collaborative approach architecture using various tracking and tracking techniques, communication, GPS, identification, RFID-based positioning is presented. A collaboration is an intense association among different nodes, actors, devices, processes, tools and techniques, managers to work for a common objective. The collaboration starts right from the agricultural land to consumer. In order to achieve a collaborative supply chain for agro-products, a peer-to-peer supply chain communication has been established so the different actors of IoT-based agro-products supply chain management can easily join and leave the network. A hybrid control unit is also established to allow direct decision-making in case of disconnection from rest of the system. An asynchronous transportation module is established to work efficiently even in the rural areas where network coverage may not efficient. So the communication can take place in asynchronous manner with waiting for other responses. A mobile-centric service is to minimize the network connectivity issue and to provide a consistent user support. Decentralized and distributed cloud-based storage of the information are provided so the applications and users can fetch the real-time information about the progress of different functions and state of goods. A decentralized and distributed cloud-based storage for updating the logistic information is available. An entity authentication mechanism is designed to resolve the governance-related issues and to keep the real-time record of the products and agents along with a distributed security mechanism. An auto-system is designed which helps the agent to add and disconnect from the network without affecting the functionality of other agents. So the product flow and ownership-related issues can be automatically resolved. A unique identification mechanism of the logistic objects is established using SGLN and GRI to resolve governance-related problems. A virtual identity section for the objects has been installed. This facility helps to avoid the use of active digital objects for virtual entities. A secure human intervention in the supply chain management has been created for the decentralized certification process. An ftp and http interface is design for secure information exchange.

9.4 Cold Chain

An IoT-based agro-products supply chain potential errors of the cold chain can easily identify, locate and resolve. An automated temperature control system activates or deactivates according to the temperature with respect to specified threshold. Cold chain is mainly having transportation and cold storage [29] to maintain the freshness and quality of the products (i.e. vegetables, pharmaceuticals, etc.). To maintain the required environmental conditions, a cold chain mechanism is required. An IoT-enabled controlling and monitoring mechanism installs in the cold chain placed which can easily monitor the temperature requirement of the agro-products as well as can assess the health of the products and quantities monitoring of the products. To monitor the product qualitatively and quantitatively wireless sensor network, radio frequency identification is the best usable electronic tools. These devices and sensors are capable enough to identify the product and monitor its health through temperature and moisture. RFID implementation cost depends on the services, middleware and hardware. IoT-based systems are capable enough to process the volume of data through big-data tools at less cost. It is capable enough to integrate with data mining and AI applications [29].

9.5 Globalization and Communication Technologies

We are living in the global world and customization of the pricing, and requirements are the main challenge for IoT-like technologies. Risks for the IoT-based agro-products global supply chains are because of both internal and external factors. Global connectivity and globalization are the macro-factors which enhance the complexity of IoT-based global supply chain. Other challenges are related to the efficiency (i.e. real-time inventory, operational cost reduction, lean manufacturing, supplier consolidation and product lifecycles [30]. Agro-products supply chain also needs the global resources like seeds, sales, row products, processed products, which demand the global information exchange technology. In Industry 4.0, we are focusing on the use of new technologies in the global agro-products supply chain with the help of robotics, AI, IoT, sensors and many more to give a feel like home to the consumers. New technologies can improve the information exchange transparency, friction reduction, minimize transactions cost, efficient and accurate data analytics and requirement prediction. An architecture of cold chain traceability is given in Fig. 4.

To address the globalization challenges of the food supply chain, a cloud-based decision-making, monitoring, control and inspection mechanism is highly needed. An efficient global food supply chain must address some basic challenges:

(1) **Global Architecture Integration**: A closed-loop management is needed to have the global architecture so the technology exchange, creation of integrated models and supporting tools can be achieved.
(2) **Sustainability**: There must be a strong integration of the producers, economic institutions, distributors, suppliers and consumers to minimize the food wastage and enhance its recycling, tools and applications sharing is another strong point in the global supply chain.
(3) **Physical Internet**: It is highly demanded because it encapsulates the protocols and interfaces and has the capability to convert physical object into digital object and achieve the high operational interconnectivity. Physical Internet can improve the food handling by improving the intercommunicated logistics storage, deliver, movement, etc.
(4) **Data Collection and Analysis**: A cloud-based data storage, collection and analysis are remotely possible with the help of big data and AI tools.

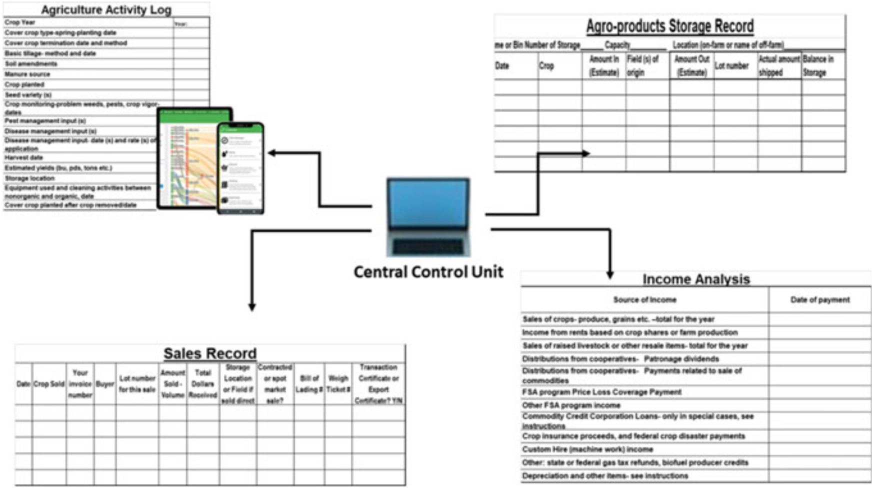

Fig. 4 An architecture of cold chain traceability system

(5) **Decision-Making**: A distribution decision-making is the very important in the global supply chain management. A local authentication and ownership mechanism are needed at the local level, so the actor setting in the remote area and in any part of the earth can take a real-time decision for uninterrupted functioning of the supply chain.

9.6 Agro-Product Supply Chain Management: Logistic Challenges [31, 32]

Logistics of agro-product supply chain is the mechanism (i.e. plan, grow, implement, control the flow, procurement, cold storages, preservation, demand forecasting, packaging, transportation, distribution, etc.) which works from the growing of crop to the end-user distribution of the raw or processed agro-products with the insured quality (originality of the product) and hygiene of the product as per customer requirement. As the awareness is increasing, new industries are coming into the supply chain management system; it has been very important to design value-added services and flexible towards the market demands. One of the logistic examples in agriculture can be taken from the potato chips, where demands from the consumer and industry can be translated in all agriculture activities like preparing the fields, growing potato crop, limits the use of fertilizers and pesticides, managed irrigation and crop takeout from the field to cold storage, processing units, distribution to retailer, wholesaler and finally to the consumers. All these coordinated logistic activities assure the seamless supply chain management with cheap cost. In early age of the supply chain management, such logistic activities were independently working and having their individual goals without caring about the requirements and functions of other logistics. Such functional island nature of the logistics could create a deadlock among the activities and finally turned into the wastage agro-products and increasing financial losses.

However, design of the logistics is directly proportional to the system performance objectives. The ratio of demand and supply and quality/freshness requirement of agro-products must be considered before designing any supply chain management system. Nowadays, it is highly demanded to have a cost-efficient, responsive and extremely flexible supply chain management system to satisfy varying consumer demands. In [33], Lee describes four different supply chain strategies to cop up with uncertainty in both demand and supply as shown in Fig. 5.

(1) **Efficient Supply Chains**: In case of uncertain, supply with low demand needs to be taken care by the efficient supply chain strategies to optimize the profits and it can happen with the coordination of information and cost. The cost of the product can be minimized by the simplification of the process and removal of non-value-added operations and analysing the information through IoT-based machine learning algorithms [31, 32].

(2) **Risk-Hedging Supply Chains**: There must be a risk-hedging approach to resolve the low demand–high supply issue to normalize the product cost. This can be achieved by adopting the lowest safety stock strategy and inventory pooling [31, 32].

(3) **Responsive Supply Chains**: Supply chain must be flexible and responsive to the rapidly change demands of the end-user. The mass customization is the best way to handle this situation [31, 32].

(4) **Agile Supply Chains**: It is embedded in responsive and risk-hedging supply chain management. The speedy supply chain tries to eliminate the uncertainty in demand and supply and both and supply disruption can be minimized with the help of pooling inventories. With the help of this supply chain strategy, we can have some extra margin [31, 32].

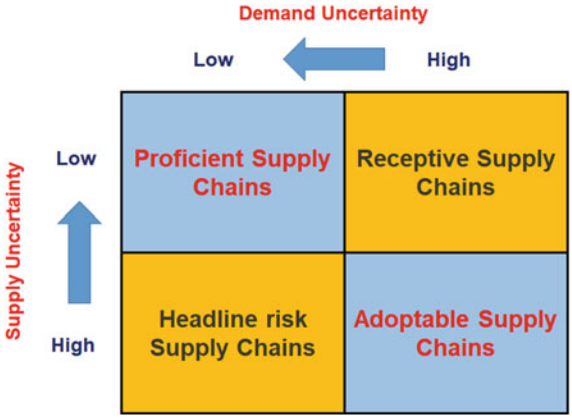

Fig. 5 Uncertainty in demand and supply [33]

10 Outcomes of the Framework

Outcomes of the IoT-based agro-products supply chain management system are encouraging enough. With the help of this framework, one end-to-end supply solution is created which works from the farm to consumer. The originality/quality of the agro-products can be ensured. Storage and transportation of the agro-product can be handled on priority basis, and their monitoring is also proposed to achieve the high extent accuracy in the supply chain. A consumer demand-based low-cost hygienic product in less time can be delivered. The errors in the storage and operations can be minimized through the IoT-based automated supply chain management system. The wireless sensors and peer-to-peer communication ensure the information exchange in remote areas where Internet connectivity is not predictable. With the help of this system, we can minimize the wastage of the agro-products which leads the low-cost purchase to the consumer and high profit to the farmers.

11 Summary

IoT-enabled agro-products supply chain management system is a revolutionary framework to uplift the traditional agro-products supply chain management and minimize agro-products wastage and operational errors. A quality fresh food can be supply as per the consumer demand at speculated time and low cost. This system is helpful to the farmers to have quality seeds and advanced tools and techniques to grow and harvest the crops with great quality at low cost. Various IoT-controlled sensors are used to assess different stages of the crop and yield in field as well as storage and their requirements. The hassles transportation and delivery of the agro-products to the cold storage and consumers are also ensured with the GPS and wireless sensor. The AI is based on monitoring system which is to help the operational activities with minimum human error with great efficiency and accuracy. With the help of peer-to-peer communication, this system can ensure the timely information exchange among different nodes even in the remote areas. The decentralized network is to ensure the timely decision and operational activities in remote areas even when the remote nodes are disconnected with central server. In this system, an auto-authentication and approval process has been introduced which is very helpful for the agents to get into the supply chain and can remove themselves the three without disturbing the other activities. Finally, this is a win–win solution to all the stockholders from grower to the consumers.

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Machine Learning Approaches for Agro IoT Systems

C. R. Dhivyaa, S. Anbukkarasi, and K. Saravanan

Abstract In agriculture, the technological advancement is essential for better growth and sustainability in the long run. Conventional way of farming is less efficient and time consumable because of more labor cost and high energy consumption. Hence, forefront technology like the Internet of Things (IoT) would be an affordable and more precise solution for the betterment in agriculture. By deploying intelligent systems, agricultural process can be automated and human intervention can be reduced. To increase the agriculture yield, most of the industries are adopting the automation methodologies in which agricultural data are collected and processed in an efficient manner. To analyze the sensed data, machine learning approaches are used in Agro IoT. Some of the machines learning algorithms are available for predicting the solution to the agriculture problems. ML algorithms learn from the given data and make the predictions precisely. A combination of optimized CNN model with deep learning neural network model provides promising results for IoT-based smart farming system.

Keywords Agriculture · Internet of Things · Crop management · Machine learning algorithms · Prediction · Productivity

1 Introduction

Agriculture is an important factor and backbone of the Indian economy. It contributes about 17% to the total gross domestic product and also produces employment to over 60% of India's population. Farming and agriculture is the major part of gross domestic product in developing countries. In order to increase

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agricultural productivity, the IoT Smart farming system is essential to monitor the crop yield for automating irrigation systems and the technological advancements are also required for better growth in agriculture industries. The Internet of Things is internetworking of physical objects for collecting and exchanging data. The focus of the IoT in agriculture is to automate all aspects of agriculture and agricultural methods to make the process quite efficient. Traditional methods of yield management, livestock management, weed management, soil management, water management, plant management, and animal tracking are not fully automated and inefficient. These traditional methods increased human interaction, labor costs, and power consumption.

The automated system consists of electronics, software, sensors, actuators, and network connectivity. In this automated system, the sensors are used to collect the data, the controllers are used to process the data and the actuators are used to complete the automation process. It reduces the overall human interaction and labor cost. Presently, the agro-industrial areas apply IoTs and machine learning algorithms for both diagnostics and control of the smart farming systems. The machine learning algorithm helps to predict the irrigation-based on crops and other weather scenarios. Many researchers have focused on Integration of IoT with machine learning techniques to monitor and control agricultural parameters for increasing productivity, efficiency in agriculture industry. It will also help to prevent situations like malnutrition and starvation. Currently, the researchers are working in collaboration with agricultural industries for developing and improving agricultural activities such as pest detection, water management, animal detection, fertilizer management.

1.1 Water Management

Water is essential for all the living things such as humans, animals, and plants. It is one of important sources of agriculture, and it will be used for irrigation, food production, pesticide, and fertilizer applications. If agricultural water is used properly, it improves crop yield and production positively. A decreased water level can cause crop production and crop yield to decrease. An extra water level creates danger in crop yield and also decreases the quality of soil. Hence, an environmental monitoring system which is based on the technology of the Internet of things is required to avoid the issues in agriculture. Smart agriculture uses sensors to monitor the crop field for soil moisture, temperature, and humidity. Based on these parameters, the irrigation system can be automated and sends an alerting message to the farmer when the soil moisture level increases or decreases. The smart irrigation system contains controller where it consists of agricultural parameter values obtained from the sensors and helps the farmer to take decisions for their crop production. The intelligent water management system [1] is shown in Fig. 1.

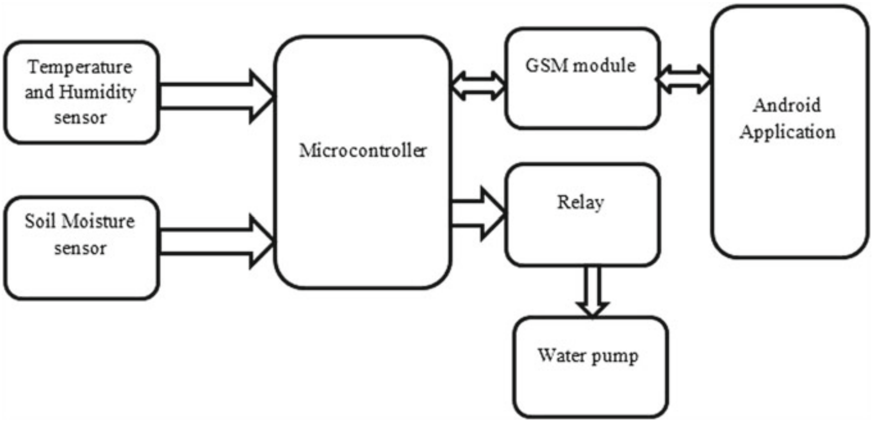


Fig. 1 Intelligent water management system

1.2 Pest and Disease Management

In agriculture, the crop health condition plays an important role to get good profit for the farmers. Crop production is related to the presence of pests and diseases in the plant. During the day, pests hide behind the plant leaves to avoid the heat and in the evening or at night, pests appear on the plant leaves. If the farmer is unaware of pest damage, the pests spread uncontrollably and damage all the crop production. Accordingly, the proper health monitoring system [2] is essential to prevent diseases infecting plants by monitoring the growth of plant at different stages. The farmers have used the various pest and disease management strategies in order to prevent plant diseases at regular interval periods. The IoT-based automated screening system [3] helps to detect plant diseases at early stages and enhances the crop production in agriculture industry. The sample images of disease infecting on plant leaves are shown in the Fig. 2.

The IoT-based system uses the sensor devices to gather the environmental information such as humidity, temperature, atmospheric pressure, water level, sun light levels and color of leaves and the farmers can monitor the environmental

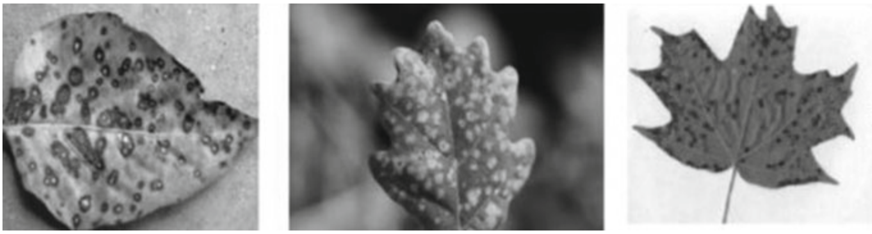


Fig. 2 Disease infecting on plant leaves

information at home. The system analyzes those data by using machine learning model and predicts the disease and pest infection on plant leaves based on the measurement variations in the parameters. The IoT integrated with machine learning produces new approach in the field of smart farming system and it consists of image preprocessing, image analysis and classification. In this approach, the images are captured and acquired using sensors and cameras. The preprocessing technique is applied to normalize the acquired images for removing the unwanted data present in the input image and the features are selected by analyzing the images. The classification techniques like deep learning model and convolutional neural network can be used to predict the crop diseases at earlier stage and increases the crop productivity. The block diagram is shown in Fig. 3.

1.3 Weed Management

In agriculture, the weed management is one of the serious problems and it affects the growth of the crops. The weed is a valueless plant which affects the quality of the plantation crops and also it causes root damage to drainage pipes and road surfaces. The weed is replicated forcefully, and it requires essential nutrients that are required by the cultivated plants. If the weed is not monitored properly it competes with other cultivated plants for nutrients such as water, soil, space, and it spoils the growth of the planation crops. Currently, the farmers remove the weeds manually or they spray herbicides to kill the unwanted plants all over the surface to keep the weeds under the control. This method is very ineffective because the chemicals damage the life of cultivated plants, it leads to pollute the environment and causes health problems like eye-skin irritation, asthma-related problems in humans. The types of weed plants are shown in Fig. 4 [4].

Hence, the smart weed management and control system [5] is necessary to avoid these effects for increasing the crop productivity in agriculture. This system uses Internet of Things along with convolutional neural network for detecting the weeds in the plantation crop without human intervention. In this system, the images are

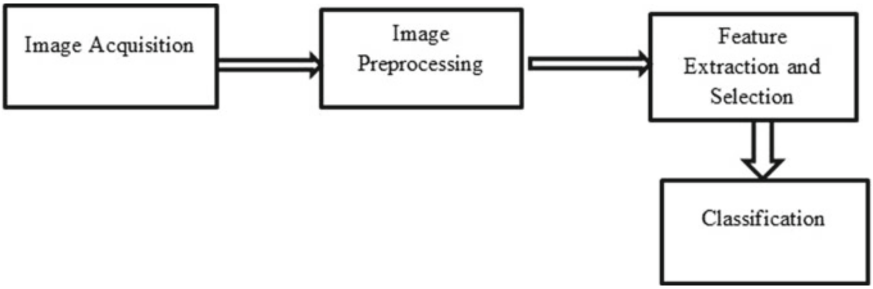


Fig. 3 Disease infecting on plant leaves

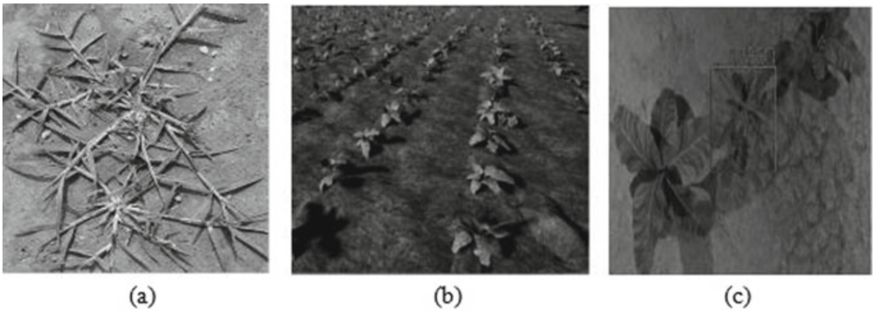


Fig. 4 **a** Picture depicts the weed plant **b** image shows the crop plantation arranged in rows **c** picture depicts the weed plant detection between two crops

acquired by camera and it segments the images into small parts using effective image segmentation algorithm. Each segment is passed to CNN model which is already trained by large images of weeds and crops. The trained CNN model classifies the image as weed or crop. If the image is weed, the specific area is highlighted in original image and sends it to farmers. In recent time, an IoT-based intelligent robot [4] will carry out the task to detect weed and removes all weeds remotely. To perform this task, the robots which can identify each plant and classify the plants into crops and weeds by utilizing the trained model. Weed detection robot access the information in authentic-time which are retrieved by IoT sensors.

1.4 Soil Management

The agriculture depends on various soil parameters such as nitrogen, potassium, phosphorus and the advancement in agriculture increases the crop productivity. The cultivation in our country is diminished due to lack of interest and awareness about the dryness of land, pesticide usages and selection of crops which is suitable for the land. Hence, the IoT-based soil monitoring system [6] is required to assist the farmer to predict the quality of soil by analyzing the information in real time variance of soil contents. It reduces human intervention and the manual monitoring of the agriculture field. The information of soil contents like moisture, temperature, and environmental factors are acquired using various sensors such as temperature, humidity and pH sensors. The system uses machine learning algorithms for deriving soil parameters, soil feature extraction and soil moisture estimation. Based on the performance calculation, the farmers can select the appropriate crop that suits the soil for cultivation. The IoT-based monitoring system helps the farmer to increase the crop production in agriculture. The system architecture is given in Fig. 5.

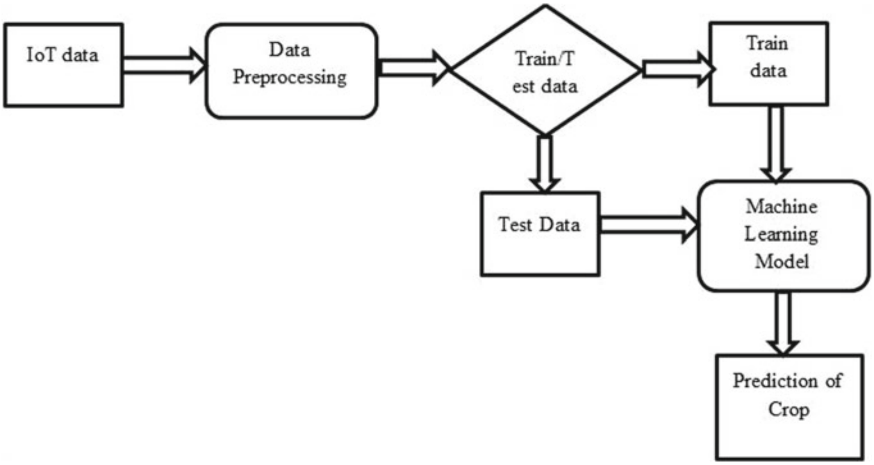


Fig. 5 System architecture

In modern generation, integration of IoT with machine learning techniques is the best suitable for yield management, livestock management, weed management, soil management, water management, and plant management in agricultural industries.

2 Various Machine Learning Approaches for IoT

Machine learning is an important emerging technique which provides a learning ability for the machine and takes the decisions on its own. It is the sub domain of artificial intelligence (AI). Each technique in machine learning uses various mathematical models and makes predictions. It is used for various applications such as sentiment analysis, product reviews, image classification, spam filtering, recommendation systems and many more. As how human beings learn from past experience, the same way machines also learn the patterns from the past data with help of machine learning algorithms. It uses historical data which is technically known as training data, to build the mathematical model to predict or make the decision without explicitly programming the machines. The basic idea of machine learning technique is depicted in Fig. 6.

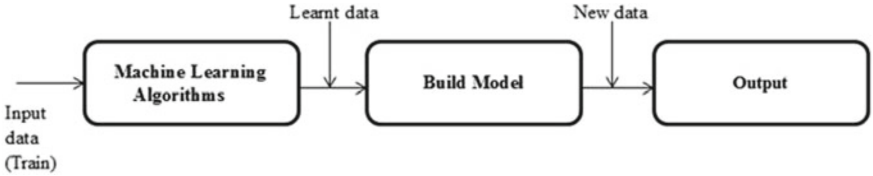


Fig. 6 Machine learning approach

Features of Machine Learning

- Machine learning is data driven. It learns on its own with the help of data without any explicit programming.
- It predicts the output from the knowledge it gained from the past data.
- It learns various patterns from the huge data.

Necessity of Machine Learning

The need for machine learning is increased today as the world deals with huge amounts of data. The arrival of social media such as Facebook, Twitter, Instagram ends up accumulating enormous data such as text, image, audio, and video. It will be difficult for human beings to handle such big data. Hence, machine learning comes into picture to deal with data, learn from the data and helps to make decisions based on those data. Machine learning plays a major role in many areas like automating self-driving cars, product recommendations, face recognition, fraud detection, disease prediction, etc., [7]. It identifies the in depth patterns from the data and produces useful information. The complex problems which cannot be solved by human beings can be easily resolved by machine learning algorithms. In a broader sense, machine learning is classified as given in Fig. 7.

Machine learning in its wider terms classified as 1. supervised 2. unsupervised 3. deep learning. Supervised learning is a method as the name suggests it learns with the guidance data. Well labeled dataset is used to train the model in supervised learning. After the training test data is fed to the system, then the system classifies the test data based on the knowledge it obtained from the training set. Classification and Regression comes under the category of supervised learning. Unsupervised Learning is a method where the system learns from the pattern without any guidance like supervised learning. No labeled data will be passed to the system to get trained. The system has to learn the pattern on its own. Clustering and Association technique belongs to Unsupervised Learning.

Deep learning (DL) is a technique which is built based on the artificial neural network (ANN). It learns the patterns from the example which is passed through various layers and performs the prediction. DL is used to classify text, image, audio, video. Self-driving cars, voice control in devices like smartphones, tablets, medical research, and aerospace defense are some of the key areas of DL. All the mentioned ML techniques can be used to address the problems we face in agriculture [8]. Along with IoT, ML plays a crucial role in agriculture management. In the

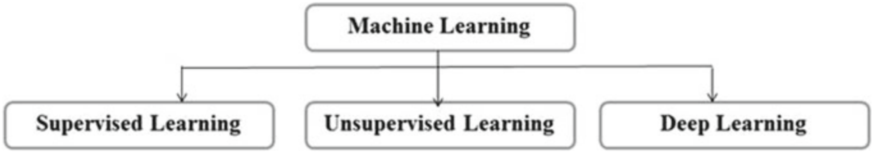


Fig. 7 Basic machine learning approach

following section, we are going to discuss various machine learning approaches [9] which are used in agriculture. Agro IoT hands with machine learning techniques help in various fields such as crop management, yield measurement, disease prediction, quality of soil, crop prediction, etc.

2.1 *Support Vector Machine (SVM)*

SVM is one of the supervised learning algorithms which are mainly helped for classification or regression problems. N-dimensional space is segregated into classes which help to create a boundary or line, so the new data points can be easily placed into the correct class. This boundary is known as a hyperplane. SVM creates hyperplanes by choosing the extreme points or vectors. These extreme points are considered as support vectors. That's why it is known as the support vector machine. Basic SVM is shown in Fig. 8. SVM is used in yield prediction, disease management, and soil management [10]. Chinese weather station information is used to predict the rice development process. Based on the geographical information obtained from the station, the classification is performed. The various parameters such as quality of soil, rainfall, temperature and sunlight plays a vital role in yield management. Thus, all these variables are captured in the work for yield prediction. SVM is implemented for soil management which determines the type and quality of the fertilizer based on the soil [11].

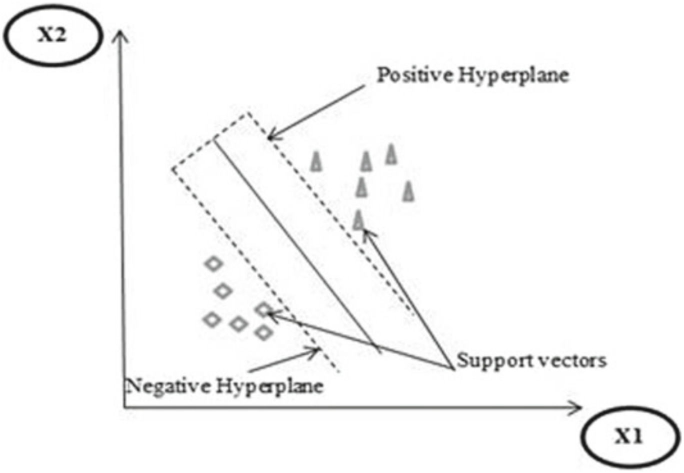


Fig. 8 Support vector machine

2.2 K-Nearest Neighbor (KNN)

KNN is the supervised learning algorithm like SVM. The main objective of this algorithm is to group the similar objects together. This similarity is otherwise known as proximity, distance or closeness. The basic working idea of KNN is given in Fig. 9.

If A is considered as input dataset and B is considered as training dataset, then the distance is considered as,

$$d(A,B) = \sqrt{\sum\nolimits_{k=0}^{n} (A_k - B_k)^2} \tag{1}$$

KNN is used in soil management for predicting soil moisture from the precipitation and evaporation hydrologic data. The dryness of soil is predicted from the data which are obtained from various IoT devices and decision is derived [12].

2.3 Naive Bayes (NB)

For high dimensional training dataset, NB is the most suitable supervised classification algorithm which follows Bayes theorem. It works based on the probability of the object hence called a probabilistic algorithm.

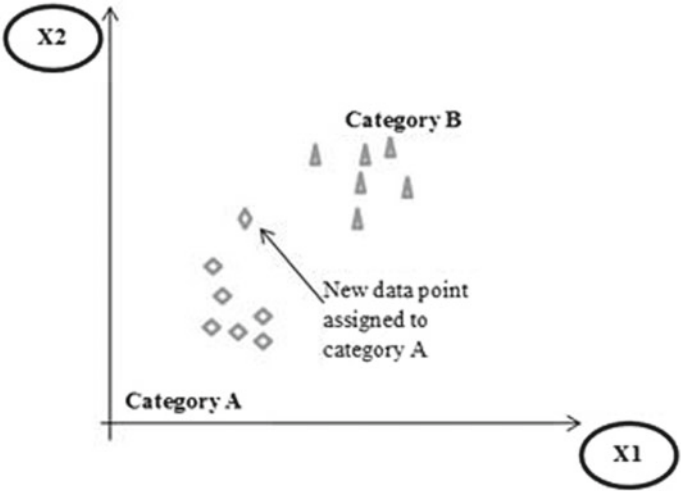


Fig. 9 K-Nearest neighbor

$$P(x|y) = \frac{P(y|x)P(x)}{P(y)} \tag{2}$$

where

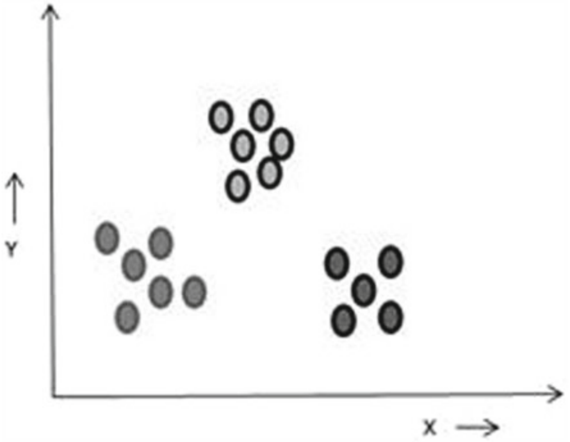
$P(x\|y)$	is the posterior probability of class (x, target) given predictor (y, attributes).
$P(x)$	is the prior probability of class.
$P(y\|x)$	is the likelihood which is the probability of the predictor given class.
$P(y)$	is the prior probability of the predictor.

Naive Bayes theorem is applied in disease management in Agro IoT systems. A unique virus called Yellow Vein Mosaic Virus (YVMV) is identified in okra and bitter gourd plants. NB is used to classify the high dimensional data with smaller dataset [13].

2.4 K-Means Clustering

K-means is the unsupervised algorithm where the unlabeled data are classified into particular clusters. *K* represents the number of clusters in the classification task. Figure 10 depicts how objects are formed into clusters. *K*-means algorithm is used in yield prediction and disease management in Smart IoT-Agro systems [14].

Fig. 10 *K*-means clustering



2.5 Deep Learning

Deep learning (DL) is the sub domain of Artificial Intelligence. DL models are trained with the given data on its own unlike machine learning algorithms. It learns the patterns from the given input data and makes the decision on the new unseen data. It works based on the principle of artificial neural network (ANN) [15]. As how human brains are connected with neurons, ANN also imitates the human brain and forms the network through neurons. ANN has three layers, namely, input, output and hidden layers. Data is passed to the model through the input layer, processed in a hidden layer and the prediction is done at the output layer [16]. Various layers of deep learning model is depicted in Fig. 11.

When an ANN is formed with more than 3 layers, that is a single input, output layer and many hidden layers is known as Deep Neural Network (DNN). Pest control and crop yield prediction is done with artificial neural network [17]. Using the IoT technology, with force sensors moisture level of soil is predicted using ANN. In wheat production, the good wheat plant is differentiated with the yellow rusted infected wheat plant using ANN [13].

3 Ensemble Methodology for Crop Management

3.1 Smart IoT-Based Crop Recommendation System Using Deep Learning

Usually farmers determine the plants to be grown in their field from their experiences and the knowledge they obtain from their ancestors. Due to various factors, including climatic changes, air pollution, and water scarcity would give less productivity. Hence, an IoT-based crop recommendation system is established to predict the crop to be cultivated in their field.

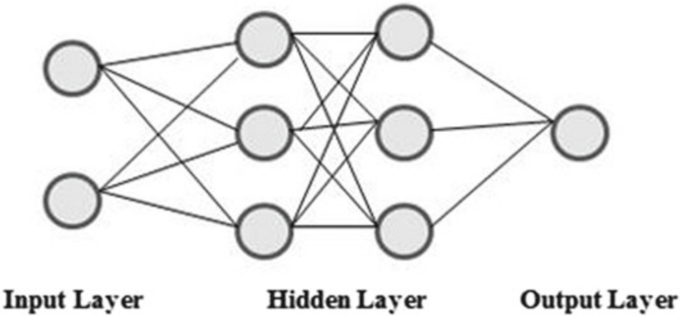


Fig. 11 Deep learning model

3.1.1 Data Collection

Various IoT-based sensors are used to collect the data for this process. The data consists of various parameters such as soil quality, pH level of soil, temperature, rainfall, Nitrogen, Phosphorous, Potassium (NPK) which determines the nutrients of the plants. These parameters are taken because it is needed to select the plant for the weather, economical situations, major plants known as rice, maize and minor plants known as lentils, fruits are considered in the dataset for recommendations. The basic architecture for the crop recommendation system is depicted in the following Fig. 12.

3.1.2 Methodology

Deep learning-based classification system involves the following steps:

- Pre Processing
- Feature Selection/Extraction
- Classification using models
- Results and Discussion.

Pre Processing

The first step in classification task is to preprocess the data. The data which we collect from sensors or various other sources would be noisy. To get the clean data, data should be gone through several preprocessing steps. The missing data should be filled in a correct way, extra symbols like tags, punctuation marks should be removed from the data.

Feature Selection/Extraction

The second step in classification tasks is feature selection. Deep learning models accept the data in terms of numbers only. Text data will not be accepted by the

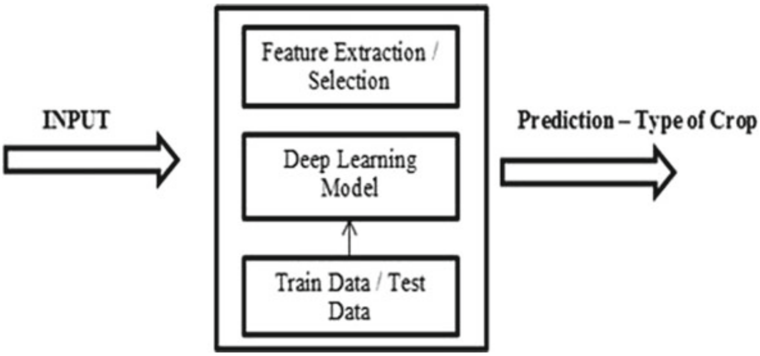


Fig. 12 Crop recommendation system

model. For that, all the text data should be converted into numerical data before it is processed by the model [18]. After converting into numerical vectors, the input sequence should be padded. This step is important as the inputs are of various sizes. The padding will help to make the input data with equal size. After all these steps, the final cleaned, processed data will be passed to the model. For this implementation we tried a sequential deep learning model, Random Forest Classifier, support vector machine (SVM), K-Nearest Neighbor classifier. Out of all these technologies, KNN yields good accuracy.

Classification

Classification of the data is done with various machine learning models such as RF, SVM and KNN [16]. Sequence-based deep learning model also used for classification purpose. We used two dense layers with 22 output channels. The hyper parameters used in the model are depicted in Table 1.

Results and Discussion

Recommendation of plants based on soil nutrients, rainfall, temperature, humidity is implemented using a deep learning model. For comparison of the system, we carried out experiments with other technologies too. One of the performance metrics such as accuracy is used for evaluation purposes [19]. The results are discussed in the Table 2.

Table 1 Parameters used in the deep learning model

Parameter	Value
Activation	Relu
Optimizer	Adam
Batch size	100
Epoch	10
Loss function	Categorical cross entropy

Table 2 Comparison of proposed systems with other models

S. No.	Technology	Accuracy (%)
1	Random forest	75
2	KNN	85
3	SVM	86
4	Sequence-based deep learning model (proposed system)	89

3.2 An Optimized Convolutional Neural Network for Disease Detection

Plant diseases are major threats to food security in agriculture because it decreases the yield and quality of the crop in many parts of the world. The diagnosis of crop diseases is a big challenge in agricultural industries. In the traditional method, the framers identify the crop diseases on human annotation by visual inspection. At present, the various technologies have been developed for detecting the crop diseases in agriculture. One of the popular techniques is deep learning with convolutional neural network for the classification of various crop diseases. The automated IoT-based screening system [20] helps the farmer to diagnose the various crop diseases in earlier stage and they can save the life of crops to increase the productivity in agriculture. The automated system consists of

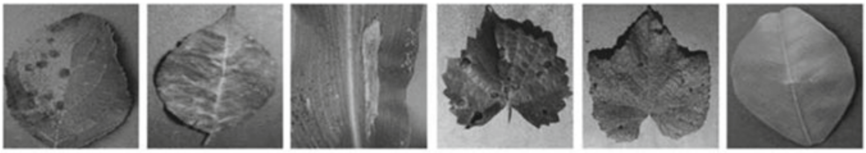
- Data set
- Pre processing
- Convolutional neural network and models
- Deep learning Optimizers
- Performance evaluation.

3.2.1 Dataset

The Plant Village dataset is used for classification of crop diseases. The dataset consists of 54,303 healthy and unhealthy leaf images and it is divided into 38 labels by species and disease. The 14 image spices include Tomato, strawberry, peach, orange, apple, pepper, cherry, squash, raspberry, blueberry, soy, grape and potato. The image dataset contains 17 basic diseases, 4 bacterial diseases, 2 mold diseases, 2 viral diseases and 1 disease transmitted by a mite. It also contains healthy leafs of 12 crop species. The input plant village dataset is shown in Fig. 13.

3.2.2 Preprocessing

As the images are captured from the real field, it may contain noises such as dust, water spots, and spores. In order to eliminate the noises present in the image, the preprocessing technique is required to remove unwanted falsification for enhancing the quality of the images by adjusting the pixel values. Normalization is a preprocessing technique which is used to adjust the range of pixel intensity values in an image. The image size is modified by performing normalization operation which divides the values of pixels by 255. This normalized image is given as initial input values to the convolutional neural network models.



Apple Scab

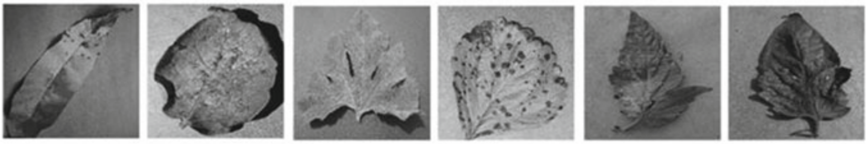
Cherry powdery mildew

Corn northern leaf blight

Grape black rot

Grape leaf blight

Orange Haunglongb



Peach Bacterial Spot

Potato Early blight

Squash powdery mildew

Strawberry leaf scorch

Tomato early blight

Tomato late blight

Fig. 13 Crop sickness from plant village dataset

3.2.3 Convolutional Neural Network and Models

A convolutional neural network contains three layers such as input, hidden and output layers in which the hidden layers perform convolution operations. The input image is passed to the convolutional layers, and it passes its result to the next layers. The convolutional neural networks include pooling layers to streamline the calculations, and it reduces the dimensions of the data by combining the neurons output into a single neuron in the next layer. The fully connected layers connect every neuron in one layer to every neuron in another layer to classify the images. Initially, the plant village dataset is divided into 70% training data, 20% for validation, and 10% for testing datasets. There are various popular and successful CNN models for image classification. In this section, the CNN models such as VGG-16, ResNet-50, Inception ResNet-v2, Inception-v3, MobileNet, DenseNet-121, and Xception are developed and compared their results for detecting the diseases of crop species. Based on the performance evaluation, the best CNN model is selected for the plant disease classification by comparing the parameters such as training accuracy, validation accuracy, training loss, and validation loss.

3.2.4 Deep Learning Optimizers

After selecting the best CNN model, the optimizers are applied to train the CNN model for attaining the highest validation accuracy. The few optimizers are listed and compared as below:

- **SGD**: It is the simplest deep learning optimizer. It applies the stochastic gradient descent optimizer along with a momentum and learning rate.
- **Adagrad**: It specifies the parameter-specific learning rates and these rates are updated that are relative to the frequency of the update of each parameter.
- **RMSProp**: It maintains a moving average of the square of gradients and divides the gradient by the root of this average. It reduces the training time observed in Adagrad.
- **Adadelta**: It is an expanded version of Adagrad in which the learning rate is based on moving window of gradient updates.
- **Adam**: It estimates adaptive learning rates using the first and second moments of gradients and it combines the best characteristics of the AdaGrad and RMSProp algorithms to provide an optimization algorithm.
- **Adamax**: It follows Adamax algorithm which is based on infinity norm and it is used for sparse parameter updates.

3.2.5 Performance Evaluation

The performance parameters such as training accuracy, validation accuracy, training loss, and validation loss are calculated for comparing the CNN models to select the best one among the others. The $F1$-score is one of the important performance metrics for the classification of the crop diseases, and it is also evaluated for predicting the best CNN model. The results of all CNN models are summarized in Table 3, and performance graph is plotted shown in Fig. 14.

From the performance evaluation, the Xception CNN model provides high validation accuracy and $F1$-score than other CNN models. Hence, it is selected as best architecture for classifying the plant diseases on plant village dataset. The performance of the Xception CNN model is further trained and enhanced by applying various deep learning optimization algorithms, and the results are compared to identify the best optimizer among the others.

Table 3 Comparison table of CNN Models

CNN models	Training accuracy	Validation accuracy	Training loss	Validation loss	$F1$-score
VGG-16	0.83	0.81	0.530	0.565	0.81
ResNet-50	0.98	0.94	0.041	0.196	0.93
Inception ResNet-v2	0.95	0.90	0.152	0.305	0.90
Inception-v3	0.95	0.94	0.143	0.183	0.94
MobileNet	0.97	0.96	0.092	0.101	0.96
DenseNet-121	0.98	0.95	0.071	0.131	0.95
Xception	0.99	0.97	0.014	0.062	0.97

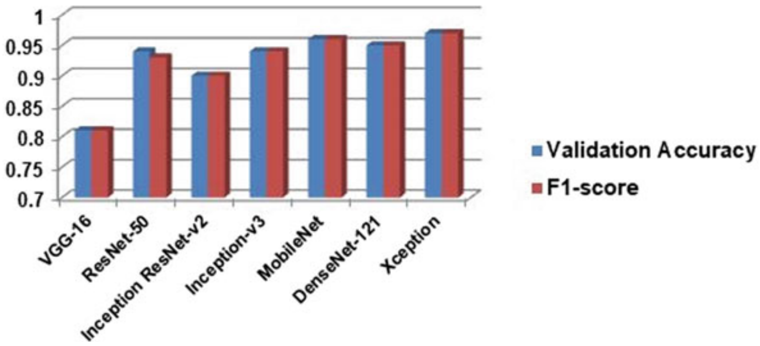


Fig. 14 Performance plots of CNN models

Table 4 Comparison table of optimizers

Optimizers	Training accuracy	Validation accuracy	Training loss	Validation loss	*F*1-score
SGD	0.9990	0.9798	0.0140	0.0621	0.9765
RMSProp	0.9998	0.9924	0.0005	0.0433	0.9900
Adagrad	0.9987	0.9621	0.0164	0.1460	0.9593
Adamax	0.9988	0.9881	0.0012	0.0415	0.9888
Adam	1.000	0.9981	0.00006	0.0178	0.9978
Adadelts	0.9990	0.9889	0.00008	0.0364	0.9900

The results of all optimizers are summarized in Table 4, and performance graph is plotted shown in Fig. 15. In this section, the comparative analysis has been performed between different CNN models and optimizers. From the experimental analysis, the Xception model secured the best validation accuracy and *F*1-score. This model is trained by several deep learning optimizers and the Adam optimizer obtained the greatest validation and *F*1-score. We suggest that the fusion of Xception architecture along with Adam optimizer provides the best accuracy for detecting the crop diseases in agriculture.

4 Conclusion

Machine learning is the popular emerging technique in Artificial Intelligence which helps the computer to learn on its own without any explicit programming. ML learns from the given data and makes the predictions precisely. In this book chapter, we discussed various machine learning approaches for Agro IoT system such as SVM, Naive Bayes, and artificial neural network. The smart Agro IoT system deals with various agriculture problems such as crop and yield management, soil

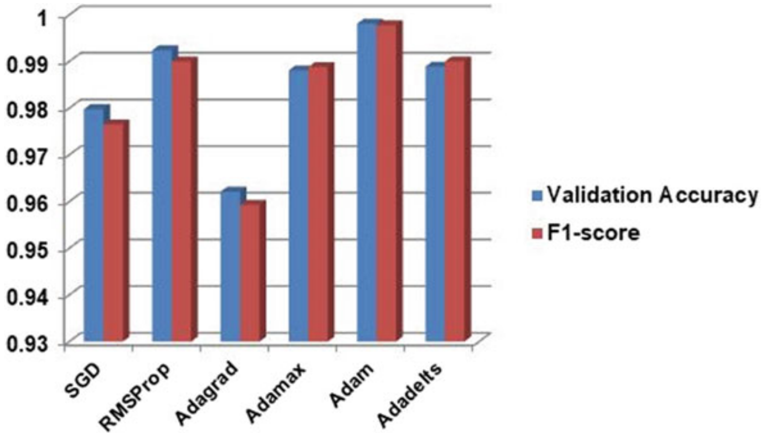


Fig. 15 Performance plots of optimizers

management, disease management, weed detection and water management. In recent days, deep learning-based neural network models yield best results in many decision making problems. This proposed work covers two of the major problems in smart agriculture system known as crop management and disease control management. As per the analysis made in this book chapter, we proposed sequence-based deep learning model with Adam optimizer for crop recommendation system and fusion of Xception architecture along with Adam optimizer for disease control in agriculture. We achieved 89% accuracy for crop management and 97% for pest control management system. In the future, most appropriate features can be extracted using advanced algorithms which would improve the accuracy of the model.

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AI-Based Yield Prediction and Smart Irrigation

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Abstract Yield prediction is the primary process of predicting the plant's growth. It can be determined by different parameters such as temperature/humidity, soil mineral contents, soil pH level, salinity level, climatic conditions, moisture of the soil, etc. These parameters must meet the optimum level to make a desirable environment to sustain productivity. Failure to provide the required condition from any of the parameters will lead the plant to stress and deteriorate, potentially leading to a loss in productivity. Laborious ways of monitoring the agricultural parameters are inefficient and time-consuming. An automated irrigation system is essential for the proper growth of crops. Excessive watering of crops and crop water dehydration can lead to stresses that affect the growth of plants. Supplying an optimum amount of water is essential for the healthy development of plants. The IoT and artificial intelligence technologies are the most viable alternative solution for traditional yield prediction and irrigation because of the remote accessibility, interoperability, cognitive capability, etc. These technologies aid the farmers in monitoring agricultural parameters remotely from embedded devices, drastically reducing human efforts. It makes farming much efficient and a smarter farming experience and also increases crop productivity exponentially. This chapter has manifested the current environmental problems and the potential future challenges that may decrease crop productivity of the crops. It also shows how the sensor technology has gradually evolved the traditional farming experience to solve problems and the possibilities of transforming the current farming practices into much more innovative and eco-friendly with the emergence of artificial intelligence technologies. The main objective of this chapter is to spread knowledge and elevate the current farming practices and several challenges that the farmers are currently facing. It also projects how to bridge the gap between these agricultural problems and challenges with the emergence of the IoT and AI technologies to sustain precision agriculture.

Keywords Yield prediction · Artificial intelligence · IoT · Smart irrigation · Precision agriculture · Climate change

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1 Introduction

Agriculture is the fundamental need for every human race that fulfills our basic requirements. It is the country's economy setter that provides occupation for the farmers and workers. Every year, the population has increased in every country, which in turn increases the food demands. However, crop yields and production growth are not going par with the food demands for several factors. The increase in the population encourages deforestation for urbanization and city establishment due to land settlement.

Deforestation is the primary cause of climate change, including human activities such as the emission of industrial gases, excessive carbon-oxide emission, dumping chemical wastes, etc. It, in turn, causes contamination to water and the air. It also increases the concentration of greenhouse gases and aerosols. These activities have a substantial negative impact on the vegetation and farming that hinders the growth of the yields and productivity. Because of these consequences, plants suffer from different stresses like heat stress, drought stress, mineral stress, chill stress, etc. Farmers are facing a massive problem in yielding enough crops for supplying human demands because of the environmental-driven stresses on the plants. Because of these problems, crop productivity is not getting improved over the years, instead, it is getting deteriorating gradually.

Moreover, the environment has been consistently changing, and it could be worse in the future due to the continuous increase in greenhouse gas emissions [1]. Due to the inevitable climate change, it is crucial to sustain the increasing agricultural demands for the survival of the human race. Apparently, the laborious form of farming will no longer support the growing agricultural demands in the near future as it requires effort and is time-consuming. Moreover, due to the inconsistency of human force, it could drastically reduce the accuracy of the farming management system. Because of these challenges, it is crucial to introduce the technologies in the agricultural domain to elevate the farming management systems and sustain the increasing food demands despite climate change.

The IoT technology is an emerging technology that has set foot on several domains and applications, including the agricultural domain. With the advancement of IoT technology, farmers can monitor and control all kinds of parameters remotely on the field in real-time. It allows the farmers to evaluate and predict the growth of the crop, which will significantly aid in the increase of crop productivity. Moreover, the IoT technology promotes interconnectivity and interoperability, allowing farmers from different places across the globe to share farming experiences to improve farming management systems. Along with the emergence of IoT technology, artificial intelligence (AI) has also paved its path in this technological era. AI technology has practically transform manual systems into automated systems in which human intervention is dramatically reduced. There is a huge scope in incorporating the IoT and AI technologies, especially in the agricultural domain, for transforming traditional farming into automated farming to promote precision agriculture.

2 Literature Survey

The estimation of crop yields before the harvest is challenging due to the continuous change in the climatic regime. Nowadays, the season has slightly shifted its pattern, making it difficult for farmers and agronomists to predict the upcoming agricultural yield. Since weather influences the plants' growth, the farmers need to be resilient with the help of technologies to improve the quality of farming. Technological advancement helps solve current problems, such as weather prediction, water content monitoring, disease prediction, and precision irrigation systems. Machine learning is widely used in various application areas for solving nonlinear problems. It also would be an excellent tool for predicting crop yields, which would highly aid in farming. Linear Regression and Support Vector Machines are the algorithms commonly used in prediction and classification [2].

One of the primary concerns in agricultural farming is water scarcity. The continuous use of fertilizers has a significant impact on groundwater contamination, which affects the growth of crops and could be hazardous for human consumption. Water has been extensively wasted in farming, whopping 60% of the water used in agriculture into waterways and over-watering the crops. Water can be preserved by supplying an adequate amount of water at the right time and avoiding evapotranspiration. The advancement in technology, IoT sensors, and AI technology can monitor the water content, pH level, mineral content, and atmospheric temperature. These technologies provide better control for the farmers in watering the crops, predicting the weather, and giving adequate minerals for healthy plants' growth [3].

The systematic irrigation system aids in watering plants with an optimum water content which provides crops and fibers a desirable condition for their proper growth. Global warming has affected the regime of precipitation and water sources. Since water is the vital source of growth in crops, it is essential to preserve water and utilize them smartly to promote a precision irrigation system. Pests and diseases also have significant impacts on crop yield. Early detection of water deficiency, stress, and invasion of pests could probably prevent the crops from being lesioned or deteriorating growth. An IoT system helps optimize the amount of water used and sends information to the edge node to process the data locally when the internet connection is limited [4].

The artificial neural network (ANN) and a multi regression model are the models to evaluate and estimate the seed yield of sesame (Sesamum indicum L.) using field data. The data includes the flowering time, the height of the plant, the capsule number per plant, the weight of the plant, and the number of seeds per capsule. It shows that artificial neural network performs much accurately in predicting the sources yield of sesame than the multi regression model [5].

An experiment was conducted in Shahrood, Semnan province, Iran, to predict pepper fruit yields. An artificial neural network has been implemented to monitor the pepper fruit yield response by considering different parameters such as the growth of the pepper fruit seeds from initial stages to the harvest stage, the height of the plant, canopy width, number of fruit bears per plant, fruit water content, and reproduction stage duration. It has achieved 97% accuracy in predicting the growth of the seeds [6].

3 Environment Impact on Agriculture

Agriculture depends on the environmental condition associated with the biological cycle inside the ecosystem, just as any other living organism. According to the seasons, farmers and agronomists plan their farming and yielding strategies for the whole year. Biologically, every plant species have their traits and growing pattern in different seasons. Due to the significant variances in their characteristics, sustaining the food products for the whole year is challenging for the farmers. However, this farming system has also been threatened by the rapid growth of urbanization across the globe. Although the urban land provides development and sophistication to the human lifestyle, there are several adverse effects on Biodiversity.

Urbanization is a primary cause of native species extinction, such as birds, wild animals, etc. Moreover, it is associated with deforestation, which reduces the tremendous amount of trees every year for the urban land. This human activity has led to an imbalance of the biological life cycle. The overwhelming growth of the population is changing the earth system's biogeochemical cycles, pushing the nutrients and compounds out of balance with the usual climatic and biological feedback mechanisms. These imbalances contribute to ocean acidification, climate change, marine dead zones, and many other environmental problems.

Urbanization is likely to widen its path even more to procure a sufficient amount of urban land for the people. Since the food demand has been increasing daily, the farmers and agronomists insist on using fertilizers and pesticides, which is the chemical composition to enhance soil fertility and significantly increase yield production to meet the increasing demands [7]. This process of sustaining yield production is not ideal since it possibly degrades soil fertility and affects the consumers because of the chemical components.

Some of the environmental impact on agriculture are:

- Water pollution—Water is one of the vital sources of life for all living organisms. Water quality has been degraded gradually because of many factors such as urbanization, pollution, sanitation, and chemical outlets [8]. Dumping wastes and chemicals by industries, hospitals, water treatment systems, construction, laboratories, and poor sanitation systems leads to empoisoning the water on the river and any other water sources that can harm animals, people, and plants. The practice of using fertilizers and pesticides in agricultural fields is also a major pollutant of water sources. The chemicals in these fertilizers could be hazardous for humans and cause several diseases.

- Air pollution—Urbanization has brought economic prosperity to society and made us stay connected with people across the globe. It promotes accessibility and also provides portability. However, despite the advantages, there is a trade-off between urbanization and environmental sustainability. One of the primary reasons is deforestation that leads to global warming. The cutting of trees for urban land created an imbalance in the ecosystem and has dramatically changed the climate over time which causes the greenhouse effect. Among several sectors, agriculture is one of the most affected by climate change. The crop yields and harvest have become an enormous challenge for the farmers since the climatic cycle has also gradually changed. The atmospheric temperature has become extreme in summer, and winter temperatures have reached beyond the optimum level. Because of these consequences, the crops are stressing by heat, chilled, and humidity stress which falls beyond the optimum temperature. Agriculture is highly dependent on climate and the environment. The anticipation of feeding 9 billion people by the year 2050 would be an enormous challenge.

4 Scope of AI in Agriculture

The current food production is insufficient to supply the requirements of food demands primarily because of the increasing population. The traditional farming practices could be limited and cannot sustain the supply of increasing food demand due to a lack of efficiency and cost. Nonetheless, machines and technologies perform a task much faster and accurately than a human force. Moreover, farmers and agronomists face a huge challenge in predicting the season as seasonal shifts affect the timing of many life cycle events due to global warming. The temperature of the summer has become higher, which potentially leads to thermal stress in plants, and monsoon rain is comparatively irregular nowadays.

Monsoon water is the primary source of water for crop growth. Since agriculture is entirely dependent on the weather and rainwater, the weather and inconsistent routine of the monsoon could disrupt the farming procedure, which reduces food production. The advancement in technology over the years gradually steps into the agriculture domain that improves the farming system. Nowadays, technological devices can monitor plant health, pests/diseases, mineral contents and deploy automatic watering systems. The incorporation of the Internet of Things (IoT) and AI have drastically improved the traditional practices of farming. It increases efficiency, productivity and reduces human intervention.

IoT is the interconnection of several devices across the globe. It enables electronic devices such as agricultural devices and sensors to connect with the farmers through smartphones or tablets that allow the farmer to have complete control over the dedicated agricultural sensors and actuators and retrieve information about several parameters from the farming fields. Moreover, farming can be operated automatically by the machines as per instruction given by the agronomist or the farmers. Some of the examples are traditional drip irrigation, automatic water sprinkler, disease detection, etc.

Artificial intelligence has paved a path toward several domains over the years, including agriculture. Since the global population grows extensively every year, food security has to go on par with the growth of the population to meet the need for livelihood. However, it cannot maintain the quantity and quality of crop yields because of environmental change, an increase in demands, lack of management, global warming, etc. Due to these circumstances, there are losses in productivity each year. Moreover, it also made the plants incur several stresses such as heat stress, water stress, mineral stress, salt stress, chill stress, etc., that hinder the growth of plants.

Experts have anticipated that the environmental problem will probably worsen because of human activities, deforestation, and globalization, which will have a huge negative impact on the vegetation, which threatened food security. AI is widely adopted in the agricultural parameters to solve problems and optimize the production and operation processes in agriculture, food, and bio-system engineering. It is designed to mimic human intelligence to work on an appliance capable of differentiating and classifying variables. Some of the applications of artificial intelligence in agricultural parameters are:

- Plant Disease Prediction—Plants are exposed and vulnerable to pests and pathogens such as viruses, bacteria, fungi, etc. Plant pathogen has caused tremendous productivity loss globally every year [9]. In the olden days, farmers manually investigate plants individually to verify whether they got infected by any pathogens. The process became tedious, inaccurate, and time-consuming for a farmer to do it mechanically. Since the population of the plant pathogen are variable in time, space and genotype, it is difficult for the farmers to predict and control. Early detection of plant pathogen is essential to reduce the spread of disease and facilitates prior management practices.

  To improve the prediction of pathogens, DNA-based and serological methods had revolutionized plant disease prediction that facilitates essential apparatus for accurate and efficient disease prediction. However, DNA-based and serological techniques are not reliable for the early asymptomatic stages [10]. Over the past few decades, artificial intelligence helps with the automatic detection of pathogens in a much faster and precise manner. In theory, the systems contain datasets that include images of diseased and healthy images, and it is trained to classify the types of images. The device will then learn to classify the leaf images and be able to distinguish between the healthy and affected leaf images. The process of AI-based disease detection model can perform the operation at high speed with a higher accuracy rate that can detect diseases even on the asymptomatic stages.
- Livestock Monitoring—Animals are one of the sources of food provider for human consumption, where they provide meats, milk, eggs, etc. So, it is necessary to keep livestock animals healthy and maintain a hygienic environment

for quality and healthy food production. Animals may be susceptible to diseases primarily because of their food habits. Early detection of animal diseases is mandatory to reduce the spread as they are highly contagious, and they could indirectly threaten human life. A farmer needs to monitor and understand the animal's behavior, gesture, distress, and disease control to better nurture experience and better decisions [11].

However, it could be laborious for a farmer to monitor each animal to check whether they are in a good health state, especially in large-scale livestock. Fortunately, AI-based livestock monitoring can be promising in animal husbandry to monitor animals' behavioral aspects individually, which helps them recognize facial features and hide patterns with the help of the Image processing technique. The AI-based monitoring system works around the clock in real-time. It better comprehends the multiple animals' gestures and behavior much efficiently.

- Smart Irrigation—Water is a vital part of farming, and it is essential to make sure crops get enough water to have proper growth. The agriculture sector is most affected by water scarcity consuming a whopping 80% of the total water use [12]. So, it is crucial to preserve water and reuse it as much as possible to avoid water scarcity. The technological modernization brought devices to promote these water preservation models in which devices such as water sprinklers and drip irrigation systems are commonly used. These devices assist in saving a reasonable amount of water and even saves time for farmers.

  However, the mechanical devices require a partial human intervention to handle the machine, so there are challenges and room for improvement to transform farming to be completely automatic [13]. AI-based Smart Irrigation System is the way to move forward for more intelligent and efficient agriculture, which is environmentally friendly.
- Weather/Temperature Forecasting—Agriculture is highly dependent on the climate and the weather variability that could potentially influence productivity and food security [14]. Forecasting weather for several months ahead could help the farmer to anticipate and prepare for the process accordingly without wasting time and resources. The weather regime has changed its pattern because of several factors and no longer follows the regular trend. The weather pattern and atmosphere are highly nonlinear, which makes it difficult to predict and anticipate. AI-based prediction is known to be the most feasible solution to solve these types of nonlinear data problems [15].
- Soil Health and Mineral Management—The fundamental factor for agricultural production sustainability relies on soil quality conservation [16]. Soil has contained several minerals that are nutritious and non-nutritious for the crops. Good soil management will help the farmers to ensure that the soil content does not incur mineral deficiency and contain harmful particles for the plants, which can indirectly intoxicate humans during consumption. Because of human activities and soil erosions, the soil has become contaminated and degraded, potentially harmful for human consumption.

Despite the soil degradation, the sustenance of the productivity with nutritional products for our healthy diets, monitoring the soil health and mineral with sophisticated technologies like AI and IoT is essential to make it environmentally friendly, efficient, less-laborious, and cost-effective. The use of these technologies is the most feasible way to sustain productivity with healthy products without further intoxicating the soil.

- Plants Stress Monitoring—Climate change has a substantial adverse impact on the daily temperature by altering the precipitation's intensification [17]. Because of these consequences, the plant tends to have several environmental stresses like heat stress, chill stress, salt stress, and mineral stress. Plants typically have severe inner damage when it develops visible symptoms due to the several environmental stresses [18]. Early detection of environmental stresses at the asymptomatic stages could save the plants from deterioration and complete leaf damage. The IoT and AI technology have been considered the primary viable solution to solve these problems and challenges. Image processing has become a powerful tool for monitoring and object detection, detecting plant stresses at a very early stage. It is a non-invasive form of technology and also environmentally friendly.
- Yield Prediction—Crop yield prediction is essential for sustaining food production. Depending on the prediction of the yields, it provides information about the feasibility of growing crops within a specified timespan. Since agriculture is the economy setter of the country, policymakers rely on the yield prediction that will highly impact the import and export of the country [19]. It also provides essential information for the farmers and agronomists to decide on the farming, harvestation, and management strategies. However, yield prediction is highly challenging as multiple factors and parameters are considered for the evaluation. AI technology is deemed to be the most powerful tool for plant stress prediction. It has been demonstrated in several articles [20–22].
- Supply Chain Management—One of the most important things for the farmer is selling their end products. Without a proper middle man or a reseller, farmers could face a hard time dealing with the products and selling them into the market. Supply chain management involves location planning, purchasing, inventory management, routing/scheduling problems, and freight consolidation [23]. This process could be tedious and time-consuming for the farmer to do it manually. Artificial intelligence is powerful in evaluating the data and the correlation of different nodes on the supply chain.

5 Yield Prediction

Crop yield prediction is essential for the farmers to know the reason behind the farming strategies and management. Prediction of yield could be a huge challenge as there are multiple parameters such as temperature, pesticides, rainfall, fertilizers, humidity, ph level, and other atmospheric conditions to predict crop yields. In the past, farmers observe and learn manually from their experiences during their farming days [24].

Apparently, they could sustain their products with their observation and occasions for quite a long time in the past. However, gradual climatic changes make it challenging to predict the timely seasonal crop yields. With the inconsistency and volatility of the current climatic conditions, the prediction of crop yields could be miserable with the traditional techniques. To mitigate these problems, sensor technology and artificial intelligence are rapidly emerging in the agricultural sector.

Artificial intelligence is one of the most powerful tools for modeling and prediction. Datasets play a significant role in AI models. For many farmers, it might be challenging to adopt the technology into the agricultural land as it required knowledge for bridging the gap between agriculture and technology. So, awareness and workshops must be made mandatory for the farmers to promote farming practices and promote precision agriculture. Crop yield prediction comprises several parameters in which any one of these could not be less emphasized because they help to thrive the growth of the crops collectively. Some of the main parameters that are to emphasize for precision agriculture are:

- Temperature—The farmers must maintain the temperature of the growing environment to sustain crop growth. Because of the climatic regime variability, the temperature is becoming extreme, causing crops prone to encounter heat or chilling stress. So, controlling the temperature to the optimum level would sustain the growth of the plants.
- Minerals/Soil Health—Soil is the primary source of nutrients and minerals for the life of the crops. Smart soil management would drastically aid the farmer in ensuring healthy soil and non-toxicity for the plants' growth [25]. Additionally, soil in a particular area might not necessarily have required minerals for the specific plants since the plants are variable in traits, characteristics, and morphologically different from one another. These parameters will allow a farmer to emphasize and treat particular plants according to the mineral and vitamin requirements.
- Humidity—There is a high correlation between humidity and temperature. Humidity is essential, just as the temperature, which impacts the growth of the plants. Some particular plants thrive in a specific area with higher humidity, where some plants have difficulties sprouting. Depending on the plants' requirement, controlling the intensity of the humidity would help the farmers to grow desire particular plant species pretty much anywhere regardless of the suitability of the area of land.
- Water Intensity—Water is one of the vital sources of livelihood for the plants. The precipitation pattern is gradually changing because of climate change that affects water availability, which eventually causes drought in many arid and semi-arid areas and a lack of water sources for agriculture [26]. Sustenance of water for agriculture solely implies not wasting water simultaneously, supplying an adequate water source for the plants.

- Pests Control—Pests, weeds, and pathogens are the types of harmful organisms that have invaded crops in the field, causing significant losses in food production every year [27]. Early detection helps protect and prevent the deterioration of the plants attacked by several types of pests and diseases. Since it is variable in time, space, and genotype, it is a challenge for farmers to predict and respond whenever the invasion occurs.

6 Machine Learning-Based Yield Prediction

Machine learning is a sub-branch of artificial intelligence inspired by the human intellect to solve real-world problems [28]. It is a process of training a system to make a decision depending on the circumstances and solve complex problems without human intervention. Unlike traditional programming, machine learning works with data from which it learns and provides relevant output. IoT and machine learning have been adopted in technology, science, and commerce streams such as banking, medical, traffic, autonomous vehicle, defense, agriculture, etc. [29]. Because of the vulnerability of agricultural productivity, machine learning has gradually emerged in the farming sector for sustainable food production.

Precision Agriculture (PA) combines technologies, management strategies, and farming practices to solve agricultural problems [30]. With the help of sensor and IoT technology, wide ranges of data are generated from sensors such as temperature and humidity sensors, electrochemical sensors, soil moisture sensors, mechanical sensors, weather sensors, smart cameras, etc.

Moreover, it also provides interoperability and the capability of controlling various devices remotely over the network. These sensors technologies can collect data from the sensors, such as soil condition and mineral content, temperature and humidity, visual representation, etc. Researchers are concentrating on improving the current farming strategies and techniques using machine learning and deep learning techniques.

6.1 Soil Health and Mineral Content

The soil contains different mineral contents, pH levels, and salinity depending upon the geographical location. Due to this, some particular plants could grow in specific places. In order to make plants thrive despite the geographical location, the required minerals and vitamins must be provided to the plant in an adequate amount. Soil testing is the key to determine the soil contents and the availability of the required nutrients, which helps the farmer to evaluate the amount of nutrients needed for the specific plants.

Suchithra et al. [31] presented an article in which the soil test results have been used to classify several significant soil features such as Phosphorus (P), Potassium (K), Boron (B), Organic carbon (OC), and Soil Reaction (pH). The classification and prediction of these minerals would help in reducing the fertilizers expenses, increase productivity, improve soil health, and environmental quality. Moreover, it will also reduce the expenditure and time for the experts to analyze the soil. Extreme learning machine is implemented for the classification of the soil parameters. Several activation functions such as sine-squared, Gaussian radial basis, hyperbolic tangent, triangular basis, and hard limit were tested; the Gaussian radial basis acquired the highest accuracy of 80%, and hyperbolic tangent attained the highest in the pH classification with the precision of 90%.

Extreme learning machine is the feedforward neural network that uses Moore—Penrose generalized inverse instead of gradient-descent-based backpropagation. Soil salinity is one of the most common causes of soil degradation [32, 33]. It can degrade soil fertility and cause soil erosion which affects vegetation and decrease food productivity. Since water is attracted to salt and when the intensity of salt content is high in the soil, it can absorb the water and possibly cause dehydration for the plants.

Habibi et al. [34] presented a detection of soil salinity using machine learning and hyperspectral data in Sharifabad-Saveh Plain, Iran. A 93 soil samples were collected with the electrical conductivity, which measures with the hypercube technique. The sample was taken from different geographical areas, and satellite images from Landsat 8 were taken at different parameters such as TWI, TCI, STP, DEM, and LS.

Figure 1 illustrates how the intensity of saltiness of the soil with the electrical conductivity salinity sensor probe is connected to a micro-controller. Use ANN, neural network, genetic algorithm, ANN-GA, PSLR, and decision tree and compare these algorithms on the data generated for the model's prediction. The datasets are split into 70% for training sets and 30% for validation sets. ANN-GA has the highest accuracy prediction rate compared to other algorithms and concludes that it shows two dS/m EC at alfalfa and cucurbits farmlands. In contrast, pistachio orchards have low salinity, and bare lands have moderate and high salinity. A pH value is a measure of water and soil acidity.

Processing soil is crucial for prepping for the crop plantation to ensure the soil is not acidic, i.e., pH level. Shabbir et al. [28] presented a classification model of pH value, alkalinity, and basicity using 40 soil images. These colored images were then classified using MLP, Naïve Bayes, Random forest, and Random tree algorithms to calculate the pH factor from the soil images. Prediction of soil moisture content help farmers for the proper management of water resources. It is crucial, especially in arid and semi-arid areas, as comparatively fewer water sources sustain agriculture.

Cai et al. [35] proposed the deep learning regression network (DNNR) with big data fitting capability for constructing a soil moisture prediction model in the area of Beijing. The prediction results concluded that deep learning has high feasibility and is effective for soil moisture prediction.

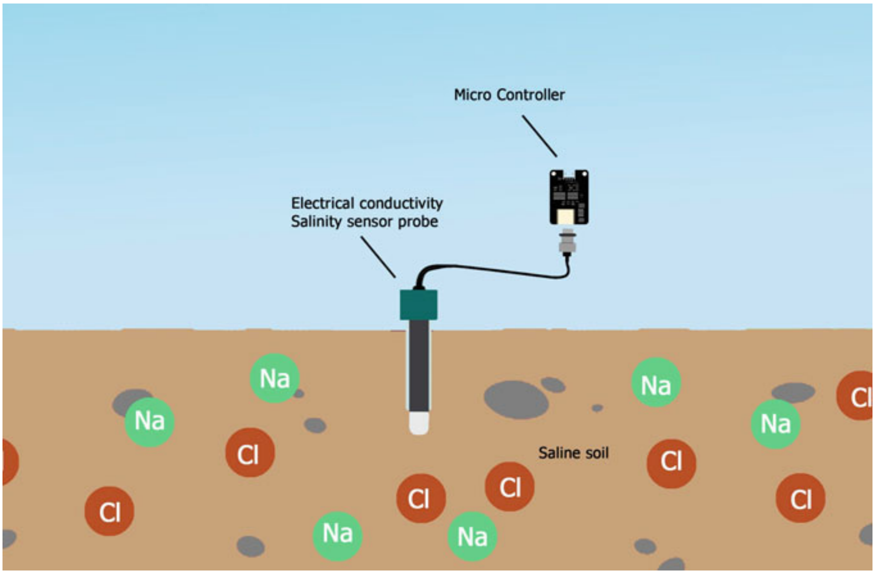

Fig. 1 Detection of salinity of the soil using electrical conductivity salinity sensor

6.2 *Temperature and Humidity Prediction*

Temperature and humidity are some of the most significant factors for the propagation of the growth of plants. There is a high correlation between temperature and humidity, and there are high humidity chances when the temperature became higher. However, humidity does not necessarily increase when there is a temperature rise. It rather depends on the area of water mass present in the area, as humidity occurs due to the evaporation of the water mass. Depending upon the variety of crops, the changes in temperature and humidity have significant effects on their growth. For instance, sweet potatoes and hot peppers are likely to thrive in places with higher temperatures, whereas apple, barley, wheat, etc., are adaptive toward places with cold temperatures.

Technological advancement brought the ability to monitor these parameters and even control according to the optimum requirements of the plants with the help of sensors and artificial intelligence systems. Moreover, with the help of several experiments samples from across the globe in the form of datasets, we could predict the optimum parameters for sustaining the growth of specific plants despite the geographical areas and places.

Taki et al. [36] presented a prediction of the environment variables inside the greenhouse. The traditional prediction model is not viable to solve the nonlinear problems as the atmosphere inside the greenhouse is a nonlinear system. Artificial neural networks and support vector machines are adopted to predict and evaluate greenhouse variables such as correlation and energy exchange, including the soil, air, and plant temperature. The environmental factors which influence the temperature inside and outside, such as wind speed, air temperature/humidity, and solar radiation, were collected for samples in datasets.

Kim et al. [37] developed a prediction model for controlling the temperature and humidity inside the greenhouse. Machine learning techniques such as artificial neural networks, recurrent neural networks, and multiple regression were implemented for the prediction model and evaluated the information in the datasets. The datasets comprise different seasons, summer, monsoon, autumn, and winter, on given parameters. It has been concluded that an artificial neural network has the highest accuracy with the selected dataset, while the multiple regression model has acquired the highest accuracy with the complete datasets.

Jung et al. [38] adopted nonlinear autoregressive exogenous model, NARX; and recurrent neural networks—Long Short-Term Memory, RNN-LSTM; artificial neural network (ANN) for the prediction model of the environmental changes and their impacts on plants growth within the greenhouse. This model helps to determine the optimum temperature, humidity, and carbon dioxide for plant growth and management strategies. RNN-LSTM acquired the highest accuracy over any other algorithm staggering up to 96% accuracy. It has been proved that the potential capabilities of machine learning techniques in prediction model and effective management of greenhouse to sustain the optimum intensity of the parameters; temperature, humidity, and carbon dioxide for precision agriculture.

6.3 Plant Pest and Disease Prediction

Plant’s pest and disease invasion is agitating the farmers since it is challenging to predict because of their time, space, and genotype variability. The evolution of machine learning has brought Image processing techniques into the benchmark, which has revolutionized conventional farming systems into smart farming. Image processing is the process of classification of image pixels and extracts significant information. It performed well as it is non-destructive and environment friendly. The biological test methods required apparatus and experts, which tends to be expensive and also inefficient.

Additionally, although DNA-based and serological method of plant diseases detection has revolutionized disease diagnosis, it is inefficient during the asymptomatic stages as it required few days to process in the laboratory [39]. The image processing method has the advantages of early detection of the lesion or blight before it gets critically injured. The feasibility of adopting image-based plant disease detection is much higher than any other method because of its cost-effectiveness and significantly higher accuracy rate.

Ferentinos [40] presented a plant disease detection model using a Convolutional Neural Network. Open datasets of 87,848 plant images consisting of 58 distinct classes were used for training the model. These images comprise healthy and diseased leaf images of a different variant. The prediction result acquired a 99.53%

accuracy rate. A Convolutional neural network (CNN) is a class of deep neural networks specializing in processing imagery data. Additional layers are added called the “Convolution layer,” which is intended for feature extraction before feeding to the deep neural network.

Figure 2 shows the architecture of the CNN model. In a nutshell, it is the combination of a convolution layer with a deep neural network. A filter known as the kernel is stridden across the pixels in the convolution layer, and the dot product is obtained. The activation function is then applied to the result, followed by pooling. This process is repeated many number of times. The convoluted pixels data are flattened and fed to the neural network for the prediction process.

Saleem et al. [41] presented how machine learning and deep learning evolved over the years. The comparison between different algorithms in machine learning and deep learning for predicting several plant leaves has been described. Without visualization technique, the identification of tomato leaf disease achieved the best performance and accuracy rate with CNN-ResNet over AlexNet and GoogLeNet. For identifying disease in banana leaf, AlexNetOWTbn, AlexNet, GoogLeNet, and VGG architectures in which VGG outperformed all the other models. Extreme learning machine (ELM), support vector machine (SVM), and K-Nearest Neighbor (KNN) have been implemented with the deep learning models, namely ResNet-50, GoogLeNet, InceptionResNetv2, Inception-v3, ResNet-101, and SqueezeNet to predict the diseased leaf of a collection of eight different plants. Among all these models, SVM with ResNet-50 has the highest performance results. A traditional CNN and Super-Resolution Convolutional Neural Network (SRCNN) have been implemented to diagnose the cucumber disease and achieved 0.823 accuracies. SqueezeNet v1.1 and AlexNet models were implemented to detect tomato leaf diseased, and the AlexNet model happened to be higher in prediction accuracy than SqueezeNet v1.1.

In several research works, deep learning (DL) models are employed with the visualization technique for the prediction of plant diseases. 13 types of different plant diseases were tested with the help of CaffeNet CNN architecture which has an accuracy rate of 96.39%, which is much higher than that of SVM. PlantVillage datasets are preprocessed with three parameters: color, grayscale, and segmented, which have been evaluated. AlexNet and GoogLeNet CNN are used and compared

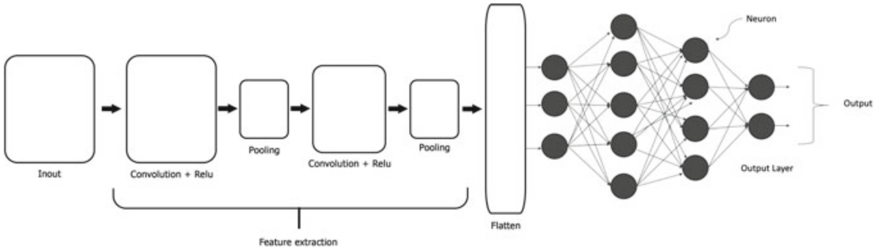

Fig. 2 The architecture of convolutional neural network (CNN)

on the three parameters. It is concluded that GoogLeNet CNN achieved higher accuracy than AlexNet. LeNet has been used to detect the olive oil leaf disease. The leaf images are preprocessed with the segmentation and edge map technique for extracting features.

Random Forest, support vector machines, and AlexNet models were employed to detect the four different cucumber leaf diseases. The leaf images were segmented to highlight the spot on the leaf. A comparative study was done on Faster- RCNN, RFCN, and SSD with GoogLeNet, ZFNet, VGG, ResNet-50, AlexNet, ResNet-101, and ResNetXt-101 for the plant disease prediction, and it is concluded that ResNet-50 with the detector RFCN achieved the highest accuracy. A plant disease prediction model has been implemented with three CNN models such as MobileNet-V1, ResNet-50, inception-V2 with the help of a detector SSD, and Faster-RCNN to diagnose banana leaf disease.

AlexNet and GoogleNet were implemented for the tomato leaf disease prediction with the occlusion technique for extracting the region of the diseases. Between these comparisons, GoogleNet achieved better accuracy than AlexNet. A wheat disease prediction model was presented in which the VGG-FCN and VGG-CNN models were applied. VGG-CNN model was proposed for the detection of a disease in a radish called Fusarium wilt. K-means clustering is used for reducing the dimensionality of the diseased images.

Arsenovic et al. [42] proposed traditional augmentation and a state-of-art Generative Adversarial Network (GAN) to improve the current limitation in the disease prediction model. The datasets have been generated, and they will mimic the real-world scenario. The leaf images have been generated in different weather conditions, illumination exposure, and different angles containing 79,265 leaf images. The augmented images are then fed in a novel-two-stages neural network which achieved a 93.67% accuracy rate.

Golhani et al. [43] presented a review article on the implementation of an advanced neural network model with the hyperspectral imagery data. Research work on plant disease prediction implementing the major Neural Network types, models, and a classifier were discussed. Single-Layer Perceptron (SLP), Radial-Basis Function (RBF), Multi-Layer Perceptron (MLP), Radial-Basis Function (RBF), Kohonen's Self-Organising Map (SOM), Probabilistic Neural Network (PNN), and Convolutional Neural Network (CNN) are some of the types of neural network adopted. The model-like feedforward neural network (FFNN), backpropagation neural network (BPNN), generalized regression neural network (GRNN have been discussed on how it performs on the hyperspectral image data. Hyperspectral image data is the information that is collected from across the electromagnetic spectrum. The human eye can see the electromagnetic waves ranging from 380 to 780 nm of visible light, and the human eye cannot see the electromagnetic spectrum waves outside this range. Some of the spectrum waves are radio waves, microwaves, infrared, ultraviolet, X-rays, and gamma rays. With the use of the specific camera for capturing the electromagnetic spectrum, wave could generate additional information that human cannot see within the leaf image.

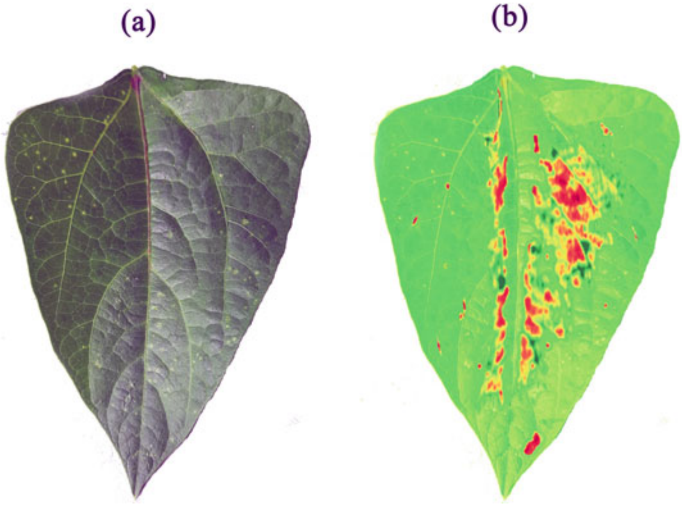

Fig. 3 **a** Normal leaf **b** hyperspectral images

The disease prediction model with hyperspectral images could be potent because it can extract more information that cannot be seen physically on the leaf surface and cannot be captured by the traditional camera. However, it might be a little costlier than the conventional image processing technique where traditional cameras are used. It required a special camera that could extract spectrum waves apart from the RGB image. So, there is a trade-off between the cost and the accuracy.

One alternative to extract more information from the image data and improve machine learning and the deep learning prediction model is image preprocessing. Nowadays, researchers have spent a reasonable amount of time implementing the actual models. It is the process of enhancing the images so that more information could be extracted and removing irrelevant information. Some of the image preprocessing parameters includes:

- Color correction
- Noise reduction
- Geometric Transformations
- Brightness and contrast correction
- Segmentation
- Edge detection
- Augmentation
- Image orientation correction
- Thresholding.

These are some of the primary preprocessing parameters that are used to tweak the input images to improve the accuracy of the machine learning prediction model. Image Segmentation, Canny Edge detector, K-Means, Binary thresholding, Otsu's

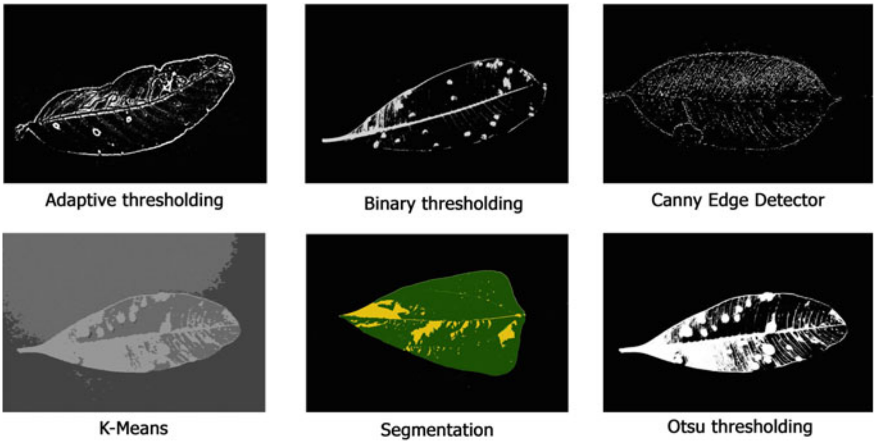

Fig. 4 Image preprocessing techniques

thresholding, and adaptive thresholding are the leading studies in the field of image-based prediction.

Figure 4 illustrates the preprocessed images with several image preprocessing techniques on a plant leaf.

7 Material and Method

Sensors and actuators are the vital source of information for the prediction model. These devices are responsible for the accumulation of relevant information around the environment. There are different types of sensors such as temperature, humidity, and CO_2 injection sensors. They have their respective unique capability of sensing and gathering information.

Figure 5 illustrates the primary sensor in the market where (a) DHT 11 is the temperature and humidity sensors and (b) CO_2 sensor is used to evaluate the amount of CO_2 content in the air. There are electronic products from basic quality to high-end products in the sensing technologies, so depending upon the size of the projects, the material can be implemented. A carbon dioxide generator is a device generally used for controlling the CO_2 content inside the greenhouse to provide the optimum condition for the plants. It sucks the oxygen from the open environment and converts it to carbon dioxide gases.

Figure 6 illustrates the basic setup for generating information in the form of data to predict crop growth. Initially, several numbers of plants were placed inside the greenhouse. A temperature and humidity sensor and CO_2 sensor were installed inside and outside the greenhouse for comparing the parameters in different environments. CO_2 Generator is also installed to evaluate and generate carbon dioxide

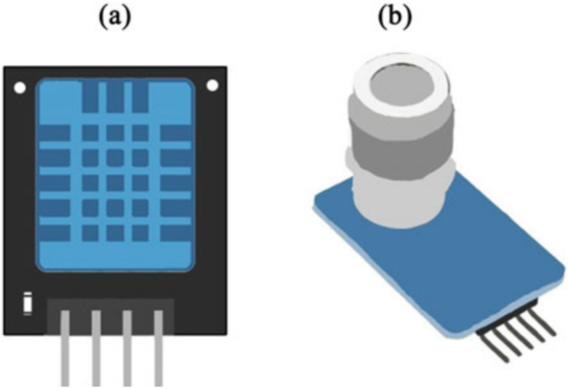

Fig. 5 **a** DHT 11 **b** CO_2 sensor

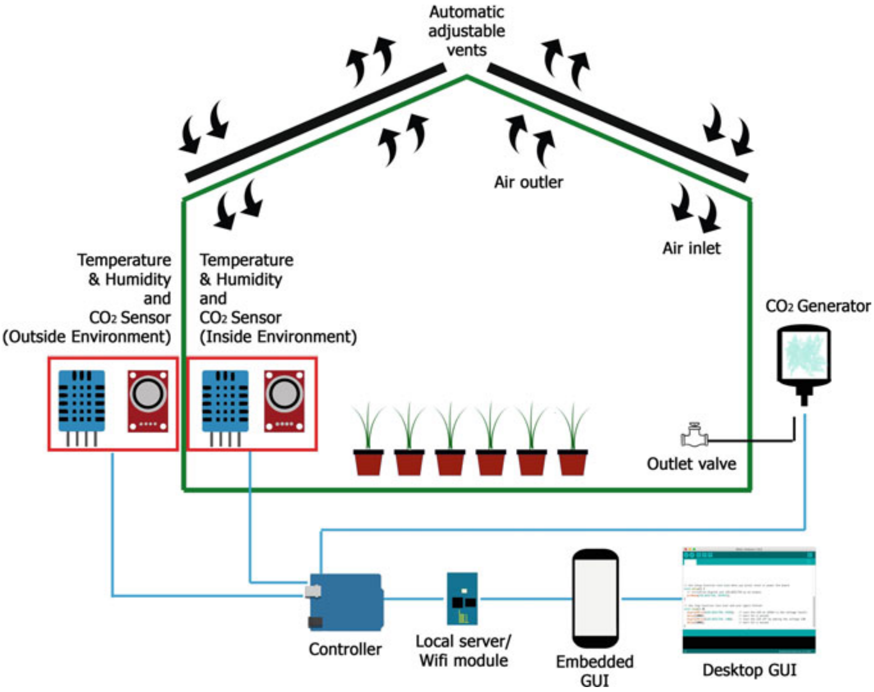

Fig. 6 Smart greenhouse

content for optimum CO_2 level for the plants' intake. These sensors and actuators are connected to the controller connected to the embedded device or desktop through the local server, wire cable, or wifi module, which can remotely control these sensors. These sensors generate real-time data, which can be used by machine learning and deep learning models.

7.1 Remote Sensing

The Internet of Things (IoT) has been extensively growing since the last few decades. The advancement in IoT has paved the way for traditional farming to the next level. There is a huge potential in increasing productivity and obtain a huge global market [44]. Because of the portability and interoperability of the IoT technology, many agricultural industries have adopted an effective farming experience, which is also environment friendly. Some of the advantages of the Internet of Things are:

- Interoperability of a variety of devices across the globe
- Minimization of human intervention
- Time complexity
- Compatibility
- Easy Access
- Speed.

Different types of sensors and actuators are available in the market for generating data and information on various parameters. These sensors are generally connected to an autonomous controller that can be programmed and powered up with any power source. Arduino and Raspberry Pi are the most common controllers that are widely used in agriculture purposes.

Figure 7 illustrates the controllers, Arduino setup for the temperature and humidity monitoring device. Arduino is the most common micro-controller which is widely used for several projects. Besides Arduino, Raspberry Pi is also commonly used for the same projects. There is a bunch of other versions on these devices available depends on the objective of the projects. The advantages of using these controllers are the flexibility and ability to work with any kinds of projects such as smart irrigation systems, soil monitoring systems, weather forecasting models, temperature, humidity monitoring systems, etc.

The wireless sensor network technology significantly reduces human efforts, yet it is efficient and accurate to perform a specific task remotely. However, the architecture is not designed for future prediction and decision-making, depending on different parameters such as temperature, humidity, and climatic condition. These parameters are highly complex which keep on changing each year. Artificial intelligence is the key answer to support complex variables.

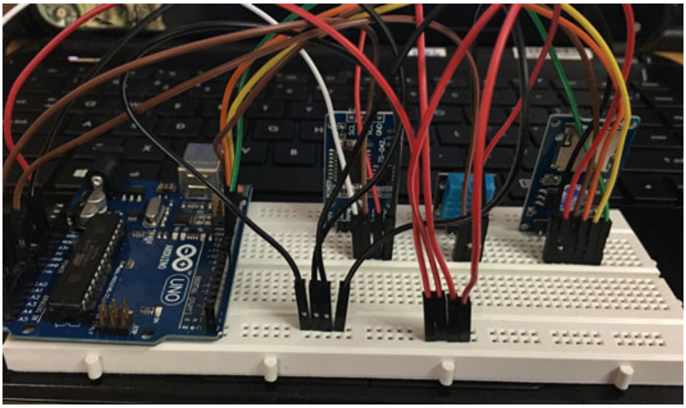

Fig. 7 Temperature and humidity monitoring using Arduino micro-controller

7.2 *Machine Learning*

Machine Learning is broadly classified into supervised, unsupervised, and reinforcement learning. The labeled datasets are used in supervised learning, and the unlabeled datasets are used in unsupervised learning. Reinforcement learning deals with sequential data for the prediction. It is crucial to know the datasets before feeding them to the machine learning model, as each algorithm is designed to solve problems on specific types of datasets.

Figure 8 illustrates the architecture of the machine learning model. The total number of datasets is divided into training sets and test sets using cross-validation. Training sets are fed to the machine learning algorithm and train to classify variables according to their traits. The model is then tested with the test sets for validation of the prediction.

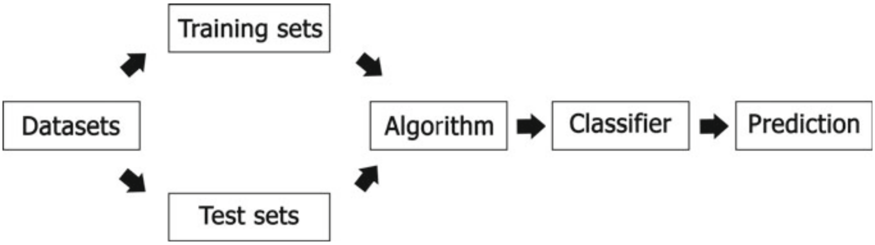

Fig. 8 The working architecture of the machine learning model

8 Smart Irrigation

Human and industrial wastes have extensively contaminated water. Water scarcity has become a global concern and affects agriculture and many other sectors [45]. Many research works have been going on to tackle this problem and sustain precision agriculture to increase productivity despite the water issues. Water sprinkler is helpful in industries, agriculture, and gardens for watering purposes. The conventional automatic water sprinkler automatically spreads and distributes the water in the designated area by spinning the nozzle. This system could sound helpful in the agricultural fields. However, there could be a massive amount of water loss because of the soil's moisture and climate humidity variability. The amount of water distribution is entirely under the farmer's control which can be inaccurate. Today, with the advancement of sensor technology, several improvements are made with the engineering and functionalities of the traditional water sprinkler [46].

- Rainfall Shutoff Device—This device is designed to detect raindrops water during rainy days. So, when it is raining, this device will see and send information to the water sprinkler controller to turn off the water flow which helps to compensate the rainwater (Fig. 9c).
- Soil Moisture Sensors—This sensor can monitor the soil moisture condition. When the soil is dry, the water sprinkler will provide the optimum amount of water. Otherwise, it will stop supplying water (Fig. 9a).
- Watersense Labeled Controller—The device is weather-based humidity and moisture monitoring device that helps the sprinkler supply the optimum amount of water to the plants (Fig. 9b).

Drip irrigation is the micro-irrigation system that supplies water by dripping slowly either to the soil's surface or the plant's root. The primary aim is to reduce wastage of water and minimize evapotranspiration. It is cost-effective and sustainable.

Figure 10 illustrates the working architecture of drip irrigation. Initially, a water tank is set up for the supply of water which is connected to a valve or a controller

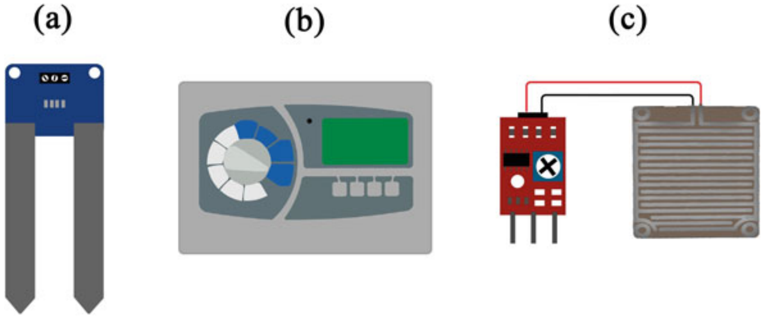

Fig. 9 **a** Soil moisture sensors **b** watersense labeled controller **c** rainfall shutoff device

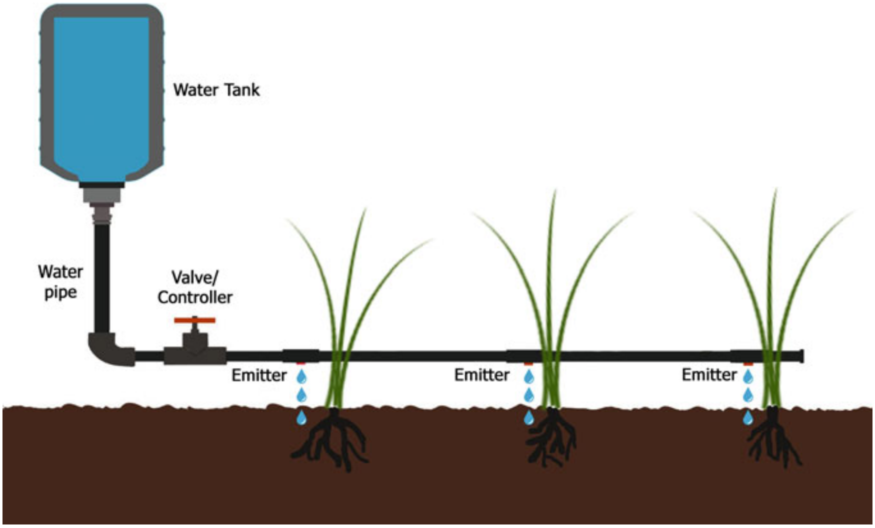

Fig. 10 Drip irrigation

for switching the water flow on and off. Several pipes are laid on the field that connects the outlet of the valve. These pipes have an emitter interval for the outlet drop of water directly to the soil surface or the plants' root.

Although drip irrigation helps to save a tremendous amount of water, it can be improved further with the help of the machine learning and deep learning model. Traditionally, the drop of water is continuous in every interval regardless of any parameters around the soil and environment. The ground and moisture level temperature are the primary parameters to identify whether the soil's moisture level is high. This is when machine learning and deep learning model comes in handy. With these technologies, we can predict supplying an optimum amount of water concerning the temperature and moisture of the soil.

Seyedzadeh et al. [47] presented an AI-based drip irrigation system with uniform emitter discharge regarding the temperature and pressure. The emitter outlet nozzle is simulated with the AI-based model on specific parameter settings with a temperature of 13–53 °C and operating pressure of 0–240 kPa variance. Least square support vector machine (LS-SVM), neuro-fuzzy c-Means clustering (NF-FCM), artificial neural network (ANN), and neuro-fuzzy sub-clustering (NF-SC) were adopted in which LS-SVM model achieved the lowest error followed by the NF-SC model.

Goap et al. [48] presented an IoT-based irrigation management system using a Machine Learning model. Parameters like soil temperature, soil moisture, and environmental condition, UV radiation, and humidity of the field were taken as a medium of measurement for the prediction. An IoT sensor and actuators are implemented to generate information of several parameters and collected over the cloud using web services and web-based information visualization. K-means clustering methods and support vector regression are used to predict humidity, soil moisture, and weather forecasting based on the sensors data.

Vij et al. [49] presented an IoT and machine learning-based automated field irrigation system. Distributed Wireless Sensor Network (WSN) is established on the farm to monitor and sense temperature and the weather parameters are connected to the standard server. The implementation of Machine Learning would support the prediction of irrigation management based on the parameters. This model helps in the supply and management of water much precisely and efficiently.

Water infiltration of the soil is one of the most crucial parameters for irrigation in agriculture [50]. Figure 11 shows the variability of water infiltration on several types of soil. For instance, some soil-like Sandy loam has bigger pores inside the ground, making the water infiltration much more accessible, while some other soils need more water. The variability in the water infiltration can significantly affect the plants' growth since some plants have deeper roots. Moreover, there are limitations for the moisture sensor as the sensitivity frequency radiates within the upper layer of the soil, as shown in Fig. 11. To solve these challenges, an AI-based model is the most feasible model for predicting and evaluating soil infiltration despite the variance in soil type.

Sayari et al. [51] presented a water infiltration prediction model for a sustainable irrigation management system. Artificial intelligence models which include Adaptive Neuro-Fuzzy Inference System (ANFIS), artificial neural network (ANN), Multivariate Linear Regression (MLR), Group Method of Data Handling (GMDH), Support Vector Regression (SVR), and Firefly Algorithm (FA) have been proposed

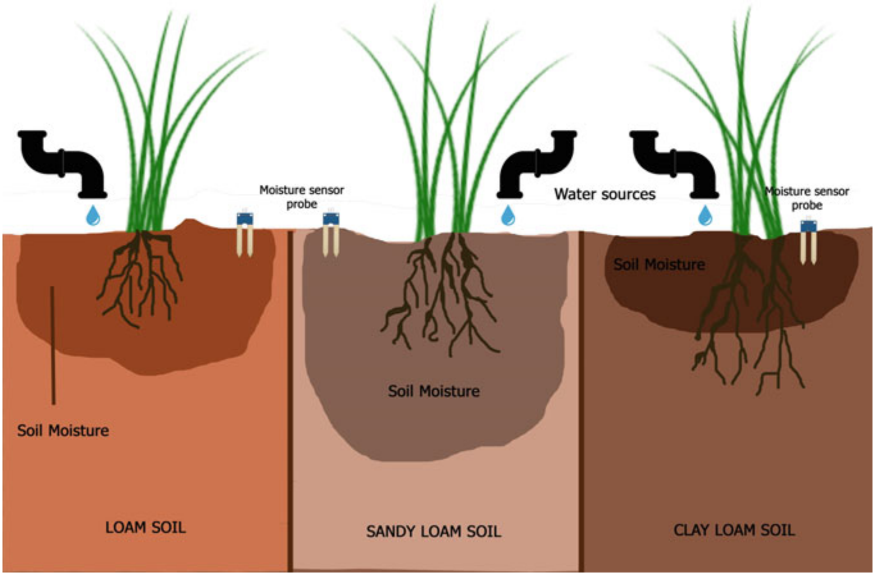

Fig. 11 Water infiltration on different types of soil

for forecasting the water infiltration to sustain the irrigation system. The data are collected from published literature and field experiments conducted on researching farm at SBUK University, Kerman, Iran. Several parameters are used for the prediction model, which includes the inflow rate (Q), furrow length (L), cross-sectional area of inflow (Ao), advance time at the end of the furrow (TL), and infiltration opportunity time (To). For the evaluation of the prediction model, the mean absolute error (MAE), the correlation coefficient (R2), the root mean square (RMSE), the Nash–Sutcliffe efficiency index (NSE), and the index of agreement (IA) were used for the proposed AI models.

Groundwater is one of the resources for human consumption and the development of the country. The agricultural sector is the primary consumer of groundwater globally [52]. So, crop productivity is highly dependent on the groundwater in which any threat to sustainability could potentially have an adverse effect on vegetation.

Groundwater is vulnerable because of the constant climate change and anthropogenic activities. This deterioration has made it unsuitable for drinking and vegetation. This problem has become a global concern as it could threaten the agricultural sector and, most importantly, human livelihood. Studies and researches have been concentrated to sustain the groundwater. Many material, methods, and AI-based models are also proposed to evaluate and improve the groundwater quality, in which the results tend to be promising.

El Bilaliet al. [53] developed groundwater quality classification model using groundwater quality indexes which include Potential Salinity (PS), Total Dissolved Solid (TDS), Sodium Percentage (ESP), Sodium Adsorption Ratio (SAR), Exchangeable Magnesium Adsorption Ratio (MAR), and the Residual Sodium Carbonate (RSC) parameters through electrical conductivity (EC), Temperature (T), and pH as inputs. For the evaluation, Random Forest (RF), Adaptive Boosting (Adaboost), support vector regression (SVR), and artificial neural network (ANN) were applied. The sample data of 520 images were collected the groundwater quality parameters from fourteen different places in Morocco. It is concluded that the Adaptive Boosting (Adaboost) and Random Forest (RF) have achieved a higher accuracy rate in the prediction model.

In agriculture, farmers' experiences are valuable and essential for the sustenance of productivity. Their experiences and skills are difficult to share and pass on as it requires efforts. This type of traditional farming is laborious and consumes more time. To fix these challenges, Chang et al. [54] presented machine learning-based smart irrigation model LoRa P2P networks to automatically learn the parameters of irrigation experience inside the greenhouse. The models calculate the optimum water requirements depending upon the temperature/humidity of the air, soil, light intensity, and environmental conditions. This model will reduce time consumption as the optimum settings have been evaluated, and it is comprehensive for the farmers and agrarian to follow and carry on to sustain precision agriculture.

The use of Unmanned Aerial Vehicles (UAV) in the agriculture industry is constantly growing, and it helps to monitor the field with high scalability, low cost, and efficiency. The modern smart UAV are generally equipped with imagery systems and electromagnetic sensors, generating multispectral and hyperspectral images. These images are the combination of RGB images and wavelength beyond the visible light, electromagnetic spectrum bands such as infrared rays, x-ray, radiation, and ultraviolet. Spectral imaging can extract more information from the wavelength that even a human eye cannot see. In agriculture, this technology could be significantly helpful in monitoring the fertility and water status in the soil on a large area of land. Romero et al. [55] presented an AI-based water status estimation model using the UAV platform. With the help of a UAV drone, the multispectral images of vegetation indices are captured to estimate grapevines' midday stem water potential. The artificial neural network (ANN) is applied to the water estimation model, and the result shows a high correlation between the two parameters, such as vegetation index and the water potential.

Figure 12 illustrates the multispectral images captured from the UAV drones on the agricultural fields. From Fig. 12, the green and red colors are the electromagnetic spectrum waves that are invisible to the human eye. Depending on the parameters, the electromagnetic waves are captured. It is generally used in the vegetation index, dryness, and wetness of the field. In fact, it can scan the soil type of several areas, which can be significant information for an AI-based prediction model.

9 Conclusion

The sustenance of precision agriculture highly depends on the yield prediction and irrigation system. Crop productivity primarily depends on multiple factors such as temperature/humidity, water content, minerals, light, etc., and the growing plants need to meet the optimum environment for their proper growth. This chapter has discussed the potential deterioration of the climatic parameters caused by several human activities that can significantly affect crop productivity.

It also discussed the general idea of how the IoT and artificial intelligence technologies have gradually developed in the farming sector and how it improves

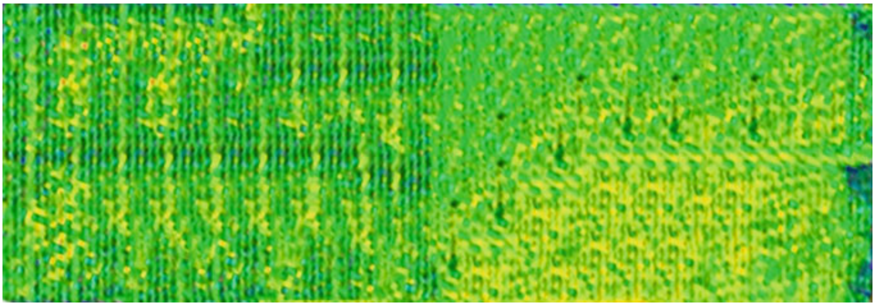

Fig. 12 UAV multispectral imagery on agricultural field

the efficiency and accuracy of prediction on several agricultural parameters. Since the unpredictability and variability of the weather make traditional farming vulnerable, the emergence of the technological model in the agricultural sector is broadly presented.

IoT and artificial intelligence are some of the most feasible solutions for the challenges in farming practices and to sustain precision agriculture. However, there are several challenges in the implementation of the technological model and room to improve for higher accuracy and efficiency. In the future work, emphasis will be given to how AI technology can technically improve and support the prediction efficacy of remote sensing technology on different agriculture parameters. Also, the scope of image processing using several Imagery data such as hyperspectral images, chlorophyll fluorescence images, and spectrum images.

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IoT Enabled Technologies in Smart Farming and Challenges for Adoption

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Abstract Technologies are transforming the universe with the help of digitalization, where IoT is leading in digitalization in almost every field such as health care, agriculture, livestock management, smart houses, cities, renewable energy management, cyberspace environment, etc. 5G wireless technology is also playing a vital role in the management of these IoT devices due to its unique network virtualization functionality. Traditional agricultural methods are continuously changing due to the involvement of the emerging technologies. Food security and food safety are the big concerns in the recent years, and it is expected that up to 2050 world population will grow approximately 33% of the total world population. It is foremost required to adopt smart technology in farming that can help in maximizing food production with minimum cost. Smart farming is a key interest of the scientific community to increase the yield production with minimum cost because due to urbanization agriculture land is continuously depleted. Smart farming uses AI/ML techniques, IoT infrastructure devices, computer vision technology, and unmanned aerial or ground vehicles to maximize the yield productions with minimum production cost. The work embodied in this chapter is focused on how smart farming is digitally transforming using emerging technologies such as machine learning, IoT, computer vision, unmanned aerial vehicles. Several key challenges for the adopting smart farming are also discussed for providing sufficient information before actual implementation.

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1 Introduction

The world population is increasing rapidly and food production/food safety will be a great challenge in the coming years because of increasing urbanization and shortage of land for agriculture. In this growing infrastructure era, the living standard of the human being is rapidly changing due to introduction of new technology. Farm protection and food security are becoming defy in recent years. It is estimated that up to 2050, the total population of the world will be increased by 33% of the world's population [1], and there will be an urgent need to increase the yield production and livestock management to minimize the food crisis. The human being is responsible for the changing environmental conditions, i.e., global warming is one of the biggest factors influencing the increase in temperature on the earth as well as deteriorating natural resources. Due to the increase in manufacturing, production, and urbanization, natural resources are decreasing day by day. In this modern world, everybody is moving toward cities that lead to increasing urbanization and decreasing farming works. The population is also one of the biggest factors that are equally responsible for the shortage of food. In this situation, where the marginal land is left for agriculture, the concept of smart farming needs to be introduced. Smart farming help farmers to increase yield production in the minimum farming land and control livestock management that will reduce manpower and human efforts. Various concepts were introduced in smart farming related to the sensor network and advanced mechanical machinery that can do very large area cultivation and harvesting in a small amount of time. Internet of Things (IoT) is one of the growing technologies that enable smart sensors to update crop data in the cloud and provides detailed analysis reports to the farmer. IoT consists of several computing and sensing devices that enable transfer of data using an internetworking protocol over the cloud. In general, IoT architecture comprises of three main components, viz. sensors, controllers, and actuators, where data collection is being done using sensors (i.e., a device like soil moisture sensor, temperature, and humidity sensor), data processing is accomplished using a controller and the automation process is carried out using actuators. IoT in smart farming mainly focuses on automation to reduce manpower, accurate data collection, and monitoring of crops [2, 3]. The automation process in agriculture and smart farming reduces human intervention and increased yield production. It is observed that most of the population of any country depends on farming. More populated countries, i.e., China, India, etc., need to grow more food resources. IoT sensors in smart farming are responsible for collecting weather data like temperature, humidity, moisture, soil state, sun ray exposure on plants, and water management system for crops. IoT-based water management system is helpful to find out the exact irrigation time for crops by using sensors to collect environmental data such as humidity, temperature, and water level [4, 5]. IoT not only helps in smart farming but also contributes to pest control, weather monitoring, nutrition monitoring, and greenhouse management. On the other hand, pesticide helps in improving agriculture, but in general, the correct type and amount of pesticide needed is not known to everyone. Usually, farmers are not able to estimate the exact amount of pesticide needed for the crops as per hectare ratio and the type of diseases are concerned. IoT-enabled devices not only help in controlling the amount of pesticide required but also helps in identifying the disease-related information in the plant. Fertilizers are also playing important role in increasing the crop productions by contributing toward plant development. Farmers can seek several advantages in agriculture by using IoT for soil monitoring, and type and amount of fertilizers, as well as pesticides, are needed [6]. On the other hand, the basic requirement to achieve smart farming is the availability of good internet connectivity so that timely data could be updated to the cloud platform. It is evident that, due to the rapid deployment of 5G mobile technology, this smart farming task will speed up in near future. 5G technology enables inbuilt IoT infrastructure, network virtualization, Machine to Machine (M2M) communication, and high data transfer rate as compared to other mobile technologies. Furthermore, the usage of fiber optics in smart farming is costly to the farmers, so they require new mobile technology instead of wired technology that can be cost effective and can facilitate real-time communication for IoT devices over cloud infrastructure. 5G enabled IoT smart farms will have numerous sensors deployed on them to collect real-time data such as weather, air, soil parameters, crops growth, animal behaviors, etc. Along with IoT, Unmanned Aerial Vehicles (UAVs) facilitate the capturing of high-quality images of plants for analyzing crop growth, diseases, weed detection, nutrient deficiencies, etc. [7].

Various 5G projects related to smart farming were deployed in China in the year 2019–20 [8]. The basic IoT framework for smart farming is shown in Fig. 1 that comprises of four layers, viz. perception, transport, processing, and application [9]. The perception layer is responsible for collecting data from sensing devices, i.e., soil moisture sensor, humidity sensor, temperature sensor, RFID, Zigbee, Infrared, etc. The main function of the perception layer is to collect raw data from sensors and transfer it to the higher layer for subsequent processes.

The transport layer, therefore, is the communication layer that is responsible for ensuring error-free transportation of data from one process to another process. It consists of several protocols needed for enabling efficient and error-free transportation capabilities. The transport layer also acts as a communication medium between the perception layer and the processing layer. Transport protocol enables wireless communication between sensing devices and applications [11].

On the other hand, the processing layer is responsible for data storage, retrieval, and processing resources. For data storage, big data analytics is going to work in this area for the storage of complex data. Data processing techniques are used in correlation with complex data so that efficient prediction can be made through state-of-the-art algorithms, i.e., decision tree. To achieve the higher level of

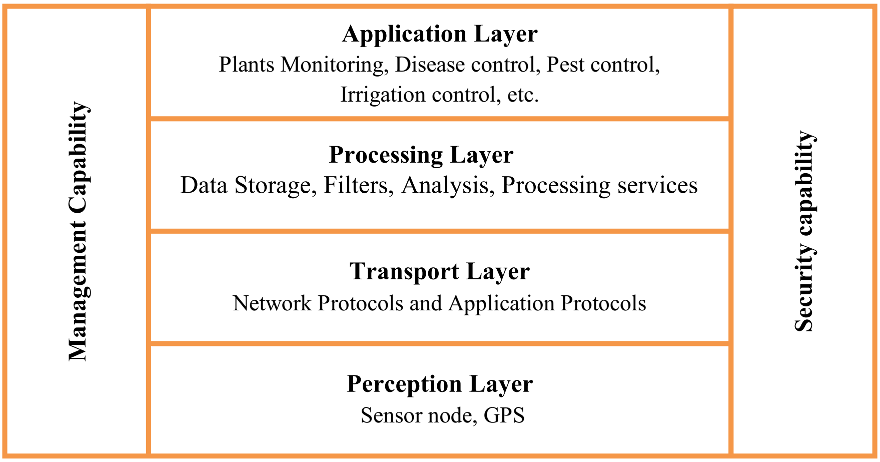

Fig. 1 IoT architecture for smart farming [10]

abstraction in precision agriculture several artificial intelligence and machine learning algorithms work collaboratively by doing effective data visualization, prediction, and decision analysis.

Application layer is the user support layer that is used to provide managed information to the farmers. Farmers can manage, control entire production process of the smart farming through this layer [12]. There are numerous applications of IoT that provide better solution in smart farming for example, chemical control is related to pesticides as well as fertilizers, disease control for controlling several diseases at different levels in the plant, irrigation control enables optimum irrigation in less amount of water, etc. The major problems in agriculture farming are the pest and fertilizer control, and timely identification of disease. With the help of IoT technology various data is being collected that enables farmers to monitor and control crop growth in an efficient way. Soil management and irrigation control is another solution that provides adequate details regarding soil moisture content, soil types, pH value of soil, and type of fertilizer require for crops. Irrigation control mechanism provides autonomous control to farmers using alarming alert whenever crops need irrigation. Vehicle and machinery controls are primary focused toward increase in automation and decrease in human efforts. Automatic machinery such as driverless tractors or other machinery can be controlled by farmers remotely due to the advancement in unmanned aerial vehicles and ground vehicles [9].

On the other hand, supply chain traceability is the biggest concern in the recent decade. Due to the lack of potential supply chain facilities, farmers are facing several issues in selling their good quality crops. Industry 4.0 enables smart transportation that can solve this problem to some extent. This framework can provide real-time information about the supply chain facilities to the farmers in an effective way so that optimum market value and crop related decisions can be made easily. Even IoT enabled framework provides food freshness delivery information to e-commerce platform very easily [13] (Fig. 2).

Automation in food security, safety, and supply chain traceability provides adequate information about product quality risk and incident by sharing centralize information among supply chain well in advance [14]. Livestock management is another IoT-based solution in smart farming. Due to continuously changing environmental conditions, animal breeding and production is a biggest challenge. Farm owners are unable to monitor the health of animals, as a result, several dairy farming projects in many countries are in loss. IoT enabled devices, i.e., RFID tags can easily identify the animals and IoT devices involved in monitoring health of animals and control livestock management [15].

In short, the rest of this chapter is organized as follows, Sect. 2 discussed about literature review studied in smart farming using IoT and machine learning techniques. Section 3 describes how smart farming is digitally transforming. Section 4 discusses about the key challenge in adoption of the smart farming technology and Sect. 5 concludes the chapter.

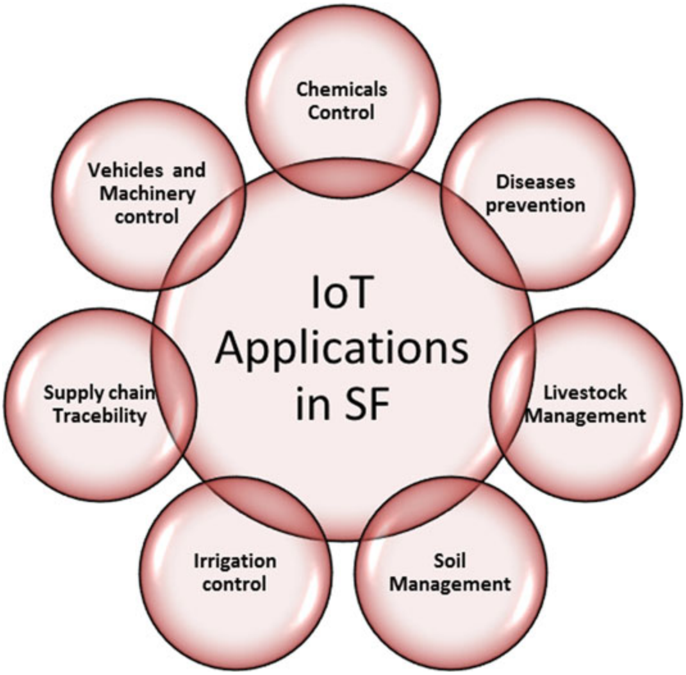

Fig. 2 IoT applications in smart farming

2 Related Work

Plenty of work has been conducted in IoT for providing sustainable solutions to smart farming. Navarro et al. [9] conducted a systematic review of IoT Solutions for Smart Farming. They described IoT enabled solutions for smart farming and identify the main application of IoT devices in farming. They have also discussed the usage of several sensors for smart farming using their applicability environments. The type of communication technology such as wifi, Bluetooth, Zigbee, LoRaWAN was also discussed in different farming. They have also presented the usage of several cloud platforms available for the smart farming such as Agro-cloud, AT&T m2x, AWS, Blynk, rural IoT, etc. They have effectively presented the review of several work related with the usage of machine learning and artificial intelligence-based techniques in smart farming environments.

Odoi-Lartey and Ansong [16] presented the task of improving agricultural productions using IoT and Open-Source Technologies. They have discussed about the general IoT architecture for smart farming that has perception, transport, and application layers for collecting and transform data to cloud platform. They have also presented the usage of several open-source technologies to build up hardware and software prototypes toward maximizing automation in agriculture. With the help of Raspberry Pi enabled base station sensor network they have connected an Arduino Uno for data capturing and subsequent analysis. Various type of sensors that were integrated in their prototype was soil sensor, humidity sensor, temperature sensor, Passive Infra-Red (PIR) sensor, and Raspberry Pi camera module. They have integrated three modules (Sensor module, Arduino Uno, Raspberry Pi model 3) together to form an effective IoT system to transfer data over cloud. Based on this prototype, they have concluded that the several cheaper IoT devices and open-source technologies can be effectively used for smart farming. The prototype designed by author is useful in testing purpose for laboratory. There may be chances that the actual readings in the real-time environment may differ than laboratory environment.

Kale and Sonavane [17] presented the task of feature subset selection for optimized high dimensional data using improved GA-based approach for ELM. Authors mainly discussed about the diseases and nutrient deficiency in plants. Sometimes farmers are not able to get the exact disease types using manual inspection of the plants leaves. There may be chances that a single disease may provide different symptoms in different environments. Mis-proportional dosage of pesticide used for inappropriate diseases type can lead to severe damages in plants life. So, the authors have proposed an IoT-based smart farming decision support system with an improved genetic algorithm-based multilevel parameter optimization feature selection algorithm for ELM classifier. The proposed algorithms used with improved genetic algorithm-based multilevel parameter optimization feature selection algorithms for ELM classifier improved 9% classification efficiency by 58% reduced feature as compared to traditional genetic algorithm.

Udhaya et al. [18] presented the role of IoT-based Indian agriculture sector. They have described various theories regarding water management for the crops, monitoring of the crops field using drone technology, RFID tags for finding out diseases in the plants, soil monitoring using IoT enabled devices. These technologies are enabling farmers to get real-time updates on the farm for effective growth of yields, designing effective monitoring and control system for green house that can control temperature, moisture, humidity, etc. They have also discussed about the usage of drone technology which is very effective in both capturing high-quality images as well as in surveillance of the field. Automatic monitoring and control system in green house play very important role in setting temperature, humidity, moisture, and other factors that are necessary for the yield growth.

Bacco et al. [19] presented a survey of several research activities toward digitization of agriculture. They have surveyed about the adoption of smart farming combing with ICT infrastructure, especially smart farming adoption in European countries and types of sensing technology used. Numerous research and development related activities to smart farming in European countries were also analyzed in their work. Most of these activities are based on remote sensing, Unmanned Aerial Vehicle (UAV), cloud and edge computing, data analysis with respect to agriculture operations, i.e., water usage, imagery, crop harvesting, optimization of food security, etc. All the information related to crop monitoring is being stored in the cloud with the help of IoT Devices. UAVs basically focused on the robotics system to control various farming activities. Robots move within orchard or greenhouse to monitor and collect data. Authors also discussed various other projects related to satellite base system to collect data and monitor activity within a farm. There are various challenges discuss by authors regarding implementation of the smart farming, challenges related to information, network, and data. Here security of the information in cloud, data management, and network connectivity are major challenges that need to be addressed.

Boursianis et al. [20] presented a comprehensive review of IoT and Agricultural UAVs for smart farming. Basically, UAVs work on the robotics technology in the form of intelligent drones that are automatically and remotely control by users. Intelligent driverless vehicle also come under this category. IoT also integrates wireless sensor networks that can capture data using sensor and transmit these data using communication protocol to the cloud. The authors also describe about several intelligent sensors, i.e., temperature sensor, wind sensor, moisture sensor, soil water content sensor, weed seeker sensor, and PH sensor used in agriculture for monitoring and control smart farming environments. They have also discussed the applications of several wireless protocols such as WiFi, Wimax, Bluetooth, LRWPAN, LoRaWAN, SigFox, and NB-IoT that are useful in IoT enabled infrastructure. UAVs have numerous applications in smart farming such as capturing plant images and analyzing the plant growth according to the crop types. Authors have also discussed various models that are supported in unmanned vehicular technology along with various trends and challenges in smart farming related to practical implementation environments. However, the main problem is that the research carried out in Unmanned technology are limited to laboratory or implementation in some small area of the field. There are a lot of challenges which are hurdle in implementing UAV technology in real smart farming environments.

Goap et al. [21] presented an IoT-based smart irrigation management system using machine learning and open-source technologies. They have discussed about the importance of effective utilization of the freshwater resources in agriculture. In addition to this, they have proposed an intelligent system that predicts the soil moisture information through sensor nodes deployed in the field and weather parameters to find out the prediction of the rain, and amount of irrigation required in the plants. At the server end software has been deployed for sensor node connectivity along with information visualization and decision support features. The algorithm proposed in their work was aimed at prediction of soil moisture by using sensor node data in the field and weather forecast data using machine learning technique. It shows optimum result with effective decision on the irrigation process. The algorithms proposed by authors are based on smart decision support system for irrigation in agriculture field. The proposed model collects and transmits the physical parameters such as soil moisture, soil temperature, air relative humidity and sun radiation in the farming land and weather forecast data to effectively managed irrigation system. The purposed algorithm used both supervised and unsupervised technique using support vector regression and *K*-means clustering for estimation of difference in soil moisture due to weather condition. The soil moisture difference of upcoming days is predicted using trained SVR model and predicts value of SMD using *K*-means clustering for improving the accuracy of the soil moisture difference. The authors find effective approach to predict soil moisture and weather data for smart irrigation control in agriculture field. The system prototype design was cost effective and uses open standard technologies. However, the authors using weather data for acute weather or other online available repository for prediction, which may be not accurate all the time.

Shi et al. [22] presented a Quality of Service (QoS)-aware UAV coverage path planning in 5G mm-wave network. UAV can be used in a variety of application such as disaster relief, monitoring and surveillance, tracking, goods delivery, etc. Conventional UAV coverage path planning observes that the UAV offloads its data when flight is completed. So, there is a serious issue regarding data loss and delay in data in real-time application. In this regard, authors presented a model to the new UAV path planning problem using 5G millimeter-wave in the context of QoS. They also derived solutions for nonlinear optimization problem. Basically, data loss happens in UAV technology due to flight crash and buffer overflow. Some of the real-time application wants UAV on-board data transmission to the server, so that there is no delay in the data at receiving end. The proposed work provides a solution of data loss to find the optimal path planning and increased in the buffer size for storing more amount of data. Data transfer from UAV in wireless network is tedious job due to continuous movement, shift in antenna position, continuously altering location, and run time interference. Authors investigate the new UAV path planning problem in network QoS requirement in 5G context. UAV transmit data during the flight so that the unnecessary delay will be negligible. Authors design a model for new path planning for UAV in 5G context and transform the nonlinear optimization problem in to two problems and find the two-step solution. Authors put the speed of UAV as constant and buffer size to be unlimited. While the constant speed of the UAV maintains QoS requirement and increased size of the buffer can store more data, overflow of the data is negligible. The proposed algorithms in this paper dynamically adjust UAV speed during the flight. The algorithm results are demonstrated by author's reduction in data loss and improve flight timing.

Alonso et al. [23] presented a Deep Reinforcement Learning-based methodology for the management of software-defined networks (SDN) in Smart Farming. They have described about the IoT device used in Cloud and Fog computing environments. 5th generation mobile technology has adopted software-defined networking and network virtualization to a great extent. The main aim to adopt this technology is connecting millions of devices via machine-to-machine communication. To deal with one of the biggest problems of handling data in network virtualization environments they proposed a Double Deep-Q Learning approach to manage virtual dataflow in SDN/NFV using an Edge-IoT architecture. Software defines networking as arising due to exponentially increase in number of IoT or M2M devices and there is demand for real-time transfer of the data. The major issue with M2M is the communication between devices when network is heterogeneous. In that situation, edge and fog computing is preferred in real-time communication. Reinforcement learning and deep learning are very useful in SDN/NFV, such as applied in self-driving car, vacuum robots, network and machine resource management, and games. The main task of Double Deep-Q Learning algorithm is the learning policy, which acts as a core agent that is best suited to different environmental conditions. The algorithm is also able to solve the problem of dynamic resource management in the IoT context.

Anand et al. [24] presented the work for monitoring of soil moisture and atmospheric components using IoT and machine learning-based approaches. Soil monitoring is very important in the smart agriculture field that comprises of several parameters such as temperature, moisture content, and different soil types. The information about soil is utmost required for selecting a specific crops type. Their aim was to predict the types of crops suitable to the soil. Node MCU ESP8266 as a microcontroller is used to monitor and store the data on the cloud. Temperature, humidity, rain, and moisture sensors are used to collect different parameters. Authors proposed a model to test the quality of the soil, so that farmers can choose crop types for his field. Each crop type needs different environmental conditions, so that the model can test the soil and predict the crop types, send decision alerts to the farmers based on analyzed data.

Reddy et al. [25] presented an IoT-based smart agriculture using machine learning techniques. Authors purposed a model to predict the water requirement for crops using machine learning technique. Various sensors involve in collecting data such as humidity, temperature, and moisture that are essential for deciding water requirement in crops. Decision tree algorithm was employed for providing effective decisions that can be sent to the farmers. The proposed architecture consists of Raspberry Pi controller and a DHT11 as soil moisture sensor. The work is based on two-class classification problem that provides decision in the form of 'yes' or 'no' decisions. Yes, indicates that there is requirement of irrigation in the crops, whereas no indicates no irrigation requirements. The proposed model can save sufficient among of water and provides optimum irrigation to the field. However, the incorporation of weather data such rains forecasting was missing that can lead to potential improvements in the proposed model for saving additional water resources.

Hsu et al. [26] have designed and implemented image electronic fence that is based on image recognition and sensor fusion with 5G technology for smart farming. Based on image recognition technique and fusion technology, their system can find out legal or illegal entry and exit in the farm. The system has three main components, viz. image recognition and tracking, wearable device sensing, and image and sensing fusion. Image recognitions use YOLO2 convolutional neural network (CNN) model for analyzing the images and human identification. Raspberry Pi was used to identify number of incoming or outgoing people, legal or illegal persons using beacon environmental sensing technology. The overall work was based on the principle of sending image fusion to the server with the help of 5G technology for further analysis and decision making. The work has shown potential identification accuracies up to 90%.

Neethirajan [27] presented the role of sensors, big data, and machine learning in modern animal farming. The authors describe about the usage of sensing technology, ML, big data analytics that can help in increasing animal farm production, health monitoring, and better milk production. They have also explored the limitation and challenges in adopting these technologies for smart animal farming. Their system consists of various sensors that help to identify animal behaviors in real time. However, there are several technical challenges that need to be addressed while deploying sensors on the animals. Farmers or farm owners must be trained well for placing correct sensor at correct place for achieving accurate results.

Sinwar et al. [28] have presented an AI-based system for yield prediction and smart irrigation. They have discussed about various artificial intelligence technique used in yield prediction, smart irrigation, and their application. It is evident that timely prediction of yield provides benefit to both famers and government. They have also discussed about various literatures regarding smart irrigation system for crops and architecture of smart irrigation system using open-source technologies, artificial intelligence, and machine learning algorithms. AI-based yield prediction and smart irrigation technique are applicable in agriculture sector that maximizes yield production with minimum production cost and wastage of resources such as energy and water.

3 Digital Transformation of Smart Farming

Smart farming is the key research area in recent era that incorporates the involvement of several emerging technologies. Currently, agriculture invention 4.0 is already adopted in the market and continuous research is going on toward adoption of agriculture invention 5.0. This section discusses the brief of several techniques that are contributing toward the digital transformation of smart farming.

3.1 Machine Learning

Smart farming uses effective utilization of IoT that enables information communication technology and makes smart decision using machine learning algorithms. Artificial intelligence and machine learning techniques are playing very important role in smart farming for yield transformation [29]. In the recent decade, the usage of machine learning techniques in agriculture becomes very popular due to their vast applications, i.e., data analysis, weather forecasting, yield prediction, disease prediction, irrigation management, soil monitoring, weed detection, quality control, etc. [30] (Fig. 3).

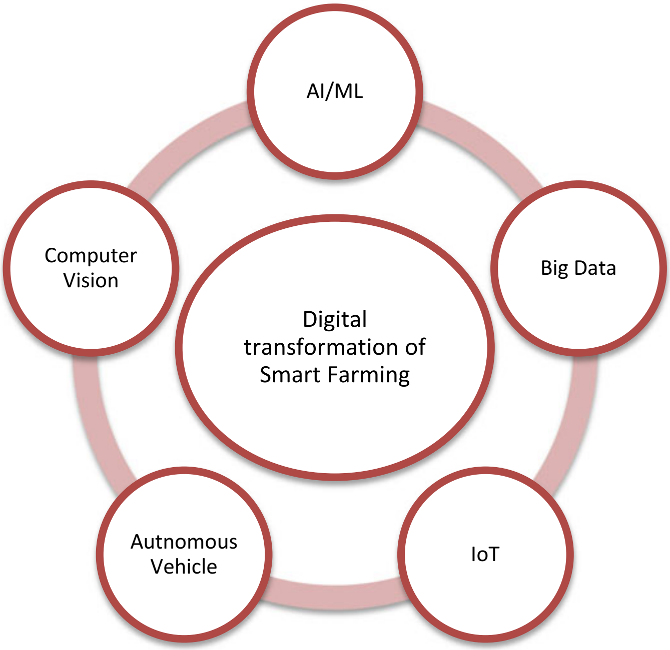

Fig. 3 Digital transformation of smart farming

ML contributes to smart agriculture by minimizing the investment cost and maximizing yield. Support vector machine (SVM), Naive Bayes, discriminant analysis, *K*-Nearest Neighbor, *K*-means clustering, Fuzzy clustering, Gaussian mixture models, artificial neural networks (ANN), decision trees, etc. [31] are the most widely used machine learning algorithms which are used in smart farming. Some of the frequently used machine learning techniques are discussed as follows:

3.1.1 Support Vector Machine

SVM technique is used for classifying the given set of instances. The idea is to find a hyperplane that best classifies the given instances without overfitting. When the width of the classifying line is expanded in both the directions, the instances that first touches the line are called the support vectors and this width is shown as width (*W*) in Fig. 4. The goal is to find the classifying line whose width is maximum, so that the overfitting can be avoided. In both directions, the boundary lines containing the support vectors can be expressed as:

$$mx^{+} + b = +1 \tag{1}$$

$$mx^{-} + b = -1 \tag{2}$$

Subtracting Eq. 2 from Eq. 1 will give yields (3):

$$m(x^{+} - x^{-}) = 2 \tag{3}$$

Further, the geometrical margin between two vectors x^{+} and x^{-} can be expressed as,

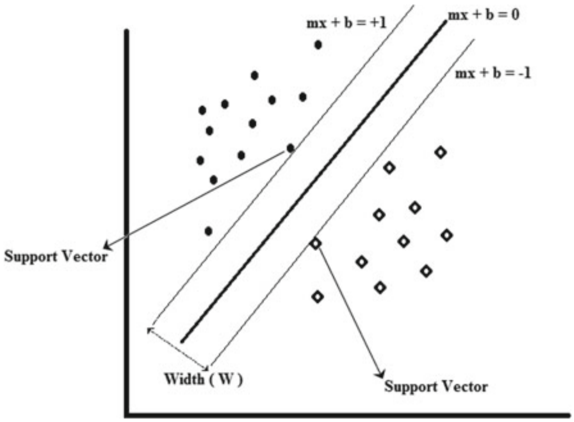

Fig. 4 Support vector machine

$$M = \frac{(x^{+}) - (x^{-})}{|m|}.m \tag{4}$$

Here, $m/|m|$ is unit vector perpendicular to the given hyperplane. Using Eqs. 3 and 4,

$$M = \frac{2}{|m|} \tag{5}$$

It is clearly concluded from Eq. 5 that for getting the maximum width, the |m| must be minimized, given that,

$$y(mx + b) \geq 1$$

Here, y is the value of the label class.

3.1.2 Naive Bayes

The Naïve Bayes classifier is based on the Bayes theorem. It predicts the probability of an event based on some previous information of related condition. The Bayes theorem can be stated as shown below in Eq. 6,

$$\Pr(A/B) = \frac{\Pr(B/A).\Pr(A)}{\Pr(B)} \tag{6}$$

Here,

$\Pr(A/B)$	is posterior probability, stated as probability of event A on given event B.
$\Pr(B/A)$	is probability of event B when the hypothesis A is True.
$\Pr(A)$	is the probability of A to be True.
$\Pr(B)$	is the probability of the event B.

3.1.3 Logistic Regression

Logistic regression is the machine learning classification technique based on the Sigmoid function, expressed as Sgm(n) in Eq. 7. The value of Sigmoid function lies between 0 and 1, can be expressed as,

$$n \rightarrow +\infty \text{ then, } \mathrm{Sgm}(n) = +1 \text{ and, } n \rightarrow -\infty \text{ then, } \mathrm{Sgm}(n) = 0.$$

Also,

$$\mathrm{Sgm}(n) = \frac{1}{(1 + e^{-n})} \tag{7}$$

When the regression function $\beta(x)$ is fed as input to the sigmoid function then the outcome will be the desired label classes, as shown in Eq. 8.

$$h(x) = \mathrm{Sgm}(\beta(x)) \tag{8}$$

3.1.4 Decision Trees

Decision tree is used to classify the data by categorizing the given instances on the basis of their attributes. It uses specific attributes to split the instances at various levels, so that the leaf nodes are marked with the labeled class. One of the most used approach to decide the splitting attribute is to calculate their information gain. If the information gain is higher, then better will be the split. The information gain for a split is expressed as shown in Eq. 9.

$$\text{Information Gain}(D, A) = \text{Entropy}(D) - \sum_{n=1} \left(\frac{D_n}{D} .\text{Entropy}(D_n) \right) \tag{9}$$

Here, the entropy can be expressed as shown in Eq. 10.

$$\text{Entropy}(D) = (-P_+ \log_2 P_+) + (-P_- \log_2 P_-) \tag{10}$$

The D is the original dataset which splits into ‘n’ subsets by an attribute A, where P_+ and P_- are the proportions of the instances which belong to that particular class in a subset.

3.2 Big Data

Big data technology is also playing very important role in smart agriculture because plenty of data is being generated by sensors that are equipped in the field of agriculture. Various machines are also equipped with variety of sensors that provide the real-time status of farming. On the other hand, it is evident that data itself is being captured in different varieties. Few sensors are providing direct readings, whereas few are combined with external sources such as weather data, market, or benchmark data of other farm. Big data requires set of techniques to reveal insights from data set that are diverse, complex, and massive in scale [32]. Big data have large volume, velocity, and variety to characterize which require specific technology and analytical methods for transforming into values [33].

3.3 Internet of Things

The use of Internet of Things (IoT) in smart farming is digitally transforming the agriculture and livestock management. Agriculture invention 4.0 is popular with IoT driven architecture in smart farming. Millions of machine-to-machine communication devices are being used in IoT framework for effective utilization of agriculture resources. Agriculture 4.0 trends are building an array of digital technology: Internet of Things (IoT), big data analytics, artificial intelligence, and ML technique are used for digital transformation and innovation. At perception layer in the IoT framework there are numerous sensor nodes that enable IoT framework. The main task of these sensing devices is to sense environments as per their nature of work; sensors can be deployed on vehicles or can be deployed directly in the fields for the purpose of disease controlling, soil monitoring [34]. There are various communication technologies such as WiFi, Zigbee, BLE, SigFox, etc. which involve in connecting these IoT devices to gateway and server for effective data transmission. The capacity of the communication channel can be measured using Eq. 11 for the IoT devices:

$$C = B * \log 2\{1 + [S/(\mathrm{No} * B)]\} \tag{11}$$

where C is the capacity of the channel (maximum throughput), B is Bandwidth measured in Hz, S is received signal power in Watt, No is noise power density in W/Hz. LoRaWAN is low power long range wide area network technology which is used for license free band such as 433, 868, 923 MHz for communication through LoRa gateway for large number of sensors and actuators. LoRa gateway can be sited at ground station, or it can be positioned in UAV. In the case of farming area is spread in many kilometers, using UAV drone whose can fly up to a few kilometers, we can monitor the farm house and collect sensors data, where other technology is unable to cover more distance [35]. The maximum travel distance D of the UAV can be calculated by the following equation:

$$D = \left(\frac{L_{\mathrm{Path}}}{\left(\frac{4\pi f}{c}\right)^2}\right)^{1/n} = \left(\left(\frac{c}{4\pi f}\right)^2 \cdot \frac{P_{\mathrm{tr}} 2^{\mathrm{sf}}}{\mathrm{SNRo.NF.kT.BW}}\right) 1/n \tag{12}$$

L_{Path} denotes as the path loss between sender and receiver, f denotes the frequency, sf is the spreading factor whose value lies between 6 and 12, P_{tr} is the transmitted power, BW stands for bandwidth and n is the path loss exponent and at the receiver end the remaining variable is SNRo which stands for signal to noise ratio, NF stands for noise figure and kT is the kelvin and temperature constant. If the SF is higher, then it will increase the communication range of LoRaWAN [36].

3.4 Autonomous Vehicles

Developing autonomous system in smart farming is very important to digitally transform agriculture and livestock sectors. It is very demanding due to the reduced labor or manpower in rural agriculture and livestock management. The use of Unmanned aerial and ground vehicle provide proper management and monitoring of farms. The use of artificial intelligence in robotics provides reliability in the machinery system to control and monitoring the farming. All the operation, i.e., seeding, weeding, fertilizing, crop sensing, irrigation monitoring and control, harvesting, etc., can be automated with unmanned machinery [37]. Unmanned vehicles, especially agricultural drones are very popular in smart farming nowadays. Continuously research is going on in this sector which carries out the advancements for digitally transformation of agriculture and livestock.

3.5 Computer Vision

Computer vision is also enabling the enhancements in agriculture sector by capturing high-quality images for crop monitoring and diseases detection purposes. As compared to manual inspection of fields, computer vision enables automated inspection of fields and subsequently, it is also providing alerts when required. There are various applications of computer vision in precision agriculture, i.e., yield improvements, monitoring crop growth, pest controlling, weed controlling, quality inspection, etc., [38]. The main task of computer vision is to characterize the plant image and extract required features that are helpful in detection of the diseases in the crops. On the other hand, with the help of image classification using computer vision we can get several insights automatically about the farm. Furthermore, computer vision in collaboration with ML provides detailed analysis and predictions [39].

4 Challenges for Adoption of IoT in Smart Farming

As discussed in the previous section that there is a need of adoption of smart farming in the upcoming future due to exponential growth of the population and at the same time, decrease in agriculture land. Due to the advancements in 5th generation mobile technology, the process of smart farming becomes easier nowadays. However, still there are several challenges in adoption of smart farming in real-time environments. This section deals with the discussion about some of these challenges which are mentioned as follows:

4.1 Network Quality

The real success of the smart farming depends on the quality of available network for connecting IoT devices together and on the real-time availability of resources. It is apparent that the network quality and availability of urban area is stronger as compared to rural areas, but there is strong need to improve the same in rural areas for the adoption of smart agriculture. Most of the developed and developing countries are working toward the enhancements of network connectivity in rural areas, but the challenge is still not resolved at all. The success of the smart farming depends on the quality of services being provided by telecom operator, i.e., service portability, flexibility and luxury two-way communication offered at low cost with customized solutions [40]. There are various communication technologies which are popular in smart farming that are playing key roles, i.e., low-power wide-area (LPWA) wireless Technology. LPWA provides efficient coverage with low power consumption on end devices. On the other hand, narrowband IoT (NB-IoT) is contributing and has strong collaboration with industries for providing cost effective solutions of smart farming [15].

4.2 Quality of Hardware

Several challenges exist in smart farming which are related to quality and cost of the hardware. IoT devices use various sensors at perception layer in the IoT architecture. These sensors are also facing various issues from environmental conditions, i.e., exposure to rain, storms, high and low temperatures, high power wind that can lead to serious damages. This challenge is not only related to hardware quality but also there is strong need to improve the quality of hardware for providing better communication medium to the overall architecture [15].

4.3 Interference Between Communication Devices

Smart farming uses IoT enabled devices that use different communication technologies (spectrum) as Sogfox, ZigBee, LoRa, Bluetooth and WiFi. Sometimes there may be chances that communication among smart farming network may experience disturbances due to interference with other sensor nodes which work on the same spectrum. This type of interference leads to severe issues in the network, i.e., connectivity issues, loss of data, inaccurate readings, packet loss, delay, etc. Power requirements of Wifi are more as compared to Zigbee, but it overlaps many frequencies with each other. However, WiFi channels are wider as compared to narrow band channels of Zigbee. Due to this interference, most of the time signals need to be retransmitted for achieving better accuracies. For successful adoption of smart farming, it is always required that such type of interference among sensor nodes should be minimum [41].

4.4 Reliability and Scalability

IoT sensors are placed and exposed in environmental conditions that may face various natural calamities, such as heavy rain, storm, tornado, excessive heat. Sensor's device is made of electronic circuit, may be due to harsh environmental condition, sensor may become faulty or partial faulty that can process or upload partial or wrong data to the cloud platform. So, in such circumstances, the biggest challenge is to make the IoT network more reliable [42]. Millions of machine-to-machine communication devices are connected in the communication environment for scaling up the smart farming architecture by using large number of gateways, sensors devices, and network protocols. Scalability refers to the ability of the device to expand its capabilities according to the expectations for meeting future requirements [43]. Data storage in the cloud should be reliable and scalable which is one of the biggest issues in the current scenario.

4.5 Cost Analysis and Lack of Knowledge Regarding Technology

Most of the advanced technologies used in the smart farming are equipped with latest IoT devices that are complex to operate by small farmers. Due to lack of financial resources as well as knowledge, sometimes it is quite difficult for the farmers to operate these complex devices. However, various service providers such as 'AgTech' in India are working hard for providing cost effective and easiest solutions to the farmers. For adopting of smart farming, it utmost required that there should be some collaboration among these companies, local government, and the farmers. It is observed that few agricultural companies are expert in training, technology, cost analysis, crops margin analysis that can provide complete solutions related to the smart farming. It is apparent that farmers in most of the countries are not aware about benefits of IoT and its technical uses [44]. On the other hand, the IoT devices for smart agriculture are much costlier as compared to the income of farmers is concerned. It is utmost required that the cost of these devices should be minimized as well as simplicity and reliability should be maximized for successful adoption.

4.6 Data Quality and Access

Smart farming is based on the prediction and decision-making capabilities of the system. These systems are heavily depending on the quality of data collected from several sensor device. Most of the things in agriculture are uncertain due to environmental factors that is why for prediction and decision-making capabilities crop related data of several years is necessary. This huge data needs to be analyzed for providing meaningful conclusions and predictions so that important decisions can be made on time. The data collecting devices need to be interoperable and scalable to meet the expectations of analysis. Furthermore, every IoT device has certain terms and conditions regarding operation and covering access [45].

4.7 Security and Privacy

Security and privacy are the big concern for the adoption of smart farming. As the risk of cyber-attacks is increasing day by day, it is challenging that these devices will work error-free and provide real-time as well as accurate data. Smart farming environments are generating enormous amount of complex data by sensor devices that needs to be processed and saved to cloud platforms. Sensor data and cloud platform is connected to the internet connectivity, that may be vulnerable to the hackers and attackers. Leakage of data can be of great threat to the farmers and the country. A cyber attacker can control the data of entire country if there is any loophole present in the IoT enabled smart farming. It is observed that for making deeper insights/analysis such data needs to be shared with industry experts [46]. One of the biggest issues in dealing with such challenges is the usage of pirated and non-licensed products that may lead to leakage of potential data.

4.8 Energy Efficiency

Smart farming uses millions of IoT devices, gateway, cloud infrastructure, and powerful data center that consumes huge electricity and battery-operated power. Most of the sensor nodes are dependent on the inbuilt battery capabilities to meet the power requirements. It is utmost required that the power utilization of these sensing nodes should be minimized to save the battery life and subsequent cost to the farmers. Due to the high usage of power consumptions, it is evident that there would be more risk to energy depletion [47]. In addition, excessive usage of 5G adversely affects certain environmental parameters due to usage of millimeter waves and higher frequency bands [48].

4.9 Technical Failure and Resultant Damage

The decision support system used in smart farming heavily depend on the data collected by IoT devices. If any of the device starts malfunctioning and provides inaccurate readings, then there would be greater risk to the crop. There may be chances that this faulty data may result in damage of a huge amount of crop. For instance, if some smart irrigation system starts malfunction, then there may be chances that inappropriate water requirements (i.e., over water or under water) are being generated. It is one of the biggest challenges to the reliability of these IoT devices that whether they will work properly and provide accurate information about the farm on time [49].

4.10 Propagation Loss

In the adaptation to smart farming there may be chances that due to communication losses the overall system stops working. Due to several environmental conditions as well as presence of few obstacles the communication among several sensor nodes may be affected. It is observed the performance of few devices is not satisfactory during adverse environmental conditions, i.e., microwaves being absorbed by water, loss of signals during rainy session, etc. Line of Sight (LoS) communication in smart farming is one of the biggest challenges, as the communication node may not work together due to external disturbances [50]. On the other hand, various farms suffer from severe environmental conditions, i.e., presence of trees, absence of flat surfaces, reflection, attenuation, signal scattering, etc. In this scenario, link quality is generally decreased, especially when node is surrounded by dense crops [51].

5 Conclusion

Smart farming plays a vital role in increasing the yield production and providing many benefits to the farmers such as efficient utilization of agriculture resources, reduced manpower, crop monitoring using unmanned aerial vehicle, timely irrigation plan for the crops, disease identification, pest control, soil monitoring, etc. Nowadays, due to the advancements in 5G communication technology, the process of adopting smart farming becomes easier due to inbuilt infrastructure, cloud computing, and network virtualization capabilities. Digital transformation of smart farming requires adoption of emerging technologies in the agriculture. On the other hand, machine learning and artificial intelligence techniques are also contributing toward deeper analysis of agricultural data for effective decision-making capabilities. The work embodied in this chapter has presented a survey of several IoT enabled solutions for the adoption of smart farming. Few works related to IoT infrastructure and machine learning techniques were analyzed for providing background toward digital transformation of smart farming. Digital transformation of smart farming requires extensive usage of several advanced technologies, i.e., AI/ML, computer vision, IoT, big data technique, and autonomous vehicles (UAVs). No doubt with the incorporation of these technologies' farmers may get benefitted by intelligently controlling the farms, provide accurate decisions, reduced human efforts, and increased yield productions. However, there are several key challenges that need to be addressed while adopting these technologies in smart farming, i.e., quality of network, hardware cost, propagation losses, reliability, scalability, etc. Various parameters of these issues must be studied while providing cost effective solutions using modern smart farming technologies. The future work will be focused on designing an IoT-based framework, in which the IoT devices will gather data using sensors, and machine learning techniques will be used to identify various plant diseases.

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IoT Based Agricultural Business Model for Estimating Crop Health Management to Reduce Farmer Distress Using SVM and Machine Learning

Ishita Banerjee and P. Madhumathy

Abstract Agriculture and farming is the backbone of the society which serves the basic needs of the human livelihood. Indian climate is always favorable for growing crops and providing agricultural platform. Though agriculture is one of the most prime fields to engage the workforce still, it lacks adequate technological support for improvement of the crop quality and build a healthy nation. The major concern related to agriculture and economy to any country is that there is a huge gap of financial gain for the farmers and the outside market. It makes the farmers incapable to estimate the inflation rates and finally leads them to distress. The proposed work deals with the above said drawback by implementing an agricultural business model which facilitates the farmers to know their crop and the market better. The farmers can grow and cultivate crops according to the market demands thus leading to a good financial prospect and lesser loss. This proposal also deals with monitoring the crop health condition during its growth period to give a clear understanding of the crop quality that can be delivered to the market. Both of the proposed methods helps the farmer to estimate and precalculate the financial investments and gains and plan the budget in a managed way. The health condition of the crop is summarized with the help of image processing and SVM. The parameters to check the health condition of the crops can be incorporated with Internet of things (IoT) and sensor networks, so that the farmers can monitor their crop conditions with ease.

Keywords Agriculture business model · IoT · Crop health management · SVM · Machine learning

1 Introduction

Agriculture is one of the major economic strength of India. It has a high impact in the Indian GDP. Still this is the hugely neglected field in terms of technological advancements, government supports and schemes, urbanization, etc., which ulti-

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mately is leading to some fatal conclusions like farmer suicidal attempts [1]. Let us consider the cotton crop. Not only the social issues but a good crop certainly depends on the environmental and weather conditions [2–4]. Due to a huge climate change, this cotton crop is facing severe fungal, bacterial, and even viral diseases which were not so common even 10/20 years back. It is very important to identify the disease at the early stage, so that the spreading of the disease can be controlled and the crop can be saved from destruction. To identify the infected crops, we make use of image segmentation which is strong image processing tool that can very minutely plot the difference between an infected and normal crop image which is near to impossible for human eyes to observe. There are several methods of image segmentation. The most popular ones are clustering, fuzzy based, neural network, histogram-based thresholding, etc., but most of the cases hybrid of these techniques are used for greater accuracy. The life span of a betel leaf tree may last as long as 2–3 years, and in this span, they might face leaf spotting or powdery mildew kind of problems. This will ultimately lead to degradation of the leaf quality, and thus, the quantity delivered to market will reduce emerging a high loss to the farmer. Another major problem is leaf rot which might happen due to pathogens attack and this leads to a 30–100% loss in the production. *Phytophthora parasitica* is a fatal parasite causing this leaf rot problem in many of the crops. The weather conditions such as high humidity also support this parasitic attack.

The proposed system aims toward developing an automated application for the farmers to estimate the crop health and determine their budget from that. It works with a clear disease detection scheme which will determine the disease in the leaves at a very early stage to reduce the spreading of the disease. The technological aspects if imposed on agricultural field results greater sustainability of crops, estimation of environmental factors harming the crops, increase in productivity, and finally a sure finance and business model [4–7]. The standard operations that can be done in any agricultural field subjected to be monitored is data gathering and processing [8, 9]. The processed data can be analyzed and automated through IoT for availability of information [10–13]. This way a disease preventive business agricultural model can be created. The proposed automated system aims on displaying the processed data to a LCD display. This can also be gathered from the application built for crop health monitoring.

As soon as the farmer is aware of all the crop conditions, he can plan on his budget according to the statistics given by the app to find different subsidies and supporting price for the produced crops. This will eventually give a clear overview to the farmer about his cultivated crop direct from field to the market.

Many times we see that the farmland to be monitored is far away from home and traveling every time for operating the irrigation pumps is not a convenient option. Along with this, the road conditions are not up to the mark and transport facilities are also not much available at the country sides. Walking through the farm field may lead threads of bugs, snakes, and other types of hazardous insect bites. If weather condition becomes hostile, then this may even lead to thread due to lightning, thunder, and electrical shocks. Thus operating the pump several times a day itself calls for tremendous unknown dangers. Adding to it, farmers face additional problem such as frequent power cuts, theft, and power-level fluctuations which results in a state where the field pump needs to be switched on several times a day.

Another major problem associated with crop disease used to be detected by human eyes. This way identifying a disease and detecting the kind of infection certainly happens at a much later phase when almost the disease might have spread among the entire farm land. Many of the country sides the farmers do not have facilities to discuss and contact the experts to discuss and take suggestive measures to protect their crop from the crop diseases. This might be expensive or need much time and effort which will ultimately lead to destruction of the crop and a huge financial loss for the farmer. The proposed method adds value in terms of technological support to overcome the above said problems by simply implementing some automated techniques to detect the crop disease at the early stage. This aims for automated process control with machine learning and inspects the crop health in regular intervals, so that any damage can be spotted at the very early stage and the farm can be saved.

The visual and manual plant disease identification process cannot be done much accurately and timely. The automated crop detection technique will enhance the accuracy and the disease can be spotted very fast. By using image processing techniques, the type of disease can also be identified much effectively.

2 Literature Survey

Sujatha et al. [14] work with the difficulties faced by of plant disease in agriculture field. Late and incorrect identification of the disease can lead to huge loss to the production of the crop. Identifying a plant disease manually through naked eyes needs tremendous knowledge in identifying whether the infection has caused and if it has caused what kind of infection is it. Ultimately late identification or inaccurate identification leads to damage of the crop. Here, the authors have proposed some techniques using MATLAB to identify the plant disease. The techniques used include capturing the image, contrast enhancement, image conversion, feature extraction, etc., and use of *k*-means clustering is used along with image processing techniques to identify the disease from the images of the crop leaves. This process is much better than manual identification of plant disease. The steps followed to perform image procession on the captured images are image preprocessing, segmentation, feature extraction, and classification. If a disease is identified at a sufficiently early stage, it can be controlled using pesticides and the crop production can be maintained at a sufficiently good level. The process requires lesser hardware and cost and is much effective also.

Dubey et al. [15] state in their paper that there is a huge importance of working with color image segmentation on the received input image. In case of identifying the disease in cotton leaf, it is important to segregate the healthy leaves and only collect and work with the images of the infected leaves. The use of roughness measure of the leaves makes it easy to identify if the image is of an infected leaf or not. Then, the image of this leaf can be classified simple linear iterative clustering. For image extraction, roughness measure is used. The image is grouped into superpixel value segments, and image extraction is done from this using gray-level co-occurrence matrix. SVM helps to classify the leaves into groups such as Alternaria/ Bacterial/White flies/Healthy cotton leaf. This work increases the accuracy by 94%.

Abhishek et al. [16] proposed an online marketing scheme for the farmers to facilitate proper value of their crop in the market. Here, the provision is given to sell the crops from farmers to directly the consumers by avoiding the middle man's profit. This application established direct communication of the consumer and the farmer, so that the crop can directly be delivered to them by the farmer. One expert team is set to rate the quality of the products, so that the consumer gets a clear idea about the product while buying it. This will ensure fair pricing and good quality products. Farmers solely play a major role on cultivating the products and finally get distressed by middleman in the transaction. Even consumers have to pay an unnecessary hefty amount for the products. This proposed work eliminates the middle man profit and is proved to be profitable for both farmers and consumers. It also provides seed and pesticide purchasing suggestions for farmers. This application-based approach aims on provide deserving profits to the farmers.

Agarwal et al. [17] proposed implementation of application "Agro-App" in their paper. This app facilitates the need of the farmers as well as a common man who is keen on growing his/her own farm. This app provides an end-to-end knowledge to the cultivators. The detailed information can be availed here. The finance related clear overview can also be analyzed in the application proposed. The seasonal crops if grown in correct environment can provide much more profit, and this app provides a proper information about the crop that can be cultivated during which weather according to the geographical location of the farmer. Government of India has lately started many schemes for the agriculture related start-ups and even for the farmers, but we can definitely say that this field needs much more user-friendly support. The procedure to be followed for government help may be reason for many of the cases for the farmers to set back in availing the facilities. Low literacy and lesser exposure to technology may also be one of the reasons. This proposed app though needs technical knowledge to operate, but this is a very simple and user-friendly application and designed kept in mind about the feasibility of the user group. This "AgroApp" is specially designed keeping in mind about the user friendliness, so that the farmers do not restrict themselves from using it. It can provide adequate required knowledge about cultivating a crop. If we concentrate of the financial or budget part of this app, then this app keeps the farmers up to date about the current government schemes and policies for the farmers to extract maximum benefit out of it. Another feature of this app is that if the farmer selects the crop he is cultivating, then the app will show the probable diseases it may encounter according to the climate and precaution in terms of pesticides or insecticides can be taken much earlier to prevent loss.

Yimwadsana et al. [18] propose IoT and experimental-based application to control the growth of the crop affected by environmental factors. The plant growth data is collected by the sensors and collected in a database. This data from the database is analyzed manually or using a rule-based control panel to extract exact information about the health condition of the crop. The application helps in monitoring the environmental factors as well such as soil quality, humidity, heat, ground water level, and soil moisture, and the hard ware is solely dependent on the sensors that are mounted on the field to measure different categories of factors to be monitored, and the collected data management is done through IoT. The technology is kept hidden from the farmers, and only end application is provided to them, so that they can completely concentrate on a healthy farming environment.

The implementation of IoT in the field of agriculture has made a huge difference. The high-quality sensors mounted on the field of observation can provide data accurately which can be analyzed for the better crop production. Using IoT, the farmers can monitor this from a remote location. The experts can also suggest required fertilizers, pesticides, etc., sitting far away. This knowledge sharing has only been possible due to real-time monitoring of the fields. There is also an alert condition put in the app which will set an alarm for any serious condition that need quick attention to save the farmland and the crop. The initial implementation cost might be high due to hardware installation. The benefits in long run are more evident.

To observe the plant growth condition the sensors mounted in the field give data about favorable conditions for it. The factors affecting the plant growth can be monitored through this collected data. Out of many of the environmental factors, two major factors are sunlight and soil moisture/ water supply which are very crucial for photosynthesis. The data collected by the sensors such as temperature sensor, light intensity sensor, and humidity sensor is sent to the central hub where several data analytic techniques are used and an effective plant grown model is suggested to the farmers [3, 19].

Now when the farmer receives the data about the most effective plant growth model, a comparison is set to understand the lacking factors for the proper growth of the plants depending on the current real scenario. This way the environmental factors can be adjusted to the best possible way for better growth of the crops. In this proposed work, environmental setup is established, and data is collected by the sensors by varying the measuring factors. Each time a factor value changes, the growth of the plants are measured in centimeters and stored for further analysis. This experiment was conducted for 7 days.

Pallavi et al. [20] proposed LMD or labor monitoring device for the purpose of labor monitoring in the field from a remote location. LMD used the hardware such a RFID reader, computational unit (CU), GPS, and weighing machine. The labor working in the field will have to wear a RFID tag as a wrist band. The crop weight is measured by the weighing machine. The collected data is uploaded in the cloud. The analysis of data related to soil, temperature humidity, and crop with the supported IT infrastructure. The data is acquired through some sensors and images of the crops are taken by a camera. This information is stored in cloud and later is analyzed by agricultural experts. The IT infrastructure along with the sensor hardware supports the agricultural needs. The farmers may receive the solution via SMS.

This application analysis part has client/server stub. Server stub consists of group of application such as message process, query process, database, and analytical process. The server stub accepts queries sent by the client stub. The server stub has a storage of information about all the details of the farmland such as soil moisture, air temperature, crop health, and fertilizers to be used. Programmable system on chip (PSOC) is implemented for green house monitoring. This system also helps in regularized water supply to the fields according to the need.

Another factor for plant growth is the respiration rate. If the moisture level of the soil falls/ increases than the normal value, the respiration process of the plant gets disturbed. A study is shown in the proposed paper by the authors where the respiration rate changes with the change in soil moisture level. The factors controlling the growth of the plants such as moisture level and temperature can be tracked through WSN to encounter the issues faced by the farmers. Though the hardware implementation and sensor network implementation is a tedious process, but once implemented, this can be controlled using software process control techniques. A control system for an intelligent farming composed mainly two parts in intelligent farming (IF) that is sensor system and control system used to monitor and control the farm field. The filed monitoring is incorporated with IoT. The architecture for IF and the information decision is calibrated by using Kalman filtering, to monitor weather condition of farm field.

3 Procedure

The proposed project aims toward proving a sustainable and completely automated farm field monitoring, crop diseases can be detected, and the farmer can be warned at an early stage to prevent any kind of crop loss and financial loss. This developed application can keep the farmer up to date about the health condition of his farm land remotely.

The proposed system architecture is shown in Fig. 1. Arduino UNO is a microcontroller board based on 8-bit ATmega328P microcontroller that is used in this work.

The moisture sensor used is a typical soil moisture sensor that can measure the water moisture volume present in the soil to be tested. This moisture content is measured using some electrical properties (resistance, dielectric constant, etc.) to save time. The soil moister reflects the microwave radiation. This property is used to sensing soil hydration level.

The soil moisture sensor as shown in Fig. 2 has two probes that conducts electricity through the soil to measure the resistance it offers. More moisture means more conductivity thus less resistivity. The moisture sensor used is FC 28. The potentiometer present has some threshold value which can be compared by the LM393 comparator. According to this output value of the comparator, LED operates.

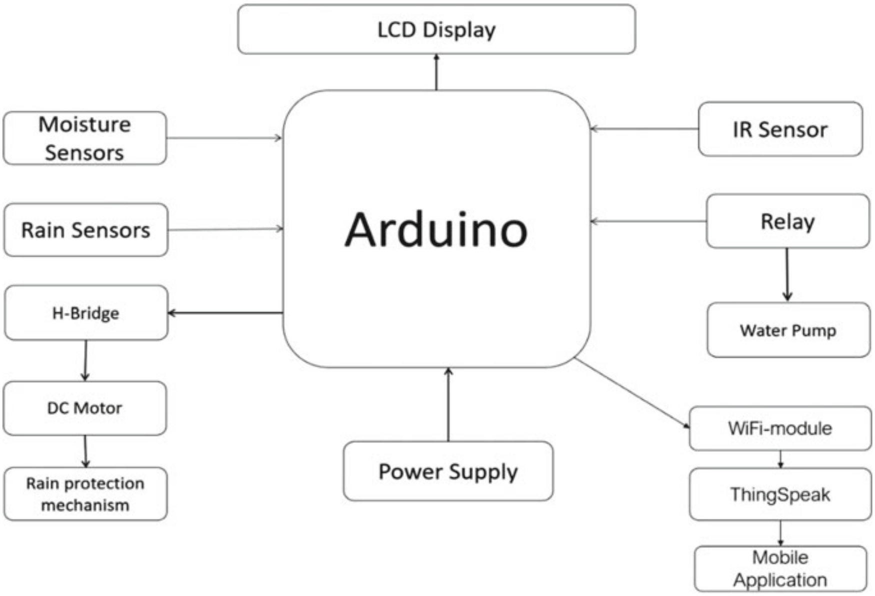


Fig. 1 Proposed system architecture

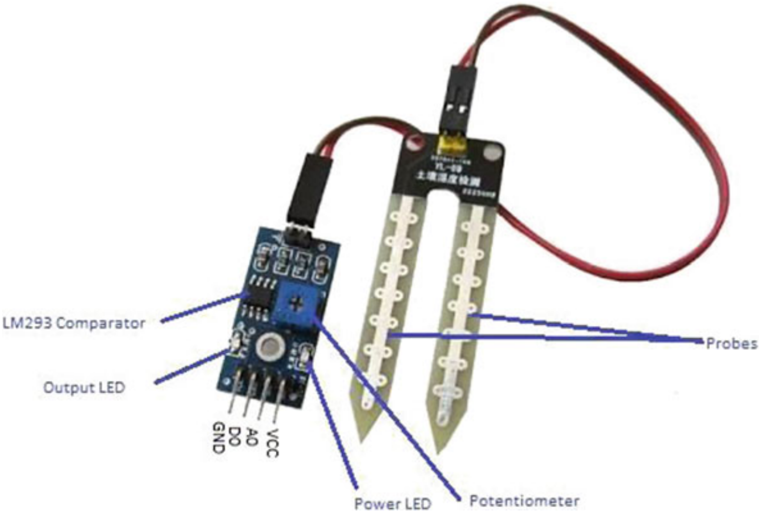


Fig. 2 Soil moisture sensor

The raindrop sensor used is FC 37. It has electronic and collector board. The resistance variations of the board decide if rainfall has occurred or not. Wet board offers more resistance, and output voltage reduces. Dryness in the board means less resistance and high output voltage. This is shown in Fig. 3.

The Hbridge and the relay are used for operating the motors. The IR sensor is used for temperature and motion detection. The LCD module helps to display the output measured by the respective sensors. The collected data are also transmitted by Wi-Fi module ESP8266. To communicate with ESP8266 via Arduino UNO, a logic level controller in between the two is needed. The Arduino software supports all the programming interfaces in between stages. The collected data then is stored in cloud through Thingspeak. Now, this is how the sensors help to monitor the basic environmental needs at the first step.

Next stage is the crop disease detection. The images of the leaves go through several steps as shown in Fig. 4.

The captured images go through machine learning and SVM process which helps to identify the disease with more accuracy. Let us see the machine learning method in two phases as shown in Fig. 5. The general approach of machine learning goes under two phases. The initial phase is the training phase where the model is trained with some set of data which is later fed to the testing phase. The

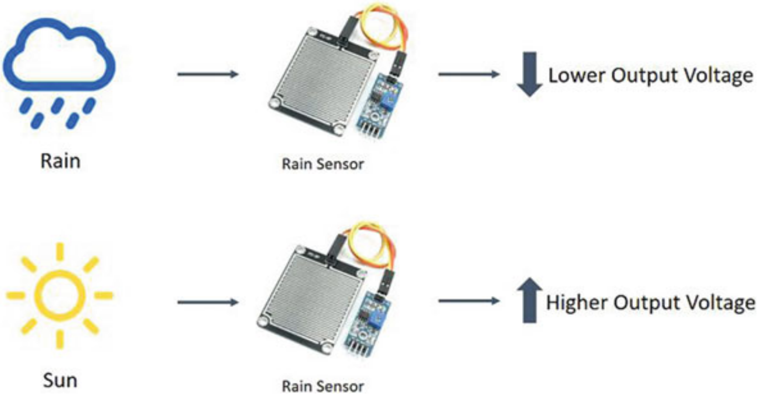
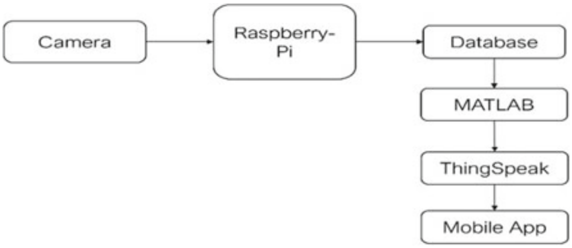


Fig. 3 Working of rain sensor

Fig. 4 Flow of image processing for disease detection



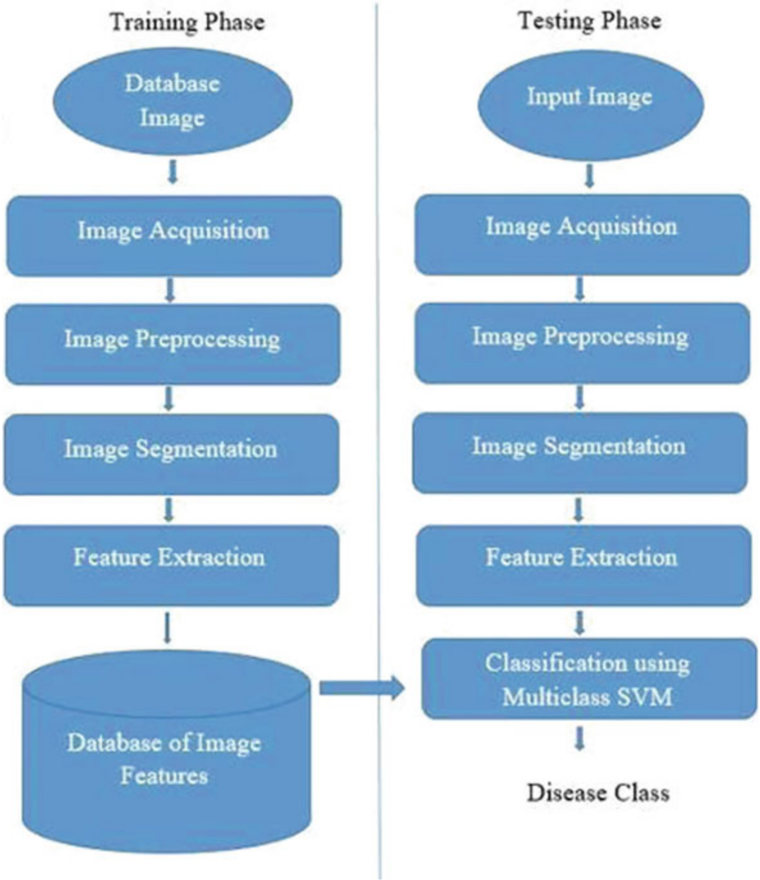


Fig. 5 Two phases of machine learning

processes that are conducted through the phases are image acquisition, image preprocessing, segmentation, feature extraction to identify the disease, and SVM classifier to classify the diseases using machine learning approach [21–23].

The image of the leaf is taken by some camera from predefined distance and lighting requirement and sent to go through the machine learning process. These set of data are initially used for training purposes. These images need to be converted to some standard format of contrast and background brightness, etc., on these set of data image preprocessing takes place. The main aim is noise cancellation. It may use filters, color contrast transformation, and histogram equalization. Following Fig. 6 shows an example of RGB to HIS image transformation. HIS stands for HUE, i.e., the major color attribute, SATURATION, i.e., the brightness of the image, and INTENSITY, i.e., the amplitude of the light. After filtering, only the H part is kept for further analysis.

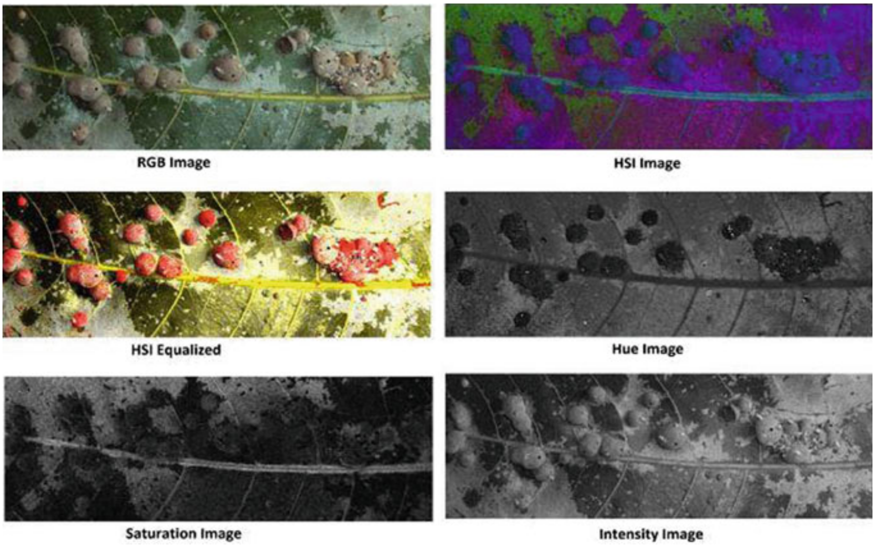


Fig. 6 RGB to HIS

As we need to identify the disease attacked leaf, the green pixel adds no value to the information as green leads to a healthy leaf. To reduce the processing time, thus we eliminate the green pixels present in the image by some masking techniques.

Once the image information is available, this way it is sent for segmentation. There are several segmentation techniques available such as threshold based, edge based, cluster based, neural network based, and hybrid techniques. Here, we chose to use the *k*-means clustering segmentation technique. In this project, *k*-means is a clustering method to get *k* numbers of clusters which matches the specified characters like to segment the leaf. Figure 7 shows the flow of *k* cluster algorithm.

The algorithm steps are as follows:

Step 1: Image is captured and converted to RGB. Capture the image in RGB format.
Step 2: The image color transformation is done.
Step 3: Conversion of RGB to the space specified in that application for analysis.
Step 4: Image segmentation is done using K-means clustering.
Step 5: Green pixel is done.
Step 6: Edge elimination for mask cell clearance in the infected cluster.
Step 7: Conversion of RGB to HIS.
Step 8: From the hue value SGDM matrix is created.
Step 9: Feature extraction using GLCM function.
Step 10: Texture statistics measurement of the infected leaf.
Step 11: Image recognition using KNN classifier.

The *k* clustering algorithm helps to detect and classify the disease of the leaf. The first step is to capture images. Next color transformation structure formation and

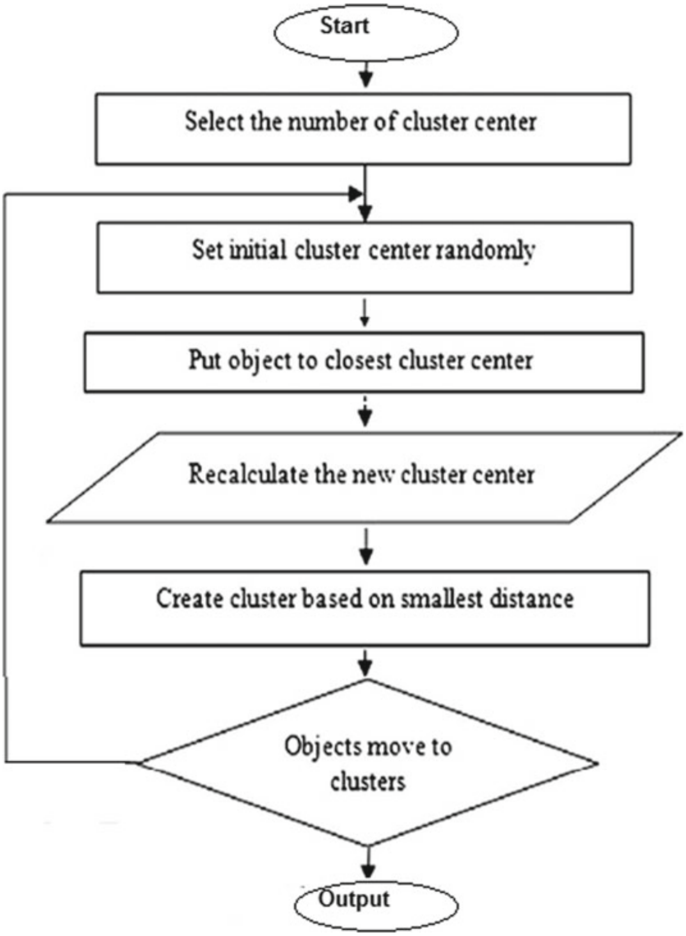


Fig. 7 Flow of *k* cluster algorithm

color space transformation take place in the following two steps. Finally, the image can be segmented now in step 4 as shown in Fig. 8. Next step is green pixel masking. In sixth step, the edge pixels of the infected leafs are eliminated. Also the ‘0’ value pixels are removed. In seventh step, the RGB to HIS transformation gives the H information which is used to build SGDM matrix. This is done to know the texture statistics of the leaf. Thus, the features are calculated for the pixels present inside the edge of the infected part of the leaf. The final step is then recognition process. These steps are performed for each captured images. The data collected by these several steps are transferred for storing in cloud and also displayed in LCD.

Support vector machine or SVM is used here in the process of machine learning to classify the image and also for regression analysis. Raspberry Pi is the backbone of the hardware used to synchronize the data obtained from the previous steps to make it available for some practical purpose.

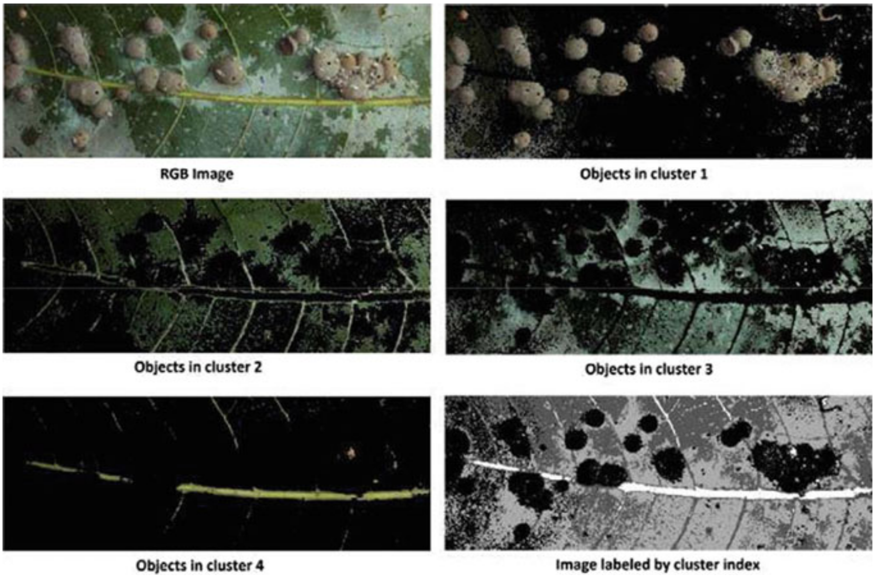


Fig. 8 Image segmentation after performing *k* clustering

Following Figs. 9 and 10 show the flowchart of the proposed methodology in two different locations.

The system proposed is subdivided into three parts: (i) Automated field management, wherein all the sensors and actuators work hand in glove to keep the farm completely functional virtually eliminating the need of human presence. (ii) Disease detection part of the system which is done using MATLAB, to detect diseases if any at the earliest to prevent any spread. The support vector machine (SVM) is used for testing. Three types of cotton leaf diseases are being detected, the first being bacterial blight, the second being *Alterneria*, and the third being crumple. (iii) The mobile application, which displays all the real-time sensors' data, various parameters related to the crop marketing, and enables the farmer in knowing the farmer about the current health position of the crop.

The rain drop sensor is responsible for detection of rain over the farm. If detected, then the flaps are retracted thereby cutting off the farm from the rain outside. The moisture-level sensor maintains threshold that is set, which is different for different crops and also depends upon the soil type. If the sensor senses inadequate moisture content, then water is pumped into the field. The passive infrared sensor is responsible for detection of suspicious animal activity on the field. The corresponding actions are shown on the LCD, and the same are reflected on the mobile application.

The camera which is integrated to the Raspberry Pi takes the image of the leaf whenever the farmer wishes to do so. The image is then preprocessed, segmented, and the feature extraction is carried out, 13 features are extracted, and

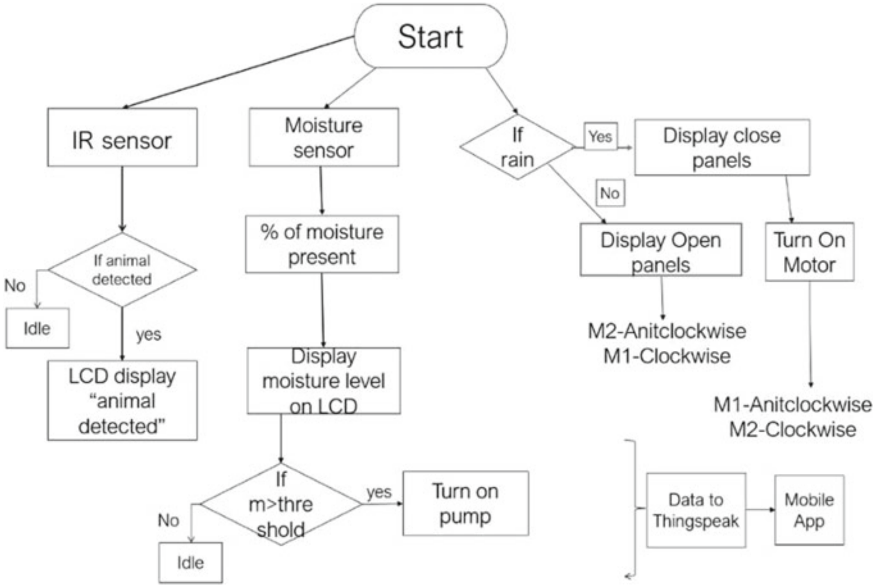
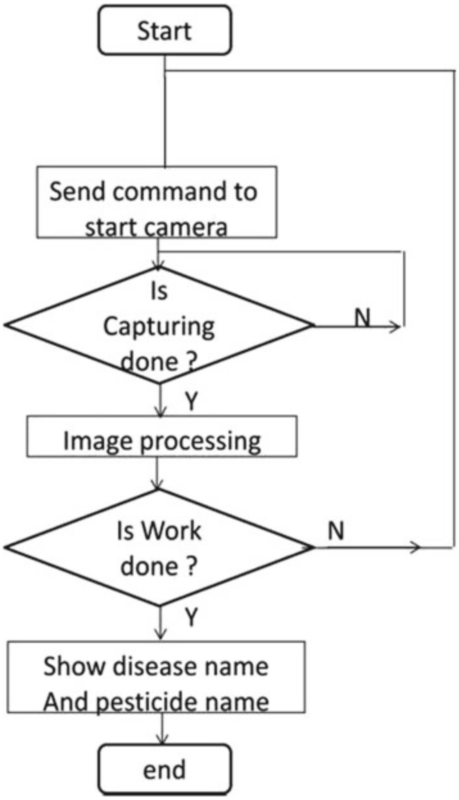


Fig. 9 Data flowchart at location 1

Fig. 10 Data flowchart at location 2



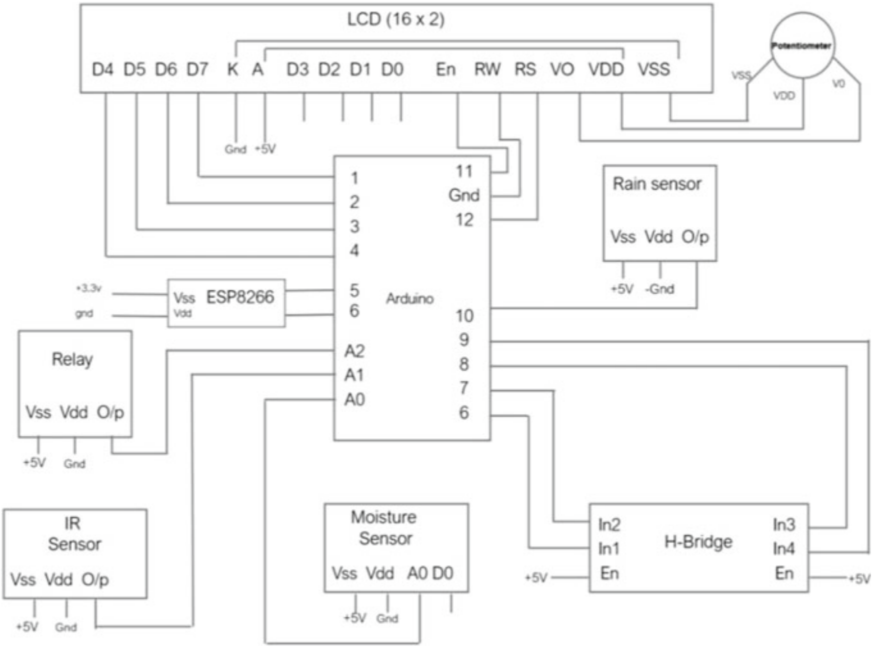


Fig. 11 Circuit diagram at location 1

co-occurrence is checked with those of already stored in the database, which corresponds to different types of leaf diseases. The leaf if diseased is informed to the farmer, so that the further assessment of the crop can be done in time preventing the crop failure.

The application developed has three tabs (a) The tab which informs the farmer about all the sensor data. (b) The tab which gives the farmer a preestimated budget for the crop that the farmer plans to cultivate. (c) The tab that informs the farmer about the health status of the crop. The circuit diagram at location 1 is shown in Fig. 11.

Figure 12 shown the real implementation at location 2.

4 Results

This proposed system acts along with few sensors for environmental condition detection. The rain sensor detects the rain fall, and the soil moisture sensor helps to make a decision whether to turn on the pump or not. The IR sensor helps any animal or intruder has come to the field or not. The image processing is done using MATLAB and three diseases are detected, which are (i) bacterial blight, (ii) *Alterneria,* and (iii) crumple as shown in Figs. 13, 14, and 15, respectively.

Fig. 12 Webcam connected via Raspberry Pi at location 2

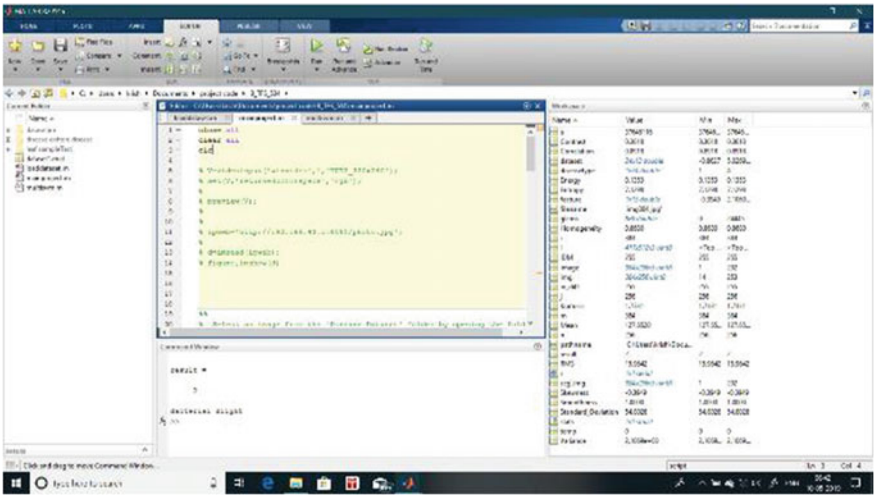


Fig. 13 Result for a leaf diseased by bacterial blight

The mobile application developed shows different tabs, which shows for different sensor data, market trends, and the leaf disease detected.

In Fig. 16, we can see that the different values collected by the sensors are sent to the mobile application.

Figure 17 depicts the overall weather condition for the selected location and field to decide if there is any need to monitor or change the plan in crop production. Finally in Fig. 18, we can see for a particular product such as cotton that the cost estimation is studied in detail. We can even set data for state-wise cost of cultivation and cost of production and make the budget accordingly.

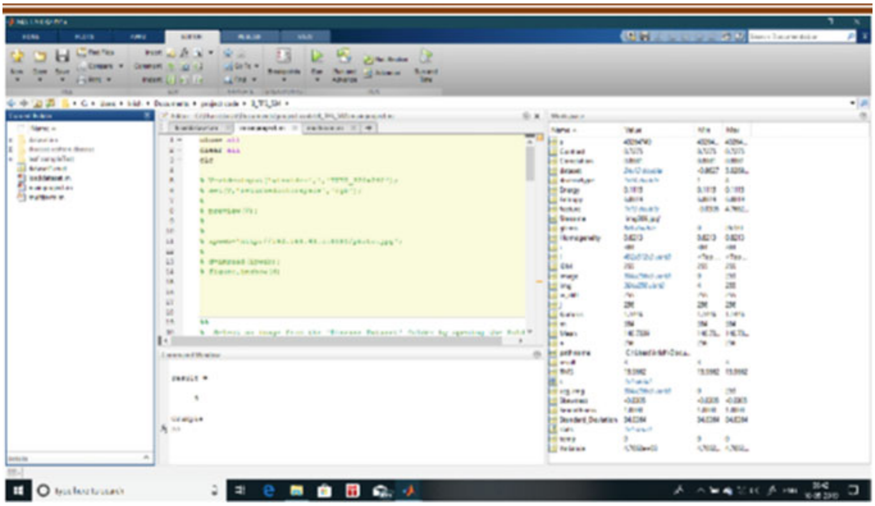


Fig. 14 Result for a leaf diseased by crumple

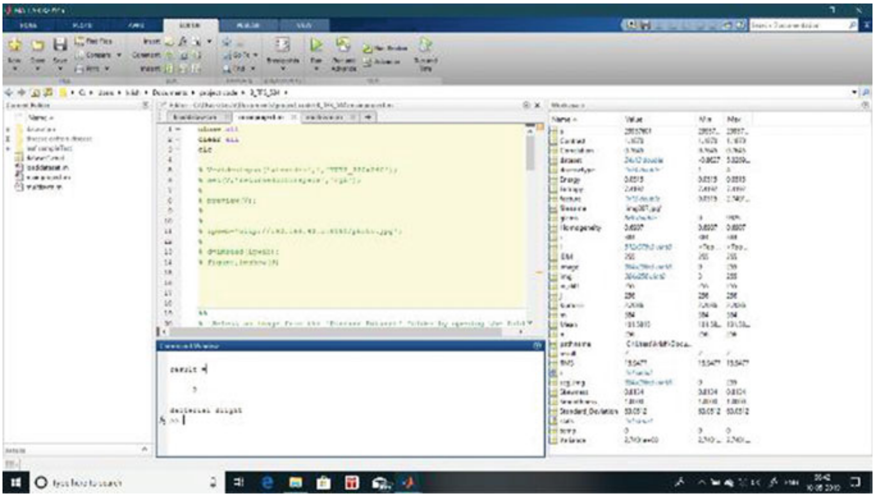


Fig. 15 Result for a leaf diseased by *Alterneria*

Fig. 16 Sensor data in mobile app

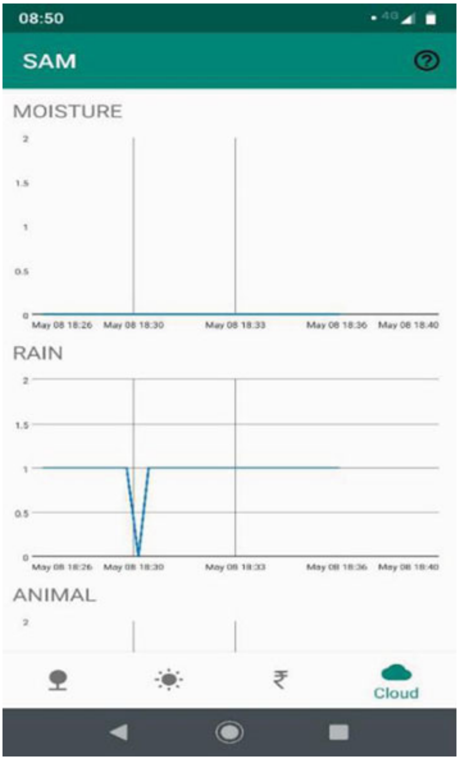


Fig. 17 Mobile application showing current weather

Bangalore

Current weather and forecasts in your city

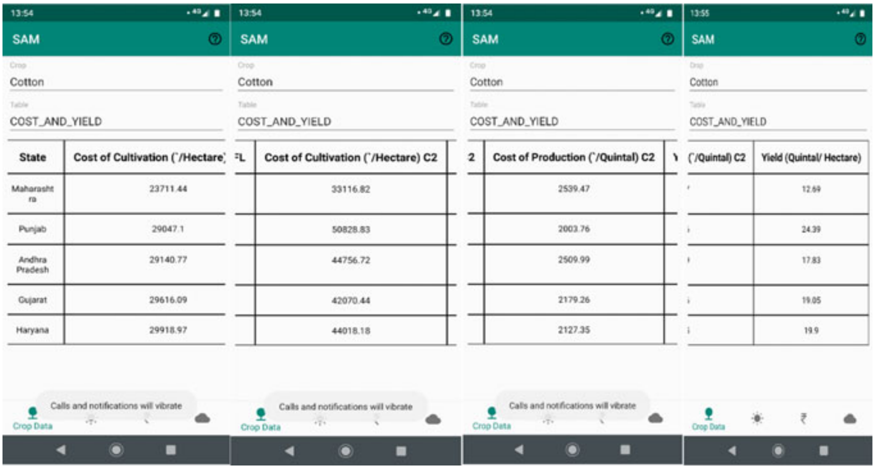
Weather in Bangalore, IN

29 °C

Broken clouds

19:54 May Wrong data?

Wind	Gentle Breeze, 4.1 m/s, West (270
Cloud ness	Broken clouds
Pressure	1011 hpa
Humidity	74 %



Crop
Cotton
Table
COST_AND_YIELD

State	Cost of Cultivation (´/Hectare)
Maharashtra	23711.44
Punjab	29047.1
Andhra Pradesh	29140.77
Gujarat	29616.09
Haryana	29918.97

Cost of Cultivation (´/Hectare) C2
33116.82
50828.83
44756.72
42070.44
44018.18

Cost of Production (´/Quintal) C2
2539.47
2003.76
2509.99
2179.26
2127.35

Yield (Quintal/ Hectare)
12.69
24.39
17.83
19.05
19.9

Fig. 18 Application developed exhibiting different cost parameters of cotton plant

5 Conclusion

The business model for crop management keeps in account for all the necessary conditions for providing a healthy agricultural environment. Starting from reading and understanding the environmental conditions of the fields through different sensors, it also acts on the health monitoring of the crops by checking any kind of infectious attacks on the crops. For experimental purpose, there were three types of cotton plant diseases that are taken into account. The main processing part is done by image processing and machine learning using SVM for classification techniques to get greater and better accuracy. The identification of the leaf disease is done by *k* clustering SVM process. This process of disease identification of crop in the field certainly adds value to the health monitoring system in agriculture. This identification of the disease can lead to applying effective pest control techniques and find the best pesticides according to the disease as well as the environmental factors. This can also be achieved by different algorithms of segmentation and classification. This application helps to understand the cultivation background environmental condition at the first stage. Then, the health of the crop is monitored by finding that if the crop is infected by any disease or not. Finally, the cost effectiveness and budget management also are proposed in the application. We can definitely say that this application is an endtoend business agricultural model that helps the farmers sitting far away from urbanization but availing maximum benefits from their crops using this application.

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Rice and Potato Yield Prediction Using Artificial Intelligence Techniques

Chiranjit Singha and Kishore C. Swain

Abstract Crop yield prediction during the growing season is important for crop income, insurance projections and even ensuring food security. Yet, modeling crop yield is challenging because of the complexity of the relationships between crop growth and the interrelated predictor variables. This research work employed artificial intelligence (AI) technique for rice and potato crop yield prediction model in the region of Tarakeswar block, Hooghly District, West Bengal, for rice and potato. The major variables used were climatic factors, static soil parameters, available soil nutrient, agricultural practice parameters, farm mechanization, terrain distribution and socioeconomic condition. The analyzed datasets covered 2017 to 2018 seasons and were split into two parts with seventy percent data used for model training and the remaining thirty percent for validation. The mean rice and potato yield obtained from the seventy-farm plot location was about 4.68 t/ha and 18.67 t/ha, whereas the artificial neural networks (ANN) model estimated with 97% accuracy and R^2 value of both the crop is 0.93 and 0.94 with an RMSE of 0.29 t/ha and 1.34 t/ha, respectively. Deep neural networks (DNN) outperformed among the three model, where only support vector machine (SVM) had a sound performance for the training data but low for the validation dataset due to overfitting problem within RMSE and R^2 value. The optimized DNN model produced the highest prediction accuracy 98% for rice and potato crop (RMSE = 0.20 ton/ha and 0.95 t/ha; R^2 = 0.98 and 0.97, respectively), which indicates good correlation between the field-measured crop yield and estimated yield. These adopted methodology for prediction crop yield to provide recommendation to the farmers, decision makers and stakeholders can make farming more efficient and profitable.

Keywords Artificial intelligence · Crop yield · ANN · SVM · DNN

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1 Introduction

Agriculture is backbone of the many developing countries of their socioeconomic development and plays important role in the food management and food security [1]. Climate change, soil variability, water use efficiency, precipitation, humidity, topography, crop practice, weeds, pests and biotic stress, etc., are criteria for monitoring crop yield [2]. Crop yield forecast in precision agriculture study is well thought-out of highly significance for optimization of profit and maximization of crop production. Once the yield is location-specifically projected, the farm inputs such as irrigation, pesticide, mechanization and fertilizers supply could be applied variably according to the accepted soil status and crop requirements. Consequently, it is essential to have tools that facilitate to supervise crop growth and estimation crop yield. Ensuring the management of food demand requires proper monitoring, forecasting and estimating agricultural production for the land parcel [3]. Site-specific crop management (SSCM) dealing with precision agriculture (PA) approach that is measuring, observing and responding to inter- and intra-field spatial variability in soils and crops. Precision agriculture study requires more intensive data collection and information, processing in real time and space to take better crop production decisions of farm inputs, maintaining environmental quality [4]. Whipker and Akridge [5] include growth in demand for both technological advances and information supervision services such as, global positioning system (GPS) auto steering guidance (e.g., Real-Time Kinetic technology), fertilizer, variable rate irrigation and robotics, sprayer controllers and real-time decision making based on sensor networks and remote sensing. A reliable and accurate forecasting model for crop yields is of crucial importance for efficient decision making process in the agricultural sector. Here, widely adopted machine learning algorithms in crop yield prediction such as decision trees RF classification [6], support vector machines (SVMs) [7], naïve Bayes [8], *k* means clustering [9], supervised Kohonen networks (SKNs) [10], eXtreme gradient boosting (XGBoost) [11], light gradient boosting machine (LightGBM) [12], artificial neural networks (ANNs) [13], genetic algorithms (GAs) [14] and ensemble deep neural networks [15] have been used successfully on remotely sensed information in cultivation with high precision. Crop yield modeling is challenging because of the difficulty of the interaction between crop growth and inter- or intra-predictor variables. ANN applied for determining target corn yields using soil properties [16, 17]. According to Noack et al. [18], ANN model is a special network structure with self-adaptive and self-map organizations which contribute to better crop yield estimation as compared to other traditional linear and nonlinear approaches.

The objective of this research work was to deploy three artificial intelligence techniques, SVM, DNN and ANN, as an ordered and monitoring instrument to develop yield prediction model for rice and potato crop in Tarakeswar block, Hooghly, West Bengal, India.

2 Materials and Methods

2.1 Support Vector Machines

Support vector machine (SVM) is a statistical non-parametric, supervised learning approach to classify heterogeneous data that can also be used for regression. SVM is basically designed for binary classification with higher accuracy but can be extended for classification of multiple classes using pair-wise coupling techniques [19]. Main target of the SVM learner has the optimal separation hyperplane (OSH), which is a judgment periphery between classes that reduces classification error in training by having the upper limit margin and afterward generalize to invisible data by kernel functions [20]. According to Vapnik [21], SVM characteristics with nonlinear kernel method is used for model fitting and control the hyperplanes individually grouping sample.

2.2 Artificial Neural Network (ANN)

ANN model applicable between input and output dataset where the data set consists of a linear and highly nonlinear relationship. ANN architecture work out multi-faceted problems with one input layer, one output layer and zero or more hidden layer(s). The ANN model has been used for different crop yield prediction such as, rice [22], wheat [16], potato [23], bitter melon [24], corn and soybean [25] and maize [26]. The popularity of SVM is due to its several promising characteristics, such as the kernel trick and structural risk minimization principle [27]. A robust ANN model relies on the appropriate collection of inputs and of representative training and testing datasets. One hidden layer neural network structure to predict rice and potato yield using input variable on climate, soil and farm practice management [28]. The simulation of the neural network process learning two phases: (I) training the network with known datasets and (II) testing the trained network for model generalization with the validation purpose. The study set of the Levenberg–Marquardt algorithm for chosen to train the selected multilayer perceptron (MLP) whose computations and analyzes inbuilt function into the MATLAB *nn* toolbox. A single layer of output neuron and a single hidden neuron consists of MLPs structure. The MLP function Y essential adjusted across the subsequent linear grouping of multivariate calculation [29] (Eq. 1).

$$Y(x,\omega,\beta) = G_2\left(\sum\nolimits_j \left[\omega_j G_1\left(\sum\nolimits_{ij} \omega_{ij}x_i + \beta_j\right) + \beta\right]\right) \tag{1}$$

where x indicates ith-dimensional involvement trajectory, j represents number of hidden neurons, ω and β are neural weights and biases. The sigmoid tangent activation function G_1 and the linear activation function G_2 [30], are computed as follows (Eq. 2)

$$\begin{aligned} G_1(\xi) &= \frac{2}{1 + \exp(-2\xi)} - 1 \\ G_2(\xi) &= \xi \end{aligned} \tag{2}$$

where ξ represents weighted sum of evidence from the previous layer of neurons.

The Levenberg–Marquardt backpropagation optimization algorithm [31] coupled with Bayesian regulation used to train MLPs modifies the usual cost function F_e (the sum of squared errors) by considering an additional term, namely the sum of squared neural weights F_ω: (Eq. 3).

$$F = \alpha F_e + \gamma F_\omega \tag{3}$$

where α and γ are objective function parameters automatically set at their optimum values by the Bayesian regularization proposed by MacKay [32]. Bayesian regulation reduces variance errors because the minimization constrains the weights to small values.

Artificial neural network (ANN) structure was preset up to predict rice and potato yield using inputs twenty-one criteria with 10 number of hidden neurons. The target values consider as yield values for the ANN models in each crop. Error backpropagation (EBP) algorithm training by randomizing the network weights and training set order in the ANNs [33]. Under the EBP algorithm, models are instantiated. All the data were normalized to scale of 0–1 for use in the ANN model. The ANN model was trained and tested with measured yield data (obtained from farmers) from 2017 and 2018 (sites were divided into 70% of training versus 30% of testing sites). In a preliminary analysis, the choice of the variables appeared more significant than the number of neurons in the hidden layer. The most adequate combination of variables was thus searched using three hidden neurons, and the optimum number of neurons in the hidden layer was determined afterwards. All variables were tested individually. The one that yielded the highest model performance was selected.

2.3 Deep Neural Network

Generic AI techniques infrequently have difficulties with overfitting that can be resolved through a demanding optimization method in a deep network architecture which overcome the problem of local minima. Backpropagation algorithm improves accuracy through backward and forward optimization. In these courses, suitable activation functions, such as rectified linear units (ReLU) and sigmoid managed the delinquent of vanishing gradients of loss functions, through the backpropagation development. The parameter optimization model used for tuning of our DNN model. The 'activation' function $a()$ is liable for the network scheme's nonlinearity, and designs the real line to nearly subclass of it. We use the linear activation function (ReLU) found to substantially improve performance over earlier alternatives [34], (Eq. 4):

$$f(x) = \begin{cases} 0 & \text{for } x < 0 \\ x & \text{for } x \geq 0 \end{cases} \tag{4}$$

which is a variant of the ReLU: $a()$ $()x$ x = max 0.

Methods that we used for training neural networks and implemented in the TensorFlow Keras sklearn packages in Jupyter notebook. 70% data is spilt into training and testing data for model validation with 'adam optimization algorithm' MSE loss function [35]. This loss function is reduced through gradient descent backpropagation algorithm with an iterative method [36] (Eq. 5).

$$R = (\gamma - \hat{y})^2 + \lambda \theta^T \theta \tag{5}$$

where $\theta \equiv \text{vec}\left(\beta, \Gamma^1, \Gamma^2, \ldots, \Gamma^L\right)$ and λ denoted tunable hyperparameter. Greater values of λ lead character unbending fits, while values close to zero will typically reason overfitting in higher networks.

2.4 Performance of Model Evaluation

After calibration and validation of the SVM, DNN and ANN model, variables of each farm plot was laid into the model for crop yield prediction per unit area. The performance of the model is evaluated by calculating the root mean square error (RMSE), which gives an estimate of the standard deviation of the residuals (prediction errors), as follows (Eq. 6)

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(Z - (Z_i^*)^2\right)}{n}} \tag{6}$$

where Z_i = observed value of the ith observation; Z_i^* is the predicted value of the ith observation; and n = number of points collected. The RMSE tends to place more emphasis on larger errors and, therefore, gives a more conservative measure than the mean absolute error [37].

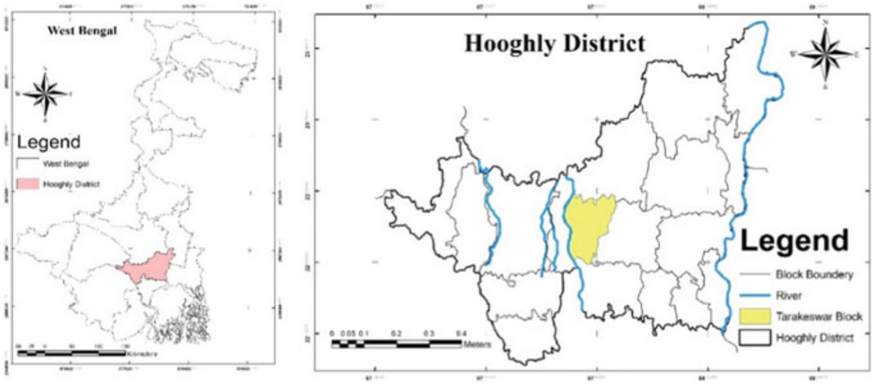

Fig. 1 Study area map

2.5 Study Region

The study region covers with a total area of 119.93 km^2 is located between 22.89° N latitude and 88.02° E longitude and mean elevation of the area is approximately 40 m above sea level (Fig. 1). In the 2011 census, total population of the area was 179,148. The study area is located on old alluvial agro climatic zone. Major growing field crop in *kharif* season is rice and *rabi* season is potato. The cropping intensity of the study area is very high and total land use for crop cultivation 63.85%. The total irrigated area was 11,828 ha [38]. The region characterized by moist subhumid type climate with higher growing period of 180–210 days as result of relatively high rainfall and relative humidity, low PET, warm temperature and low relief. The average annual rainfall of 1350–2500 mm and annual temperature ranging from 10 to 41 °C [39].

2.6 Data Acquisition

In the study area, rice and potato yields are affected by many factors, such as climatic factor, water use efficiency, biotic stress, soil conditions, farm mechanization, terrain distribution and socioeconomic condition. These factors should be measured using appropriate index. A reconnaissance survey of the study area was made in advance of the farming zone for total twenty-one factor such as, soil pH, electrical conductivity (EC), soil organic carbon (SOC), soil texture (ST), available nitrogen (N), available phosphorus (P), available potassium (K), available zinc (Zn), seed rate, mechanization level, irrigation, drainage, pesticide rate, pest affected, source of irrigation, FYM uses, farmer status, NDVI for rice and SAVI or potato, precipitation, temperature, slope and elevation. Various open-source spatial data and secondary information were collected for the proposed crop yield prediction analysis. The elevation and slope degree map of the study area has been produced from the digital elevation model (DEM)—spatial resolution of 30 × 30 m extracted from SRTMGL1_003 in Google Earth Engine code editor. Climatic data TRMM monthly precipitation and temperature data MOD11A1in degree in acquired by the GEE API.

2.7 Image Processing

In our study, GEE utilized the spatial resolution of 10 m Sentinel-2B Multi-Spectral Instrument, Level-1C, Descending direction and orbit number 33, images with filter metadata for rice 2017-10-01 to 2017-10-30 and for potato 2018-01-15 to 2018-02-15, less than 5% cloud cover images using for rice growing season NDVI and potato season SAVI analysis in the study area [40, 41]; (Eqs. 7 and 8).

$$\mathrm{NDVI} = (\mathrm{NIR}{-}\mathrm{RED})/(\mathrm{NIR} + \mathrm{RED}) \tag{7}$$

$$\mathrm{SAVI} = 1.5\,(\mathrm{NIR} - \mathrm{RED})/(\mathrm{NIR} + \mathrm{RED} + 0.5) \tag{8}$$

where NIR = near infrared band (band 8), R = red band (band 4).

Vegetation indices (Vis) were verified to be one of the maximum effective indicators of crop growing conditions in the study area. NDVI and SAVI have been widely used in crop monitoring and crop yield applications [42]. We trained the classifiers based on a subset of the farmers' declarations. Ground truth data acquired via field inspection were used to develop the models. All parameters are well-defined for reclassifying raster datasets then the extracted value for further analysis using ArcGIS 10.5 software.

2.8 Yield Data

Average crop yield information and non-spatial attributive data of each and every farm plot was derived from field survey during post-harvest periods using GPS ground truth point coordinate order. For yield map generation, kriging interpolation was selected because it is a non-biased method for predicting the values of criteria between the data points assessed using ArcGIS spatial analyst tools with natural breaks jeans method.

2.9 Soil Nutrient Analysis

Between the years of 2017 and 2018, a soil survey was conducted in the study area, resulting in a detailed within each agricultural farm site; seventy soil samples were collected at five evenly distributed points and then mixed thoroughly to obtain a representative sample according to procedures laid out in the Soil Survey Manuals [43]. Soil samples were collected at depths of 0–30 cm from the study area with the special soil auger system. All sampling positions were located by GPS measurements (GPS III Plus, Garmin, Olathe, Kansas, USA). All seventy soil samples were air-dried, crushed, and then passed through a 2.0 mm sieve and the resulting fine earth (<2.0 mm) was retained for further analysis. Measured soil chemical properties included pH (in water, soil/solution ratio of 1:2.5); available nitrogen, determined using Kjehldahl method [44]; available phosphorus (P), determined using the Olsen method [45]; organic carbon (SOC), determined by Walkely and Black method [46]; available zinc, determined by DTPA method with estimation by Perkin Elmer Atomic Absorption Spectrophotometer (AAS) in ppm. Percentages of sand (>50 μm), silt (2–50 μm) and clay (<2 μm) were determined and used to identify the textural class from the textural USDA triangle using hydrometer [47].

3 Results and Discussion

3.1 Accuracy of Yield Prediction

3.1.1 SVM

SVM-based classification models were used for the yield prediction of rice and potato crop. Experiments have been conducted involving one-against-one multi-classification method, *k*-fold cross validation and polynomial kernel function for SVM training with the result 95% accuracy level. The model used the residuals values to check model performance and reviewed after training a model, based on the difference between the predicted and true responses in terms of the trend of regression models. After training a regression model, check the predicted response versus record number. Then SVM cross validate results verified the prediction errors for investigating the predicted and true responses without using the corresponding observation. The SVM model produced the least prediction accuracy for rice and potato (RMSE = 1.09 ton/ha and 5.59 t/ha) crop, respectively (Tables 1, 2 and 3).

Table 1 Area statistics for rice yield measured and predicted

Rice t/ha	Measured		Predicted	
	Area in ha	Area in %	Area in ha	Area in %
<3	17.28	6.15	23.63	8.40
3–4	42.45	15.10	80.43	28.61
4–5	177.01	62.96	97.62	34.72
>5	44.38	15.79	79.45	28.26
Total	281.12	100.00	281.12	100.00

Table 2 Area statistics for potato yield measured and predicted

Potato t/ha	Measured		Predicted	
	Area in ha	Area in %	Area in ha	Area in %
<10	5.38	1.91	51.06	18.16
10–15	63.17	22.47	62.12	22.10
15–20	136.99	48.73	109.06	38.80
>25	75.58	26.88	58.87	20.94
Total	281.12	100.00	281.12	100.00

Table 3 Yield prediction performances of SVM, ANN and DNN model

Model	Accuracy %		RMSE		R^2		Mean predicted yield t/ha	
	Rice	Potato	Rice	Potato	Rice	Potato	Rice	Potato
SVM	95	95	1.09	5.59	0.89	0.90	4.01	18.15
ANN	97	97	0.29	1.342	0.93	0.94	4.74	18.28
DNN	98	98	0.20	0.95	0.98	0.97	4.98	26.8

Note SVM—support vector machine; ANN—artificial neural network; DNN—deep neural network; RMSE—root mean square error

3.1.2 ANN

The supervised ANN was trained with the twenty-one input predictor variables and output yield classes with ten hidden neurons multi-perceptions layer. The best results were structured along with optimum parameters of the artificial neural network modeling for estimating crop yield. In order to test the ability of the neural networks, cross validation was used by leaving 30% of all samples randomly so that after training on the 70% samples, the prediction was verified on this set (Fig. 2, Table 3). In the other hand, ANN model performance of the training, testing and validation performance showing in regression plot gave better agreement than other models (Fig. 2) with 97% accuracy, and R^2 value of both the crop are 0.93 and 0.94, respectively. The best overall results for the prediction of rice and potato yield in cross validation and independent validation were obtained from the ANN

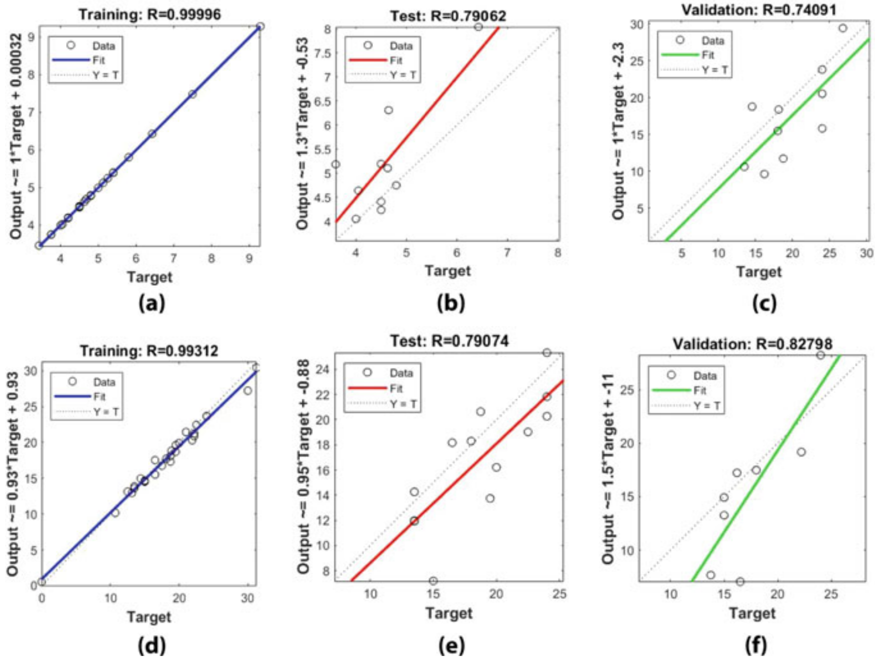

Fig. 2 ANN model performance in training testing and validation sample **a**, **b**, **c** rice; **d**, **e**, **f** potato

networks for the prediction of the low-yield category. The accuracy of prediction reached 97% for both cross validation and independent validation (Table 3). Yield maps the distinction finding between measured and predicted yield is revealed (Fig. 3), where the predicted yield is classified into four groups for rice, as high yield (>5 t/ha), moderate yield (4–5 t/ha), marginal yield (3–4 t/ha) and low yield (<3 t/ha); same way for potato yield classes as high yield (>20 t/ha), moderate yield (15–20 t/ha), marginal yield (10–15 t/ha) and low yield (<10 t/ha) built on four equal class of the yield datasets (Tables 1 and 2). High spatial similarity between the measured and the predicted yield for both the crops (Figs. 3 and 4).

Matsumura et al. [48], reported a close relationship between the predicted yield and the measured yield for maize cultivation in Jilin, China, where the fertilizer and climate variable as a good predictor. Papageorgiou et al. [49] presented that yield classification of field into four different yield categories based on combination of superior predictor variable such as soil, climate and vegetation indices, terrain distribution, local practice and socioeconomic. Uno et al. [50] have utilized remote sensing vegetation indices as crop parameters for predict yield maps similar to our study, where vegetation indices are used, NDVI for rice and SAVI for potato crop as a predictor for crop yield estimation. Area statistics were derived for rice and potato cultivation in *Tarakeswar* block, Hooghly District for different crops yields,

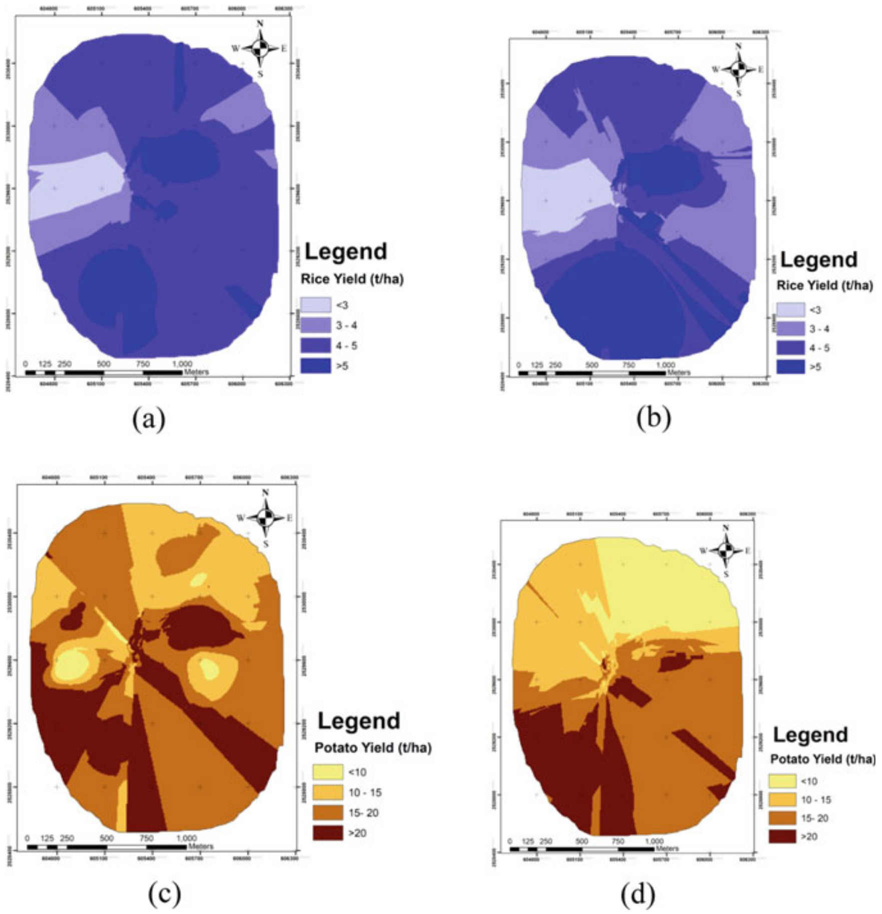

Fig. 3 Crop yield maps estimated by ANN model for rice and potato **a** rice measured **b** rice predicted **c** potato measured **d** potato predicted

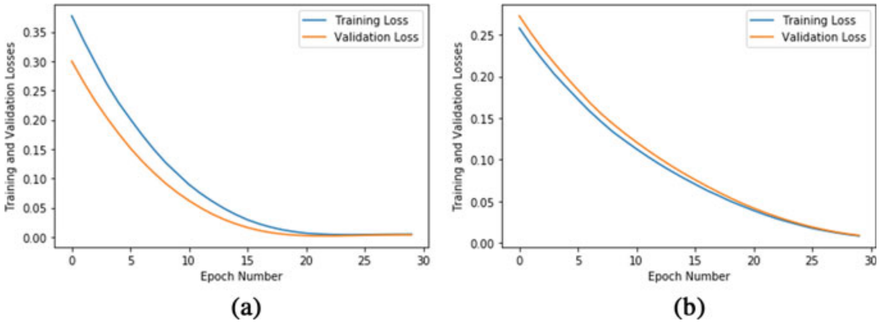

Fig. 4 Model loss progression during training/validation for **a** rice and **b** potato crop

the total area under rice and potato cultivation was also estimated as 281.12 ha (Fig. 3; Tables 1 and 2).

3.1.3 DNN

Srivastava et al. [51] reported that the DNN model output result accuracy improved for crop yield prediction depending upon by fine tuning of hyperparameters optimization level, activation function, layer structure, loss function, intensive optimizer and drop-out ratio. The optimized DNN model produced the highest prediction accuracy for rice and potato (RMSE = 0.20 ton/ha and 0.95 t/ha) with best 98% accuracy for both the crops, respectively (Table 3). Computation power of DNN model is very high due to optimizing the model in local minima within the loss surface. One set of mini batches containing the entire dataset is called ‘epoch.’ Our research work has 30 epochs and batch size 25 to model progression during training validation process for potato and rice crop yield prediction 26.8 and 4.98 t/ha in the study area with the good predictor for yield (Fig. 4).

4 Discussion

These adopted methodology for prediction of rice and potato yield help to provide recommendation to the farmers, decision makers and stakeholders, to take decisions that can make their farming more efficient and profitable [52]. The mean rice and potato yield obtained from the farm plot location was about 4.68 and 18.67 t/ha, whereas the ANN model estimated average rice and potato was 4.74 and 18.28 t/ha. The R^2 value was found to be 0.933 (93.3%) and 0.941 (94.1%) with an RMSE of 0.29 and 1.34 t/ha and, which indicates that there is good correlation between the field-measured crop yield and estimated yield. Deep neural networks (DNN) outperformed among the three model; where only support vector machine (SVM) had a sound performance for the training data but low for the validation dataset due to overfitting problem within RMSE and R^2 value. DNN model was very well predicting crop yield with low RMSE for the validation dataset nearly for the rice crop (4.98 t/ha) and potato crop (26.98 t/ha) of their respective average yield values. For validation, estimated crop yield values obtained from the model were compared with the field yield value. Training and validation of the model derived the best combination of parameters for estimation of rice and potato crop yield. The scatter plot of the ANN for the predicted versus actual rice and potato yields of training, testing and validation showed better agreement in models’ estimation. Deliberating this content by field examination with the local farmer, and it was exposed that although the low yield zones was acidic soil, low organic carbon, high electrical conductivity, low mechanization level and pest affected issue was accountable for the low yield class in the affected zones.

5 Conclusion

A powerful AI technique, integration of SVM, ANN and DNN, provides an effective tool to crop yield prediction and assesses the contribution of each aspect to the target crop yield. Non-influencing factors are adjusted by the weights of the ANN. Two other AI classifiers, SVM and DNN, were shown to be powerful for the classification and crop yield prediction; however, the remarkable results of AI on the agricultural sector enhance in precession agriculture methodologies. Hence, this tool helps the farmers, decision makers and stakeholders take decisions that can make their farming more efficient and profitable. This research tries to establish an intelligent information and crop yield prediction accuracy analysis in sustainable agriculture development. Future studies AI may concentrate on the calibration and trying of this model in macro-level region of organizing data from systematic ground observations, ground sensors, climate, UAV and RADAR remote sensing. Generalized prediction models for diverse crops utilizing parameters development of operational, real-time calculate optimum N rate prediction, crop water stress, like leaf area index, potential evapotranspiration, chlorophyll content, etc., can be developed on same lines for yield forecast.

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Socioeconomic Impact of IoT on Agriculture: A Comparative Study on India and China

Ramnath Reghunadhan and Ansel Elias Stanley

Abstract Internet of Things (IoT) has emerged as the prominent feature of the technological revolution across the world. It has been particularly linked with development, growth and other socioeconomic standards of major national economies, including India and China. Both India and China evolved from having a huge starving population to food surplus countries having socioeconomic implications. This is centred around economic and technological reforms in both countries. IoT is the lynchpin for the future of food security worldwide and has a huge role in India and China. The chapter's objective entails the emergence of IoT, and its widespread use has but provided for the evolution of state policies and strategies in India and China. The study undertakes comparative analysis, further utilising mixed-method research, which utilises both quantitative and qualitative approaches. Additionally, the chapter also deals with the huge impact of IoT on the development, growth and other socioeconomic parameters of farming communities within India and China.

Keywords India · China · IoT · Agriculture · Economy · Food security

1 Introduction

Internet of Things (IoT) is purported to be the next evolution of the internet and intends to revolutionise the "interaction of the physical world with the virtual world". IoT is generally associated with "smart" devices, from home appliances that can be controlled, ranging from smartphones to autonomous cars and smart health devices. IoT technology is at the forefront of the newly hailed digital and industrial revolution happening today. It aims at a scenario wherein every physical object is

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digitally connected and interacts with each other. Furthermore, IoT as an industry is estimated to grow exponentially in the coming years, as "more devices and people are being connected to the internet", one which is characterised as the Internet of People (IoP) [4: pp. 2787–2805, 11, 14: pp. 1–27].

The rise and fall of human civilisations have most often been overwhelmingly dependent on one major factor, i.e. the availability and access to food. Socioeconomic issues and problems that arise due to lack of availability and access to food have most often led to the downfall of civilisations and nation-states. India and China are huge examples in this regard. Food security plays a huge role in determining stability and prosperity worldwide, both vertically and horizontally. The modern-day idea of food security came in the aftermath of the decline in the availability of food because of the food crisis across the world in 1972 [10: pp. 15–37, 72: pp. 121–135]. This led to the first "*World Food Conference*" that put in place a "*Universal Declaration on the Eradication of Hunger and Malnutrition*" on November 16, 1974. The "*United Nations' Committee on World Food Security*" defines food security as the "means that all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meet their food preferences and dietary needs for an active and healthy life" [39].

Food security has been a prominent issue of discussion since then, particularly in the twenty-first century, where climate change and food security have been prioritised due to the complexities and challenges it has created so far. In 2019, around 9% of the world population "were undernourished", whilst nearly one-fourth of the world population "experienced hunger or did not have regular access to nutritious and sufficient food". About one-fifth of the "number of children under five years are stunted" due to a lack of availability and/or "access to food" [21: p. viii]. The loss of income and disruption of supply lines worldwide have also contributed to the increasing threat to food security, which has been already disrupted by geopolitical conflicts "and climate change" [31]. Additionally, the explosion of the world population has exponentially increased the demand for food into the future. Figure 1 shows the global percentage of food insecurity in various regions across the world.

Food security is a major component of the "Sustainable Development Goals (SDGs)" adopted by the United Nations General Assembly to achieve it in 2030. The SDG 2 aims to "*End hunger, achieve food security and improved nutrition and promote sustainable agriculture*" [81: p. 2]. This includes doubling the "agricultural productivity, ensuring sustainable food production systems", increasing resilience of "agricultural practices", increasing genetic diversity in farming, increasing the proportion of agricultural lands, sustainable agriculture, mitigating problems related to hunger, access to food (especially to vulnerable groups), increasing investment, improving the functioning of food commodity markets (including access to market information) and prevent the prevalence of health-related problems due to food insecurity [81, pp. 2–3]. The "*Preparatory Committee of the World Food Conference*" identified three important foci in sustaining food security across the world: "(a) to increase food production especially in the developing countries;

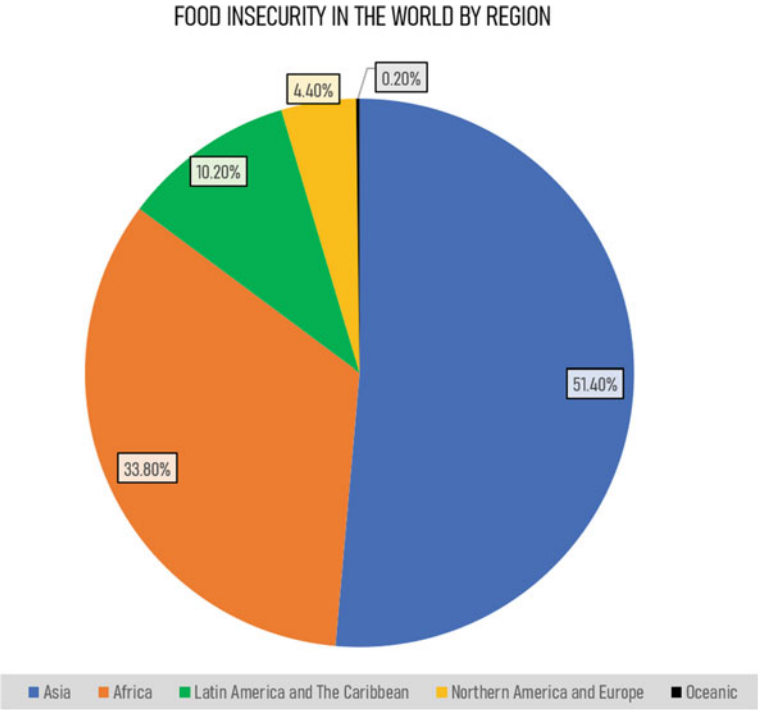

Fig. 1 Food insecurity in the world by region in 2019. *Source* Compiled from [21: p. 23]

(b) to improve consumption and distribution of food; and (c) to build a system of food security" [82: p. 63].

An important aspect of agriculture and related technologies is the trend that focuses on patent distribution. The technological areas in the field of agriculture are prominently dominated by companies like Monsanto Technology LLC (USA), Dow Agrosciences LLC (USA), Bayer Crop Science AG (USA), Syngenta Participations AG (Switzerland), BASF SE (Germany), Du Pont (USA), Bayer IP GMBH (Germany), China Agricultural University (China), Caterpillar Inc (USA) and Deere & Co (USA) (Fig. 2). Thus, the US-based multinational companies dominate the field of agriculture-related technologies and patents, amounting to six out of the top ten assignees of patents from 2000 to 2019. Meanwhile, two Germany-based companies, and one from Switzerland and China complete the top ten list. Figure 2 details the list of top ten assignees of patents in agriculture from 2000 to 2019.

The West, especially multinational companies from the US and Europe, dominates the field of patents in agriculture, whilst "countries like China and India" are only "catching up" with the scenario. As part of this study, the case studies of India and China are taken, focusing on the impact and implications of food security. Further, the development of the Internet of Things (IoT) in both countries is

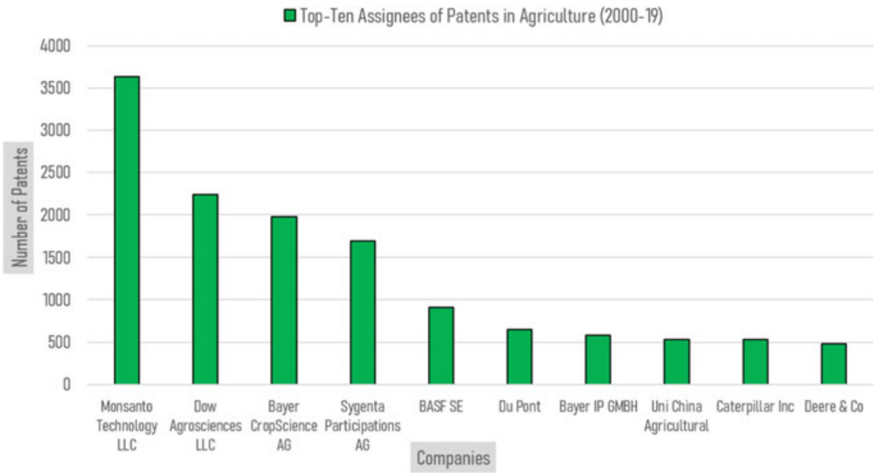

Fig. 2 Top ten assignees of patents in agriculture in the twenty-first century (2000–2019). *Source* Compiled by Authors from Derwent Innovation Database

analysed, followed by a study on the levels of integration of IoT in the agricultural sector of both countries.

2 Food Security in India

Food security in India has been a part of the colonial experience, and an effect that saw it reeling much. The British policies in the agriculture sector aimed to extract the maximum possible revenue from the farmers, to be sent back to Britain. These unjust policies increased pressure on disadvantaged farmers and reduced productivity leading to food shortages across the country [57: pp. 595–611]. The Bengal famine of the ‘40s saw millions of people die due to starvation, and the last recorded issue of pre-independence food (in) security in the country [33: pp. 445–463]. Post-independent India gradually changed from a food aid country with imports from the United States [28: pp. 73–84] to a food surplus country by introducing the *Green Revolution* in the 1960s. This stemmed from the realisation that the over-dependence on a foreign country and threatened India's national and food security [1: pp. 1–5].

The *Green Revolution* saw the production of “hybrid seeds, pesticides, fertilizers and irrigation systems—[and] had advanced to the point that new technologies” were developed [26: pp. 1176–1209, 91]. The programme dramatically boosted the production of staple foods like wheat, rice and other cereal crops [52: pp. 185–213], leading to the self-sufficiency of food grains in the country. Thus, India transformed “from a net importer to a net exporter of food grains”, creating a safety net for countries across the world, particularly in the Global South [34: pp. 2139–2148, 53:

pp. 7–14]. The aftermath of the Green Revolution saw the emergence and institutionalisation of the *White Revolution*. Under it was *Operation Flood*, which focused on increasing milk production, which improved the conditions of the farmers and export by India [35: pp. 37–45]. This improved self-sufficiency, supply to urban areas, and a decline in poverty thereby reducing the government's burden of social welfare schemes and the trend of rural–urban migration. It was linked to self-sufficiency and economic well-being amongst the farmers and rural population. A country with "more than half of its population depending on agriculture" for income and sustenance, any improvement, small or big, has a huge influence and impact on the standard of living, economic security and food security of the country [6: pp. 71–79, 49, 90]. Gulati [36] has analysed how there were national and international challenges for India to achieve the goal of nutrition and food security. This was particularly related to "market access, domestic support and export competition" and the liberalisation of agricultural markets until the beginning of the twenty-first century [36: pp. 754–760].

In India, there has been various schemes and initiatives[1] focusing on food security issues and is still relevant in the strategies and policies in the country, with few alterations in it. In India, the food distribution system (including PDS, TPDS etc.) is the foundation of the food security framework, which comes under the ambit of both the Centre and the State Governments. It subsidises the procurement and distribution of food grains to the population. The system was initially started to manage food scarcity in the country but later evolved into a food security system. The main objectives include food grain procurement to economically support farmers against market price volatility, efficient distribution of food grains in a cost-effective manner, storage and maintenance of food stock and the mitigation of any (potential) price stabilisation and food security related issues [7: pp. 37–45].

India's public distribution system (PDS) is often criticised for its leakages, inefficient supply chain management and disparity in identifying intended beneficiaries. The leakages refer to the proportion of food grains that fail to reach intended beneficiaries and end-users. It is estimated that leakages in the food distribution system are more than 45% [24]. There are distortions in regard to regional disparity in the food distribution system, mainly owing to problems related to corruption, hoarding as well as black market sales, (lack of) or lower quality and quantity of (public) infrastructure, issues of storage, warehousing and delivery [38, 42, 77].

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[1] Some of the significant initiatives include "*Public Distribution System* (PDS), *Targeted Public Distribution System* (TPDS), *Revamped Public Distribution System* (RPDS), *Antyodaya Anna Yojana*, *Mid-Day Meal Programme*, *Annapurna Scheme*, *National Food Security Act*, *National Food Security Mission*, *Mahatma Gandhi National Rural Employment Guarantee Act* (MGNREGA), *Rashtriya Krishi Vikas Yojana* (RKVY), the *Integrated Schemes on Oilseeds, Pulses, Palm oil and Maise* (ISOPOM), *Pradhan Mantri Fasal Bima Yojana* (PMFBY), *Direct cash transfer*, and *Integrated Child Development Services* (ICDS)". Some of the food subsidisation programmes run by State governments are "*Amma Unavagam* (Tamil Naidu), *Ahar Yojana* (Orissa), *Indira Canteens* (Karnataka), *Annapurna Rasoi Yojana* (Rajasthan), *Anna Canteens* (Andhra Pradesh), *Annapurna canteen* (Telangana), *Mukhyamantri Dal Bhat Yojana* (Jharkhand), *Deendayal Kitchens* (Madhya Pradesh)" (Compiled from various sources).

Often, there are issues concerning coordination between various central, state agencies and private actors. This includes the "Central Warehousing Corporation, State Warehousing Corporations, State Agencies" that will manage more than 750 lakh metric tonnes (MTs) in 2020 [25].

3 Food Security in China

Food security in China is a multifaceted issue facing the country. It is not only the ability to feed its population but also a key for achieving what president Xi calls a "moderately prosperous society" [30: pp. 86–95, 74]. "Premier Li Keqiang chaired a State Council executive meeting" that entailed further promotion of "stable grain production" and the need to "step up its ability to ensure food security". It was argued that major focus is required in the lines of central budgetary investment, procurement of grains, scaling up of technical services, optimisation of land-use rights at the provincial level, enhancement of reserves and market regulation, increase in "primary responsibility" of subnational-level agencies and authorities, strengthening farmland management, harvesting, and sowing, preparedness for flood and drought [85]. The PRC "expects to rejuvenate as well as upgrade" the agriculture and "manufacturing sector in China, and through it help achieve the goal" of becoming the world factory [70]. China's food security strategy centres on the idea of "ensuring basic self-sufficiency of grain and absolute security of staple food" through "domestic grain production, guaranteed food production capacity, moderate imports and technological support" [74].

The Chinese agriculture system was more ordered towards small-scale farming and allied activities. The average inland cultivation was estimated to be around three mu (one-fifteenth of a hectare) per capita. The proportion of contribution by agriculture reached from 70 to 58.5%. The prioritisation of heavy industry in the lines of policy strategies of the USSR affected the growth in the agriculture sector, in turn affecting the standard of living of peasants and their productivity [46: pp. 1–26, 93]. The subservience of agriculture to industry became more superficial as Mao's Great Leap Forward swept China in 1958. The workforce was drawn out of agriculture to work in factories in the countryside. The "voluntary" participation of the farmers in the large collective units called "Communes" became mandatory during the movement, and "free markets in the rural side were shut down". Private plots were banned, and existing plots were absorbed into the communes. They were also given unrealistic quotas for grain production considering the state of the Chinese agriculture system that still used traditional methods and was devoid of any modern agriculture inputs at that period [18]. The decades of instability due to war before the CPC came into power resulted in an overall food shortage. Even though CPC could bring grain shortage under control by the 1950s, the demand for grain outpaced supply [48: pp. 1228–1250].

"At the end of the First FYP, the agricultural growth rate began to decline, even with the setting up of agricultural cooperatives". The increasing dependence on industries during the great leap forward (GLF) exacerbated this. Mao put forward the task of making China a powerful socialist state. The productive forces in China remained at a low level, and over 80% of the population belonged to collective economic units. Instead of setting production quotas for collectives, the State should have decentralised decision-making, though practically, this didn't happen in China. China began to carry out the policy of "readjustment, consolidation, filling-out and raising the standards" in the early '60s. The rate of accumulation was kept under 20% during 1961–63, whilst the country saw ups and downs in IIIrd and IVth FYP during 1966–75 [15].

In the mid-1960s and 1970s, an "agriculture first" policy was adopted to reform and increase agricultural output from the agriculture sector in China. The shift of industry to agriculture as the national priority saw the mobilisation of resources to bring advancement in agriculture. The commune system was restructured into a more flexible institution where all decisions concerning production and the distribution of income were decentralised [56: pp. 593–610]. In 1978, wages were increased, raising the purchasing prices of farm products in 1979. "An increasing dilemma in terms of collectivisation of ownership in agriculture is that farm work was still being done" manually. But in the next two decades, there was hardly any raise in wages or living standard of peasants, except in a few areas. This necessitated the need to modernise agriculture. This was done by harnessing big rivers, building 330 million mu of farmland and enhancing capabilities to deal with natural disasters [93].

The major problems related to the food security system in China have often created a disparity in prioritisation between agriculture and industry. The Chinese leadership has mostly prioritised reforms in the industrial sector, often leading to the marginalisation of the agriculture sector, and thus created "structural contradictions" with effective implementation of policies and strategies [87: pp. 2–17]. The per capita productivity is considerably lower than in advanced countries like the US. The disparity "between rural and urban areas in the matter of food security" is very glaring, though varying. The decrease in the working population in the rural areas because of rural–urban migration and the demand for higher wages is a major threat to the food supply. In rural areas, almost "150.8 million people are estimated to be malnourished in China", whilst an estimated 9.4% and 19.6% of the total children were stunted and had anaemia, respectively. The concentration of agricultural lands in few areas is prone to floods and drought. Issues of "climate change and its impact" are exacerbating the situation of food security in the country [22: pp. 301–310; 94: pp. 363–374]. Another issue is the problem related to environmental degradation of soil and water due to intensified agriculture methods using chemical fertilisers, mostly related to unsustainable agricultural practices [12: pp. 1–15, 95]. China has increasingly outsourced food production to countries in Africa, which increased food security, but increased external dependence as well. The geopolitics and engagements of China with international institutions like WTO have implications on food security like agricultural subsidies [69].

The CPC has always viewed food security as an integral part of its political legitimacy in China. The country has seen its fair share of political unrest due to food scarcity throughout its history, from the Shang dynasty to modern China [45: pp. 687–707]. The literature on CPC points out that Chinese peasants supported the communist movement as one of the key promises given to them by CPC was a sufficient grain supply for the population [76: pp. 24–57]. China is trying to assert itself to compete with other powers in the international arena. The issues and impact on food (in) security in China are also the question of national security [88]. China had scrimmages with its neighbours over the fishing rights in the South China Sea to cater for the demands of its growing population. The tensions between the neighbours have only steadily increased in recent years as China has strengthened its territorial claims for redrawing Exclusive Economic Zones (EEZ) in the South China Sea [27: pp. 98–120]. The disparity between the supply and demand of food value chains can be attributed to the complacency of the CPC in reforming the agriculture sector of China, whilst undergoing rapid economic growth. This prospect of food insecurity in the country has risen as one of the major concerns for China and the CPC in recent years.

4 Internet of Things (IoT): An Introduction

IoT is one of the most important emerging and evolving fields, along with other high-technologies like nanotechnology and biotechnology. One of the key advantages of IoT compared to other technologies is the ability to integrate existing legacy devices and technology into IoT. This decreases the cost and increases the accessibility of the technology. Connectivity is a key for the development of IoT. Recently, the number of options as well as users have increased, which increases its importance in the society. The high-speed internet remains a luxury for the majority of the population. Though a relatively new concept, it has an overreaching effect on our society, culture and environment. Newman [55] predicts that the IoT market is expected to grow to over 41 billion IoT devices, and over 2.4 trillion USD annually by 2027. The number of devices is expected to increase three-fold during 2027–30 [55].

It was during a presentation in 1999 at Procter and Gamble (P&G) that “consumer sensor expert and innovator” Kevin Ashton termed the phrase “Internet of Things” or IoT. Accordingly, IoT will transform computers to “sense things for themselves” [3: pp. 97–114, 60], and thus create interlinkages for interaction between the digital and physical world. The term gained more popularity as “a key component of the Fourth Industrial Revolution” or Industry 4.0, which aims to automate traditional manufacturing, and industrial processes without human intervention. Traditional manufacturing will be replaced by highly automated manufacturing where every aspect of it can be micromanaged in real-time for cost-effectiveness or in-time production with the touch of a button. The potential benefits of IoT are boundless as they are not only limited to manufacturing but also have proposed use cases in multiple sectors, including but not limited to agriculture, healthcare, supply chain management, smart cities and robotics [61: pp. 113–137, 62: pp. 1–34, 65, 66].

According to the European Network and Information Security Agency (ENISA),[2] IoT is an “ecosystem where interconnected devices and services collect, exchange and process data… to adapt dynamically to a context… [and] is [linked] … to cyber-physical systems… [enables]… Smart Infrastructures by enhancing their [quality-of-service] provisioning” [60]. There have been variant terminologies of this concept like the “Web of things”, developed by Traversat et al. [79] during their presentation at the “*36th Annual Hawaii International Conference on System Sciences*” [79, pp. 1–9]. IoT is considered to have its roots in networked radio frequency identification (RFID) and emerging sensing technologies at the Auto-ID Centre, Massachusetts Institute of Technology (MIT). David Brock and Sanjay Sarma of the centre conceived the idea of putting low-cost RFID tags to track all products in the supply chain through the internet. The projects focused on developing RFID through the Electronic Product Code (EPC) at MIT in 1998. In the next five years, “engineers from more than one hundred companies and faculty and students from five universities were collaborating to flesh out the system, build prototypes and conduct field trials”, and within a decade, about 2.5 billion EPC tags were manufactured and integrated across the world [64: pp. 35–52].

4.1 Development of IoT

IoT has been developed, as Qiu and Zhang [59] would point out, with “the successful deployment of instant information retrieval web servers” [59: pp. 2661–2666]. Meanwhile, *Scientific American* published an article in 2004 titled “The Internet of Things”, focused on “countless ‘smart home’ projects [that] have sought to find new applications for intelligent building” infrastructure [29: p. 76, 43: pp. 495–513]. The “Institute of Electrical and Electronics Engineers (IEEE)” defined IoT as:

> a self-configuring, adaptive, complex network that interconnects “things” to the Internet through the use of standard communication protocols. The interconnected things have physical or virtual representation in the digital world, sensing/actuation capability, a programmability feature and are uniquely identifiable. The representation contains information including the thing’s identity, status, location or any other business, social or privately relevant information. The things offer services, with or without human intervention, through the exploitation of unique identification, data capture and communication and actuation capability. The service is exploited through the use of intelligent interfaces and is made available anywhere, anytime, and for anything taking security into consideration [63].

IoT can be considered as a system of “embedded sensors or devices connected to the internet” that automatically “communicate with each other” to form a well-connected system of “smart infrastructure”. This provided for a technological

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[2] ENISA is the nodal agency for addressing issues related to network security and information security in the European Union (EU) countries. It coordinates between the EU and countries in other regions as well.

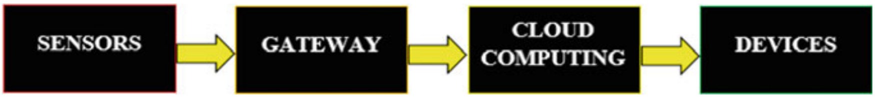

Fig. 3 Depiction of the basic concept of working of IoT devices. *Source* Compiled by Authors

upheaval, and the emergence of "smart sustainable cities", "context-aware computing", etc. IoT technology encompasses a series of technologies rather than a single-new technology. The technologies that enable IoT can be categorised into "Big Data, Cloud Computing, Sensors" and Analytics Software. The convergence of these technologies enables the functioning of IoT systems. They enable and enhance gathering, analysing and distributing data that was not previously available (n)or accessible due to the limitation of the technology. The availability of these new data parameters will help to increase capabilities, efficiency, and flexibility that was hitherto available [8: pp. 1–50; 61: pp. 113–137]. Figure 3 below illustrates and depicts the basic concept of working in IoT devices.

5 IoT in the Twenty-First Century

In the twenty-first century, an important aspect of the working of IoT devices is the collection of data. Data is collected from the surrounding environment using sensors or devices that can detect various physical phenomena. The data collected from the sensors will have various levels of complexities ranging from simple energy reading to complex accelerometer reading. The collected data is then sent to the cloud for processing through various communication protocols and technology through cellular networks, satellite networks, wide-area networks (WAN), including the low-power wide-area network (LPWAN), Bluetooth, "Wi-Fi, Zigbee, Z-Wave, Near Field Communication (NFC)". These gateways connect the sensors to the cloud infrastructure through the internet. The collected data is then analysed and converts raw data from the sensors into clean data using data analytics in the cloud. The processed data is highly organised and formatted to be easily searchable and analysed in databases. Depending on the application and complexity of the IoT system, the processed data can be transmitted to other various devices or user interfaces where the data can be viewed by the end-user [37, 84: pp. 60–84].

IoT lays the foundations for the development of a "hyper connected society". This has been explained in the book by Vermesan and Friess [83], titled "*Building the Hyperconnected Society: Internet of Things Research and Innovation Value Chains, Ecosystems and Markets*". In a "hyper connected society", machines or devices can communicate with each other and dynamically adjust the system without any human input for better capabilities, efficiency and flexibility. According to a recent report compiled by the "International Telecommunication Union (ITU)" and Cisco, titled "*Harnessing the Internet of Things for Global Development*", IoT

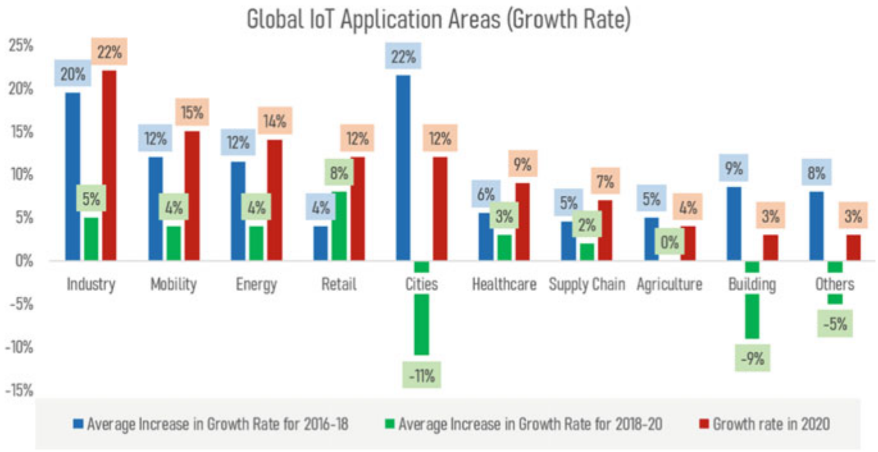

Fig. 4 illustrates the growth rate of global IoT application areas during 2018–20. *Source* Compiled based on data from [5, 67, 68]

will open up a lot of new business opportunities and can create an ecosystem that will generate new products, services and revenue models, thereby creating more jobs. It would have more profound or disruptive effects on how humans interact with themselves and machines in the near future [9, 83]. Figure 4 illustrates the growth rate of various areas of global IoT application during 2018–20.

Based on Fig. 4, in terms of the highest growth rate in 2020, industrial manufacturing (22%), mobility (15%), energy (14%), retail (12%), cities (12%), healthcare), supply chain (7%), agriculture (4%), building (3%) and others (3%) complete the list [68]. In terms of an average increase in growth rate during 2016–18, all sectors showed positive growth rate, with smart cities (22%), industrial manufacturing (20%), mobility (12%), energy (12%), building (9%), others (8%), healthcare (6%), supply chain (5%), agriculture (5%) and retail (4%) [5]. Meanwhile, this changed in the 2018–20 period, in terms of an average increase in growth rate during 2018–20, industrial manufacturing (5%), mobility (4%), energy (4%), retail (8%), healthcare (3%), and supply chain (2%) showed a positive increase in growth rates. Meanwhile, applications in smart cities (−11%), buildings (−9%) and others (−5%) showed negative growth rates [67].

Amongst these, the retail sector (8%) had the highest growth rate, whilst despite all the hype, implementation of cities (−11%) showed the lowest growth rate. Despite an increasing interest in issues related to food scarcity, drought and climate change, in terms of integration and application of IoT, the agriculture sector showed zero growth rate during 2018–20 (Fig. 4). This is a worrying trend across the globe, especially when the population growth and agricultural food production systems have shown huge interdependencies. Two major countries that are expected to have huge implications for IoT are China and India. Both countries are considered the driving engine of growth and the lynchpin of IoT drive worldwide.

5.1 IoT Ecosystem in India

India is an emerging power that is sometimes perceived to possibly threaten the rise (or status quo) of other major powers in the world in almost all domains of power. It is a major force in the land, sea (or ocean), air and outer space, and has been strengthening its power in the fifth domain, i.e. cyber domain or cyberspace, through the integration and perpetuation of IoT. This is an important aspect of the Digital India programme launched in 2015 by Narendra Modi government. In 2021, India has an estimated 761 million internet users across the country and is expected to have a compound annual growth rate (CAGR) at 6.36% annually and is expected to cross the one billion mark at the beginning of 2026 [75].

The Ministry of Electronics and Information Technology (MeitY) is the nodal agency guiding governmental agency policy-level initiative for integration and implementation of IoT in India. Since the Digital India Programme was launched in 2015, the internet penetration levels in India have been the highest and has accelerated due to impact on the market by private telecom companies and operators like Jio (of Reliance), Airtel (of Bharti Airtel Limited), Vodafone Idea Limited (Vi). It also has the highest concentration of mobile phone users across the democratic world, of which an estimated 46.25% were from the rural population. It provides a huge base of customers and accessibility to social networks like Facebook and internet search engines like Google [17, 41]. In 2020, the growth rate in start-ups adopting cyber technologies in India had been a growth of 31.25% and 87%, in terms of the number of start-ups and investments, respectively. NASSCOM is collaborating and supporting various Ministries in the implementation of the Digital India Programme across the nation [58]. The role of the public sector enterprises (PSEs) like the Bharat Sanchar Nigam Limited (BSNL) Mobile (including Mahanagar Telephone Nigam Ltd or MTNL), and the telecom infrastructure provider, Bharat Broadband Network Limited (BBNL), have all revolutionised the integration of IoT in the country [19: pp. 115–134]. Besides the Prime Minister’s Office (PMO) and other Ministries as well as Departments, other agencies include the “National Association of Software and Service Companies (NASSCOM)”; the “National Securities Depository Limited (NSDL)”; the “Reserve Bank of India (RBI) and the Indian Banks’ Association (IBA)” [50].

IoT is an important component of the broad Digital India flagship programme and has the vision to “transform India into a digitally empowered society and knowledge economy” (Ibid.). It brings to the fore all the branches of the Government of India (GoI), with participation from both public and private industries under one road for the “digital pivot”. The Indian IoT market is expected to grow exponentially and, combined with its ICT capabilities, is poised to become an emerging hotbed for many direct and spin-off opportunities in the near future. IoT investments in the Digital India programme is expected to have a CAGR of 44.22% over the last three years, increasing to 15 billion USD in 2021 [44]. The institutional and organisational aspects deal with the problems associated with (tele) communications and (digital) access to services and thus transforming governance in the country. The discourse of smart cities in India has been inadvertently dominated by the possibilities and opportunities of IoT integration, implementation and scalability as part of the Smart Cities Mission (SCM) in India. The total investment for SCM and IoT integration is estimated to be around two trillion USD and is more important towards the twenty-first century understanding of urbanisation, of which India looks forward to advancing and interconnecting as well.

5.2 IoT Ecosystem in China

The People's Republic of China (PRC), also called China, is amongst the major players focusing on the integration of IoT. IoT permeates into almost every sector in China. It is not just limited to manufacturing and industrial sectors, but also in the mobility/transportation sector, healthcare, retail, agriculture, energy and more. IoT is estimated to promote sustainability and stability in economic development, boost (quantitative aspect of) development in Chinese society, efficiency in production and services-related activities, generate and create (newer forms of) jobs, and enhance the welfare of the people. "This is in line with the Communist Party of China's (CPC's)" goal of building a "moderately prosperous society in all respects" [71]. It inadvertently determines China's role and position in the global supply chain. There has been a huge surge since the increase in Sino-US conflict, and the geopolitics of 5G technologies, trade war, techno-nationalism, cyberpower and the emphasis of the Xi Administration to reach and achieve "global peaks of technology" [51].

The Ministry of Industry and Information Technology (MIIT) is the nodal agency guiding governmental agency policy-level initiative for integration and implementation of IoT in China. Besides MIIT, other organisations include the "Cyberspace Administration of China (CAC), National Development and Reform Commission (NDRC), the Ministry of Science and Technology (MOST)", and the Standardisation Administration of China (SAC) [20: p. 5]. IoT has been identified as a "strategic emerging industry", with key areas including 5G, AI and cloud computing as critical aspects of *economic development* and *national security*. The high-level prioritisation of the IoT as the next critical technology in China can be linked to the four modernisation strategies (since the Deng Xiaoping Era) of the Chinese State. CPC has long viewed science, technology and innovation (STI) as a "major disruptor" of its technological advancement in the country, one which is a component in its *14th Five-Year Plan (2021–25)* and *Vision 2035* [47].

The *14th Five-Year Plan (2021–25)* and *Vision 2035* emphasise the integration of IoT, particularly in the promotion of "diverse industrial, supply chains", the expansion of "5G networks", the "construction of new infrastructure", promotion of international science and technology (S&T) cooperation, intellectual property governance and protection in emerging technologies, to "make plans for and incubate future industries", to promote the use of satellite technologies through the "Beidou Navigation Satellite System", enable "efforts to achieve breakthroughs in key and core technologies", to pursue "innovation-driven development" and the creation of new strengths development", increasing "self-reliance in science and technology as a strategic underpinning for national development". The plan emphasises on laying the foundation to achieve "long-term objectives" under *Vision 2035* [23, 92].

It is forecasted that China will become a key player in the deployment and development of IoT and is estimated to overtake the United States (US) technologically and become an (if not the most) advanced nation within the next two to three years [13]. Though the recent COVID-19 pandemic provided a hiccup globally, it has only increased the level of investments and integration in China. In terms of the IoT investment and integration trajectory, China is expected to achieve its aspirations and the penultimate goal of complete digitalisation and connectivity between the (political-) state (with complete control), market and society. China is well within the track to be amongst few countries to achieve what can be considered to have a State that is fully in the digital space. It increased "investments in IoT and related technologies such as 5G, smart grids and data centres", whilst installing "more than 20 million cameras" under the *SkyNet initiative*. Further, on the basis of IoT and artificial intelligence (AI), the "China Smart Logistic Network" and the "XPO Connect" were built in order to "achieve fast express delivery services" [54, 80: pp. 7–10, 86: p. 012066].

China is currently taking a comprehensive and coordinated state-led strategy by leveraging its large economic market and has established a manufacturing ecosystem to foster technological advancement and dominance. IoT technology is relatively in its nascent form, and the existing mechanisms of standardisation for IoT and its infrastructure across the world have been extremely fragmented. The current IoT-related standardisation is either proprietary, open standards or a combination of both [16]. These standards compete with each other for greater adoption around the world. China already has a technological edge in key technologies in IoT like 5G and AI compared to a lot of competing companies based in the US, Europe and other Asian countries, with the exception of some countries in the East Asian region. "Through the Digital Belt and Road Initiative (BRI)", leveraging its market and IoT-integrated manufacturing ecosystem, both domestically and internationally, China will have a greater say in international standardisation, setting scalability guidelines and establishing interoperability norms [32].

6 IoT in Agriculture

The influence of IoT automation in agriculture provides various facets to be understood and dealt with. A bibliometric analysis of the scholarly articles published in the Scopus Database on IoT in agriculture from 2010 to 2019 was undertaken. Interestingly, the same period saw a stagnation from China, growing at nearly 15.67%, and accounting for only 8.47% of the total scholarly literature in 2019. This is followed by countries like the United States (5.65%), Italy (3.34%),

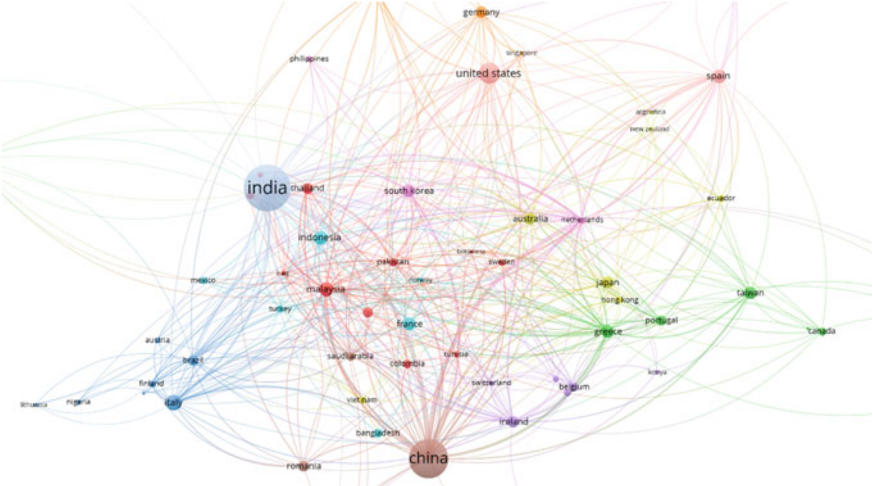

Fig. 5 Country-wise publication of scholarly literature on IoT in Agriculture (2010–19). *Source* Compiled based on Scopus Database

Malaysia (2.64%), the United Kingdom (2.64%), Spain (2.48%), Indonesia (2.37%), Greece (2.26%) and France (2.21%) that complete the top ten. Figure 5 depicts the clusters of countries, particularly India and China, related to publications related to IoT and agriculture (Fig. 5). Figure 5 shows country-wise publication of scholarly literature on IoT in Agriculture.

6.1 Socioeconomic Impact of IoT: Theoretical Considerations

According to the generally accepted understanding of advancement and development in the modern era, the socioeconomic impact of technology is inherently related to a country's R&D, innovation and (potential for) creativity. The major reason for the historical advancement of civilisations is related to the innovation and development strategies related to technology, with a global reach in terms of its impact. The invention of the light bulb, transportation, communication and many related technologies (like IoT) has been possible due to integration and advancement in many national economies, even India and China.

In the modern era, across the globe, the economic sphere is transforming with its dependence on prosperity and innovation, becoming an integral part of "knowledge economies". This has been accepted as an inherent part of sustainable development activities at an intergovernmental level itself. There is an increasing tendency for social scientists to consider knowledge through technological integration and advancement to be considered as an important value-addition to national economies. This is inadvertently considered as an “important production factor in fostering…growth [and development]”, particularly through the development of disruptive technologies as well as “knowledge-intensive sectors”. Moreover, contemporary times have shown the “direct impact of knowledge and innovation on economic growth”. These include multiple nation-states and regimes that have adhered to (a very long period of) focus on technology and (related) developments and advancements [89].

In this context, the use of neoclassical economic theories has provided an increasing impetus to what many consider the interlinkages of complex technological wherewithal (as in IoT), vis. e. vis., the knowledge economy. The theory propounded by Robert Solow, a Professor from the Department of Economics “at the Massachusetts Institute of Technology (MIT)”, developed a model that led to the conclusion that nearly half of the considered “historical growth” in developed nations cannot be directly correlated to the existence and “use of capital” investment and labour utilisation. Solow described it as “residual”, one which encompasses all factors of growth that are considered to be intangible. This, according to him, included the means of production, including the development of existing as well as new technology, R&D, human capital development (like education and technical competence), organisational restructuring and man-management and the advancement of the methods of production. Thus, the “introduction of changes in technology” was integrated into the framework of economic analysis and became a major factor in calculating the socioeconomic impact on a country [73: pp. 65–94]. This provided a methodological understanding and is considered an important driver to growth and development in an economy and society.

An important problem for the conceptualisation of theorising technology in the national economy is that it doesn’t fully take into consideration the issues concerning the sources of technological changes. Further, it isn’t able to explain what was considered to be “residual” and the relatively huge differences, particularly amongst countries of similar areas of development in technological capabilities [78]. The neoclassical considerations (of the twentieth century) entailed furthering technology-related activities as a relatively unassailable part of the indicators of growth and development in various countries. This was particularly undertaken for developed economies at the end of the twentieth century. Additionally, there has been increased support through government spending and support for technology-related advancements like IoT. Scholars like Kenneth Judd explicitly entail technology-related activities, thereby justifying capital accumulation related to monopoly for providing functionalities to technologies like IoT. The aspect of innovation as an important source of growth and development of national economies (currently IoT-related innovation and integration) is taken [40: pp. 567–585]. According to Arrow [2], this increases the societal well-being when productivity increases, and in terms of industrial output, this provides for increased dissemination of knowledge and skill sets into other actors in the economy [2: pp. 155–173].

6.2 A Comparative Study of India and China

Understanding the level of contribution towards scholarly literature, India (27.93%) and China (20.29%) take the lead over the remaining countries across the world. Scholarly literature with affiliations from India and China accounted for nearly half of the total. Scholarly literature with affiliations from China dominated the early period of the decade until 2015, accounting for nearly 68% of the total scholarly literature. Indian contribution was very negligible (2.78%) until 2015. This later saw a huge turnout showing an exponential growth since 2016, growing at nearly 92.07% and accounting for nearly one-third of the total scholarly literature in 2019 (Fig. 5). Table 1 provides various subcategories to IoT automation in agriculture, including precision farming, precision livestock farming, smart greenhouse and indoor farming, aquaculture and digital marketplace.

The automation in the subcategory of *precision farming* has varying levels in both India and China. In India, the levels of automation are agricultural machinery (Level III to Level IV),[3] smart/precision irrigation system (Level III to Level IV),[4] remote sensing and GIS (Level IV),[5] and farm management (Level I to Level II).[6] Meanwhile, in China, the levels of automation are agricultural machinery (Level III to Level IV),[7] smart/precision irrigation system (Level III to Level IV),[8] remote sensing and GIS (Level IV),[9] farm management (Level I to Level II).[10] The level of automation in *supply chain and storage management* in India includes subcategories like logistics (Level I), digital marketplace (Level III–IV) and warehousing

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[3] Companies in India include Mahindra & Mahindra, Indrones, Thanos, Tripthi Robotics Pvt Ltd, and Skylark Drones.

[4] Companies in India include Jain Irrigation, Cultyvate, Avanjial, BoreCharger, and aQysta.

[5] The satellite systems in India include “Indian National Satellite System (INSAT)”, Indian Regional Navigation Satellite System (IRNSS), “Forecasting Agricultural output using Space Agro-meteorology and Land-based observations (FASAL), National Agricultural Drought Assessment and Monitoring System (NADAMS)”. Companies in India include Farm Guide, and Gamaya, The Weather Company, SatSure, CropIn Technology Solutions, Skymet Pixel, and Skymet Weather.

[6] Companies in India include Fasal, BharatAgri, Krishitantra, Cultyvate, Senseitout, AgSmartic, Krishinetwork, Exabit Systems, and CropIn Technology Solutions.

[7] Companies in China include John Deere, DJI, XAG, i-Kingtec, auteldrones, and fjdynamics.

[8] Companies in China include Netafilm, Mottech, and RivulisSupPlant.

[9] The satellite systems in China include the “National Statistics and Remote Sensing System of Crop Production (NSRCP)”, Yaogan and Ziyuan satellite series, China-Brazil Earth Resources Satellite Program (CBERS) satellite series, Beidou Navigation Satellite System. The companies include ClimaCellh, Skywatch, and Onesoil.

[10] Companies in China include Acsm, Tian Tian Xuenong, Nongbo Innovation, Seed SenseCAP, Kebai Science and Technology Co., and Trimble Ag.

Table 1 Comparison between India and China on the level of IoT automation available in agriculture

Category	Subcategory	Parameters	Level of IoT Automation	
			India	China
IoT in agriculture	Precision farming	Agricultural machinery	III–IV*	III–IV*
		Smart/Precision irrigation systems	III–IV*	III–IV*
		Remote sensing and GIS	IV	IV
		Farm management	I–II*	I–II*
	Supply chain and storage management	Logistics	I	I–II*
		Digital marketplace	III–IV*	IV–V*
		Warehousing	II–III*	III–IV*
	Precision livestock monitoring	Monitoring	IV	IV
		Milking management	I–II*	I–II*
		Farm management	I–II*	I–II*
	Smart greenhouse and indoor farming	Growing	IV	IV
		Harvesting	0–I*	0–I*
	Aquaculture		III–IV*	0–I*

Source Compiled by Authors. *Note* *Nascent stages/prototype developed. IoT automation levels are based on standards developed by SAE International and Case IH Agriculture. "Level 0: No Automation; Level I: Limited Assistance with human control, Level II: Partial Automation with human intervention, Level III: Conditional Automation with human planning, Level IV: High Automation in limited spaces, and Level V: Supervision using AI/Full Automation". The level of technology indicates the highest level of available technology and does not necessarily mean availability across the country

(Level II–III).[11] Meanwhile, the level of automation in China includes subcategories like logistics (Level I–II), digital marketplace (Level IV–V) and warehousing (Level III–IV).[12] This created various opportunities like more avenues to sell commodities, real-time and quality interaction between farmers and consumers (often reducing the need for intermediaries), resulting in improved quality of products and financial stability for the farmers. There are important challenges like the digital divide, exploitation of small farmers by multinational corporations (as *Neo-intermediaries*) persists, both in regard with the exploitation of the commodity and the data of the farming communities (Table 1).

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[11] Companies in India include Ecozen, CoolCrop, Ninjacart, Kisannetwork, Kamatan, Gramophone, AryaS4S Technologies, Ourfood, Ecozen, Tessol, Promethean, Inficold, Agrigator, Big Basket, Grofers, Tan90, Technify, Bizecozen, TeleSense, WayCool, O4S, Merakisan, Sabziwala, Crofarm, Ninjacart, Krishihub, S4stechnologies, Tessol, SenseGiz, Intellolabs, DeHaat, BigHaat, VnF, Farmley, Bijak, Jaivikkheti, and Farmx.

[12] Companies in China include Songxiaocai, Zhaonongzi, VisionNav, Quicktron, Lehe Food, Nice Tuan, Missfresh, Yiguo, Xingbianli, Tony's Farm, Haishangxian, Pinduoduo, and Wangjiahu.

The issue of "*data ownership*", "*data localisation*" and "*data residency*" has become prominent in recent decades, especially due to its impact on owning indigenous or local information and/or knowledge, one which many multinational corporations have become aggressive (and dominant) to possess. *Precision farming* provided higher yields, increased profits and is considered more cost-efficient, has improved traceability of produce, enabled better resource and waste management, provided options for localised solutions to farming, and reduced over-dependence on inefficient human labour. However, there are issues like high-initial cost of implementation, the need for a large infrastructure complementing the efforts on the field, vis. e. vis., data centres, internet/broadband connectivity (especially to vulnerable/marginalised groups of farming communities), digital literacy for farming communities, refinement of technologies (before, throughout and even after implementation in the ground), and the loss/reduction of traditional jobs in agriculture due to automation-induced mechanisation (Table 1).

The level of automation in the subcategory of *precision livestock monitoring* has the same automation levels in India and China. The levels of automation are monitoring (Level IV),[13] milking management (Level I to Level II),[14] farm management (Level I to Level II).[15] *Precision livestock monitoring* provides better control over the livestock, improves the quality, yield and traceability of the produce, is more profitable than conventional methods, and is more sustainable. There are problems related to the integration and/or loss of indigenous varieties of livestock (particularly due to the nature of the automation), the issues of accessibility to high-end technology and infrastructure complementing/supplementing it. The level of automation in the subcategory of smart greenhouse and indoor farming has the same levels of automation in harvesting (Level 0 to Level I) for both India and China, whilst the level of automation is growing in India (Level IV)[16] and China (Level IV)[17] shows a huge gap. These have improved various aspects of climate-resilient/resistant farming, effective management of natural resources-based farming, farming in confined/micro spaces, increased access to indigenous products, real-time decision-making to prevent/reduce wastage, and lessened risks related to natural disaster and reduced ineffective human labour time. Some of the

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[13] Companies in India include Vetware, Stellaps, Brainwired, Allflex, BovSmartSmaXtec, Cowlar, Moocall, Smartbow, "TRITHI Robotics, Dronitech, Sagar Defence Engineering, DJI Enterprise, and Sunbirds". Companies in China include Yingzi Technology, and MooMonitor.

[14] Companies in India include MiRobot, Stellapps GEA, DeLaval, Fullwood Packo, Ksheera Enterprises, Lely, Delmer, Boumatic Robotics. Companies in China include GEA, Waikato Milking Systems, Dairymaster, and DeLaval.

[15] Companies in India include Delaval, Afimilk, Stellapps, Milc Group, My Dairy Dashboard, Nedap Godrej, Agrovat, Bump Gates, Fullwood Packo, Ley, and Animall. Companies in China include SmartAHC, Microfan, Yingzi Technology, AfiMilk, and Herd Management System.

[16] Companies in India include Simply Fresh, Clover Ventures, Triton Foodworks, Absolute Foods, Kheyti, Kosara Horti and TechIndia.

[17] Companies in China include Sinomach-Hi, Beijing Honggu Agriculture, Farm66, Sananbio, Gbeing Smart Agro, Seed SenseCAP, and Ridder.

challenges include increased cost related to the consumption of electricity, issues related to the implementation on a broader scale (like cost, infrastructure, integration of technology), and the problems in integrating to traditional/conventional farming models. The level of automation in the subcategory of aquaculture in India (Level III to Level IV)[18] is much more advanced than China (Level 0 to Level I).[19] This created issues related to environmental degradation, pollution and a reduction in the fish population (Table 1).

7 Conclusion

Agriculture is considered to be a mainstay for the survival of human civilization. It continues to do so, though there has been a multitude of challenges in its sustenance, which in itself is a challenge to the survival and sustenance of the human beings themselves. The technological revolution that occurred over the millennia has reached a pertinent peak in the form of the Fourth Industrial Revolution (4IR), which seems to permeate and perpetuate into the agricultural sector. Amongst the various frontier technologies, the Internet of Things (IoT) has emerged as a frontrunner with respect to its effect on agriculture, an impact which overwhelmingly dwarfs the impact of the Green Revolution across the world. Interestingly, in a world where the population seems to have increased in number (quantity) and consumption (quality), IoT seems to have a huge role to play, especially in two of the most populous countries in the world, India and China.

IoT has a huge impact on the development, growth and other socioeconomic parameters of farming communities and is the lynchpin for food security in both countries. This is very important for both nations, where poverty has been rampant until the early twenty-first century. The impact of IoT and the development of new forms and types of interconnected agricultural systems seemed to strive and spur both positive and negative aspects in the countries. A comparison of the levels of IoT automation in both the countries in the study seems to indicate the need to further improve, integrate and disseminate IoT-related benefits. In terms of research, very few studies have been undertaken in that direction and should be pursued, especially in the field of the socioeconomic impact of IoT on developing countries like India and China. The level of IoT automation is expected to create jobs, improve the standard of living and reduce the incidence of poverty. It can mitigate further (future and potential) problems that will have arisen due to the dependence on conventional forms of agriculture, and the increased competition from advanced countries and multinational corporations across the world. There should be greater efforts from the government and industry for regulation and

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[18] Companies in India include Aquaconnect, and Eruvaka.

[19] Companies in China include AKVA group, BioFishency, Qingdao, and Conson Development Group.

standardisation of IoT for seamless cross-compatibility between IoT devices, whilst ensuring that these regulations do not hinder innovation. Incidentally, all of this will be dependent on the level of economic input (funding), infrastructural capabilities, technological advancements (both theoretical and applied), skilling of personnel, policy directions and strategies that address pertinent issues that can and may arise in the future.

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The Impact of Irrigation on Generation of Marketable Surplus in the Bolpur Subdivision, West Bengal

Subhasis Mondal and Madhumita Mondal

Abstract Location of Bolpur Subdivision is at the south-eastern part of the Birbhum District, West Bengal. Sources of irrigation of the study area are canal, submersible pump, tank and river lift irrigation. After consumption and keeping seed, farmers sold their excess production to the market. Big farmers store their production long time for high value, but marginal and small farmers sold their production after harvesting because they pay the money their creditor. Governments purchase firstly the production of big farmers and then the production of marginal and small farmers. The marginal and small farmers sale their production to the middleman, because they get direct cash from them. Middleman purchases the production of farmers from their house by tractors and sale the purchased production to the mill. Sometime marginal and small farmers sale their production in loss because of low market value of crops at the time of harvesting. They have no interest to sale their production to government kisanmandi because governments pay the money by cheque and long process and sometime harass them to take their production. Big farmers are opportunist. They sale their production to the government kisanmandi and receive the money by cheque from bank account. Marketable surplus has been increased after the application of irrigation to the crop fields. The big and medium farmers bring highest amount of their lands under the practice of cultivation due to irrigation facility.

Keywords Marketable surplus · Irrigation · Production

1 Introduction

Irrigation makes double and multiple cropping. As a result, productivity increases. After consumption and keeping seeds, surplus are sold in the market. Thus, irrigation makes marketable surplus. Highest marketable surplus of crops are observed

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in big and medium farmers in the study area. Big farmers store their production long time for high value, but marginal and small farmers sold their production after harvesting, because they pay the money their creditor. The quantity of irrigated fields in the whole subdivision is 62.1%, and most of the fields are irrigated only in "Kharif" cultivation. A few field is irrigated in by canal second cultivation, i.e. "Rabi" cultivation. For "Rabi" and "Boro" cultivation, shallow tube well, submersible, deep tube well, pond and river lift irrigation are notable.

2 Statement of Problems

A large proportion of the Bolpur Subdivision's incomes come from the agricultural sectors. The secondary and tertiary activities are not numerous in this study area. Almost 76.8% of the working population are employed in agriculture, either as cultivators or as agricultural labourers. Cultivation of any crop is not possible without irrigation in the study area.

3 Literature Survey and Review on Generation of Marketable Surplus

The modern irrigation methods help to increase the productivity of various crops. Marketable surplus of crops is high where irrigation facility is high, and people are engaged in primary activity. The government can also buy surplus crops in the market to bosts its stragic grain reserves and also help stabilize the market price of crops. The highest grain yield could be obtained by applying irrigation. Irrigation is necessary both intensively and extensively for higher production and generation of marketable surplus. Irrigation plays a significant role in promoting higher yields. The availability of water inadequate amount and at the right time is one of the basic determinants of agricultural productivity. Reliable irrigation can enable farmers to adopt new technologies and intensify cultivation, leading to increased productivity and greater returns from farming. Irrigation increased the area under multiple cropping, encouraged mechanized farming, raised yield of crops, raised cropping intensity, brought out stability in yield of crops and also helped in commercialization of agriculture. Irrigation has many advantages including an ensured regular water supply and thereby increases the overall productivity of a region. The amount of agricultural land is also increased after the modification and reduction of flood by the dams. After introduction of irrigation in any region, new cropping patterns have emerged. Irrigation has also potentiality to change cropping pattern. This change will be in favour of commercial crops, and production will be market oriented. After the construction of dams and irrigation canals, cropping intensity and crop yield have increased. Agricultural productivity and marketable surplus of a region are closely influenced by irrigation. Irrigation has a great role on agricultural land utilization. Irrigation has a great role on marketable surplus of various crops. Irrigation influences to generate additional employment opportunities and provide scope for increasing the incomes. The income of common man has increased manifold after the advent of irrigational facilities. Irrigation in the Mediterranean is vital importance for marketable surplus, food security employment and economic development. Several research works are performed on the impact of irrigation on generation of marketable surplus. In this respect, the study made by Abbady et al. [1], Amiri and Kakolvand [2], Ashraf et al. [3], Baba et al. [4], Bekehanov and Lampers [5], Biswas et al. [6], Blum [7], Camargo et al. [8], Luquet et al. [9], Muhammad and Jan [10], Nkya et al. [12], Nue and Ren [13], Otieno et al. [14], Rey et al. [15], Wichelns [16] deserves worth mention.

4 Objectives of the Research

To find out the impact of irrigation on marketable surplus of crops.
To uncover the problems and suggest policy measure.

5 Database

The data has been obtained from the two sources, i.e.

(i) Secondary data is obtained from different journals, offices and books, and
(ii) Primary data is obtained from research field.

6 Methodology

Two methods have been employed to analyse the primary and secondary data that have been collected from different sources in order to fulfil the basic objectives of the study. These include

1. Statistical methodology and
2. Cartographic methodology.

This section also deals with the whole process of obtaining and processing of data. In each village, in the range of fifty (50) households were purposively selected, and survey was completed. While selecting households, it was kept in mind that the households to be surveyed must have maximum number of its working members engaged in agricultural activities.

7 Location of the Study Area

Bolpur Subdivision is extended from 23°32′30″ to 23°53′00″ north latitudes and from 87°23′30″ to 87°57′30″ east longitudes. This Subdivision is bounded by Murshidabad District in the north east, by the district of Burdwan in the south and east, by the Block of Dubrajpur in the west, by the Block of Suri in the northwest and by the Blocks Saitha and Mayureswar in the north as shown in Fig. 1.

8 Impact of Irrigation on Marketable Surplus of Crops

Irrigation makes double and multiple cropping. As a result, productivity increases. After consumption and keeping seeds, surplus are sold in the market. Thus, irrigation makes marketable surplus. Irrigation plays a significant role in promoting higher yields. The availability of water inadequate amount and at the right time is one of the basic determinants of agricultural productivity. Reliable irrigation can enable farmers to adopt new technologies and intensify cultivation, leading to increased productivity, marketable surplus and greater returns from farming. Irrigation has also potentiality to change cropping pattern. This change will be in favour of commercial crops, and production will be market oriented. In the study area, big and medium farmers produce more and generate more marketable surplus.

8.1 Marketable Surplus of Aman Paddy

The study shows the marketable surplus of Aman paddy of farmers at the rate of 0.54 quintals to 24.35 quintals per acre of land, but majority of the marketable surplus are as low as in between 8.48 quintal to 16.41 quintal per acre. Higher levels of marketable surplus of Aman paddy are observed in Kurumba, and Goltikuri villages, followed by Saota, Ruppur and Binuria villages. Aman paddy is generally consumed by farmers in the study area (Fig. 2 and Table 1).

8.2 Marketable Surplus of Boro Paddy

The study shows the marketable surplus of Boro paddy of farmers at the rate of 4.31 quintals to 28.20 quintals per acre of land, but majority of the marketable surplus are as high as in between 20.23 quintal to 28.20 quintal per acre. Higher levels of marketable surplus of Boro paddy are observed in Kurumba village, followed by Saota, Binuria, Goltikuri and Ruppur villages. Boro paddy is generally produced for marketing (Fig. 3 and Table 2).

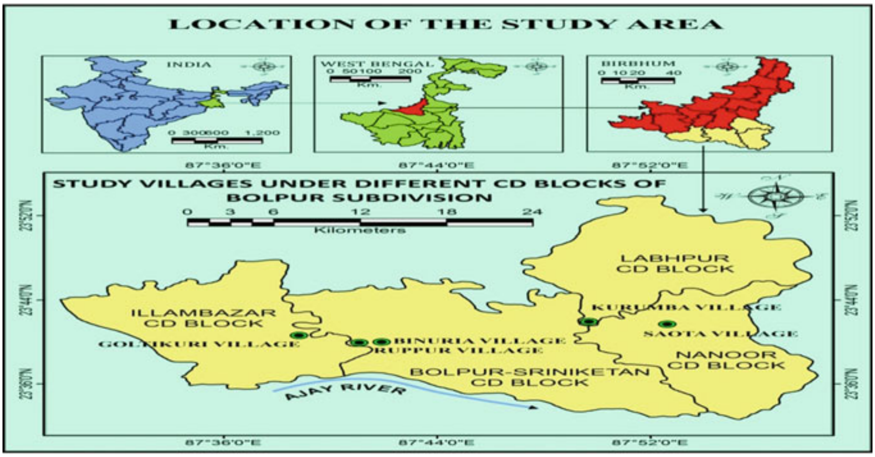


Fig. 1 Location map of Bolpur Subdivision

8.3 Marketable Surplus of Potato Crop

The study shows the marketable surplus of Potato crop of farmers at the rate of 6.89 quintals to 92.93 quintals per acre of land, but majority of the marketable surplus are as high as in between 35.57 quintal to 64.25 quintal per acre. Higher levels of marketable surplus of Potato are observed in Binuria, Goltikuri village, followed by Saota, Binuria, Kurumba and Ruppur villages. Potato is the most important vegetable in regular consumption in the study area, and it is produced to a large scale. After consumption, farmers sold it to the market (Fig. 4 and Table 3).

8.4 Marketable Surplus of Mustard

Mustard is one of the most useful oil seeds produced in this area, and it is widely cultivated in all the sample villages. After little consumption, it is totally sold into market. The study shows the marketable surplus of Mustard seed of farmers at the rate of 7.97 quintals to 11.07 quintals per acre of land, but majority of the marketable surplus are as low as in between 7.97 quintal to 9.00 quintal per acre. Higher levels of marketable surplus of Mustard are observed in Goltikuri and Saota villages, followed by Kurumba, Ruppur and Binuria villages (Fig. 5 and Table 4).

8.5 Marketable Surplus of Til

Til is one of the second most oil seeds cultivated in this area. After little consumption, totally it is sold into market. The study shows the marketable surplus of

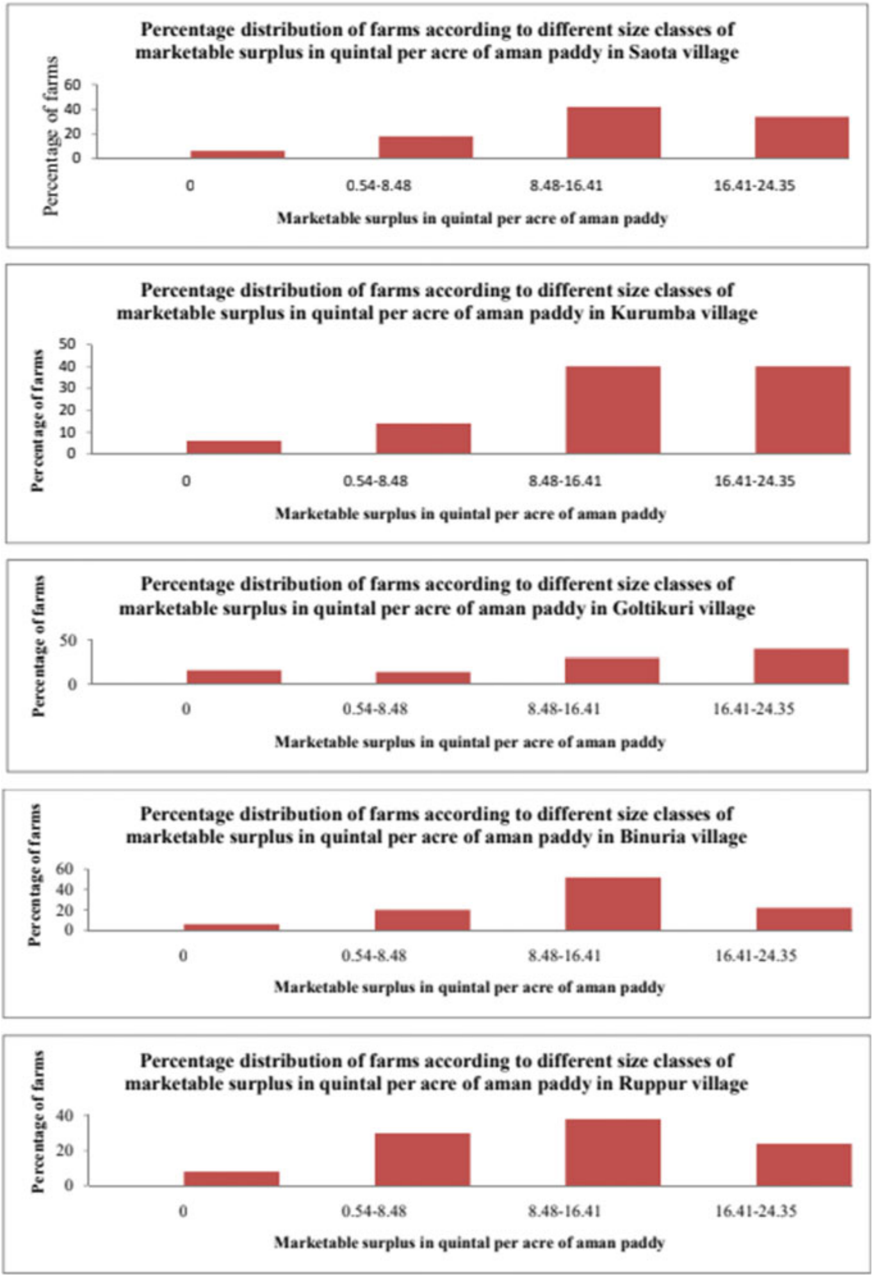


Fig. 2 Bar diagram showing percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Aman paddy in different study villages

Table 1 Percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Aman paddy in different study villages

Villages	Distribution of marketable surplus of Aman paddy in quintal per acre				Total
	0	0.54–8.48	8.48–16.41	16.41–24.35	
	Percentage of farms				
Saota	6	18	42	34	100
Kurumba	6	14	40	40	100
Goltikuri	16	14	30	40	100
Binuria	6	20	52	22	100
Ruppur	8	30	38	24	100

Source Field survey

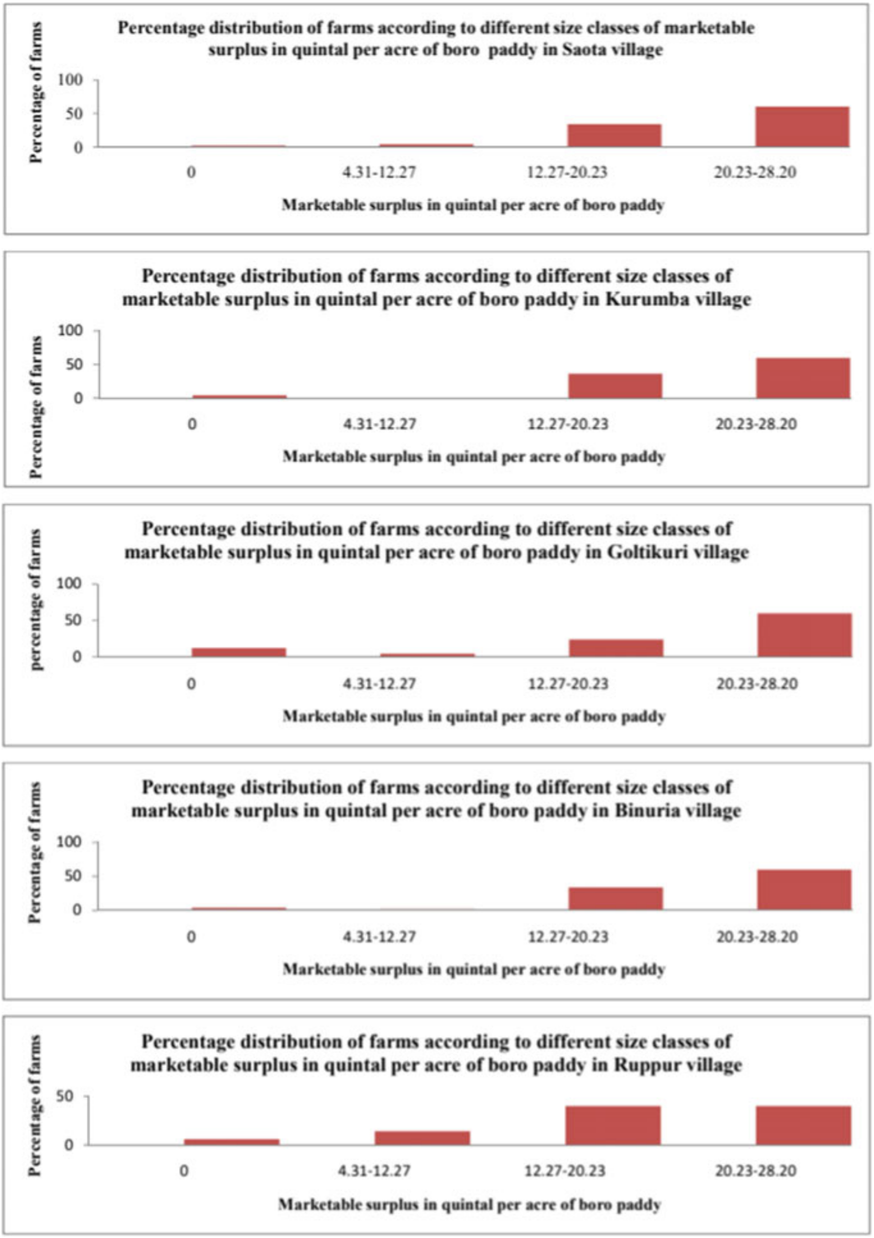
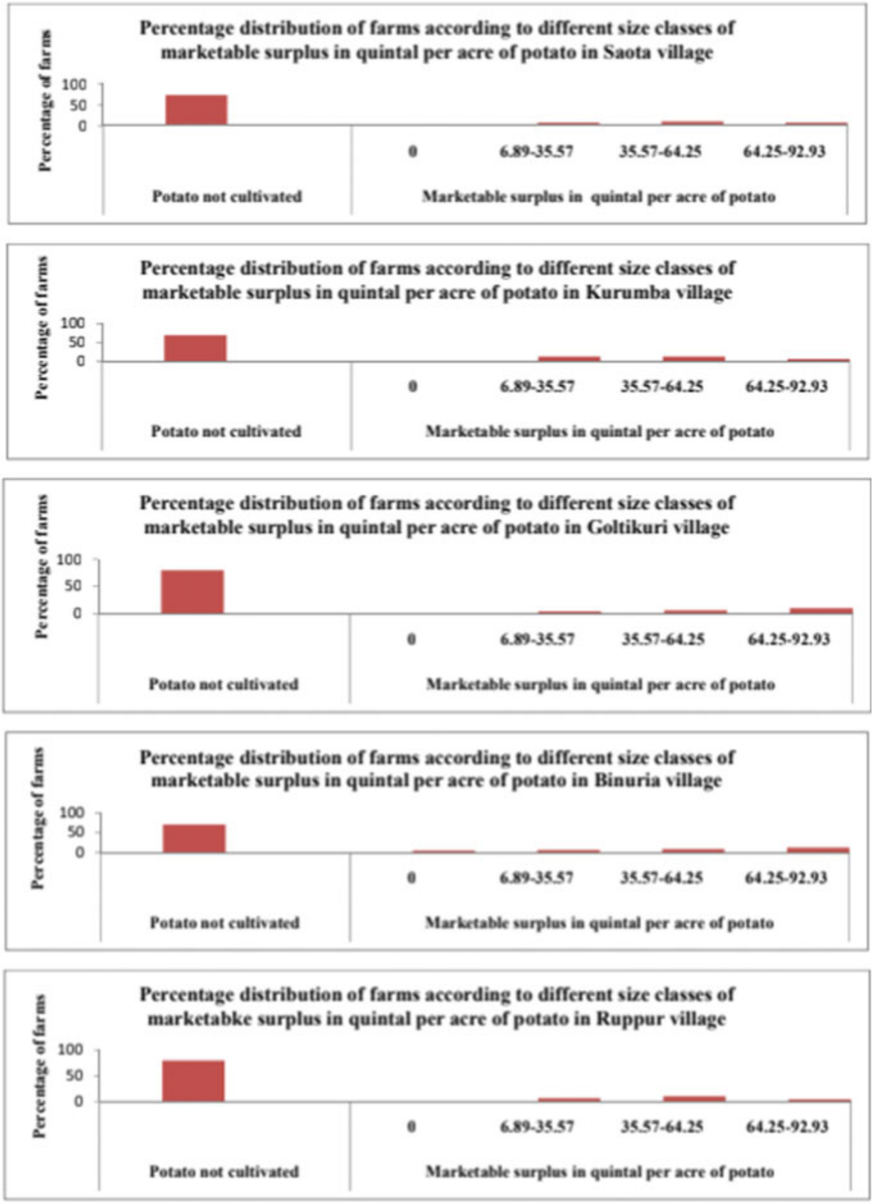


Fig. 3 Bar diagram showing percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Boro paddy in different study villages

Table 2 Percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Boro paddy in different study villages

Villages	Distribution of marketable surplus of Boro paddy in quintal per acre				Total
	0	4.31–12.27	12.27–20.23	20.23–28.20	
	Percentage of farms				
Saota	2	4	34	60	100
Kurumba	4	0	36	60	100
Goltikuri	12	4	24	60	100
Binuria	4	2	34	60	100
Ruppur	6	14	40	40	100

Source Field survey



Percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of potato in Saota village

Percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of potato in Kurumba village

Percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of potato in Goltikuri village

Percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of potato in Binuria village

Percentage distribution of farms according to different size classes of marketabke surplus in quintal per acre of potato in Ruppur village

Fig. 4 Bar diagram showing percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Potato in different study villages

Til seed of farmers at the rate of 2.98 quintals to 4.48 quintals per acre of land, but majority of the marketable surplus are as low as in between 2.98 quintal to 3.48 quintal per acre. Higher levels of marketable surplus of Til are observed in Ruppur and Binuria villages, followed by Kurumba, Saota and Goltikuri villages (Fig. 6 and Table 5).

Table 3 Percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Potato in different study villages

Villages	Potato not cultivated	Distribution of marketable surplus of Potato in quintal per acre				Total
		0	6.89–35.57	35.57–64.25	64.25–92.93	
	Percentage of farms					
Saota	74	0	8	10	8	100
Kurumba	70	0	12	12	6	100
Goltikuri	80	0	4	6	10	100
Binuria	70	4	6	8	12	100
Ruppur	80	0	6	10	4	100

Source Field survey

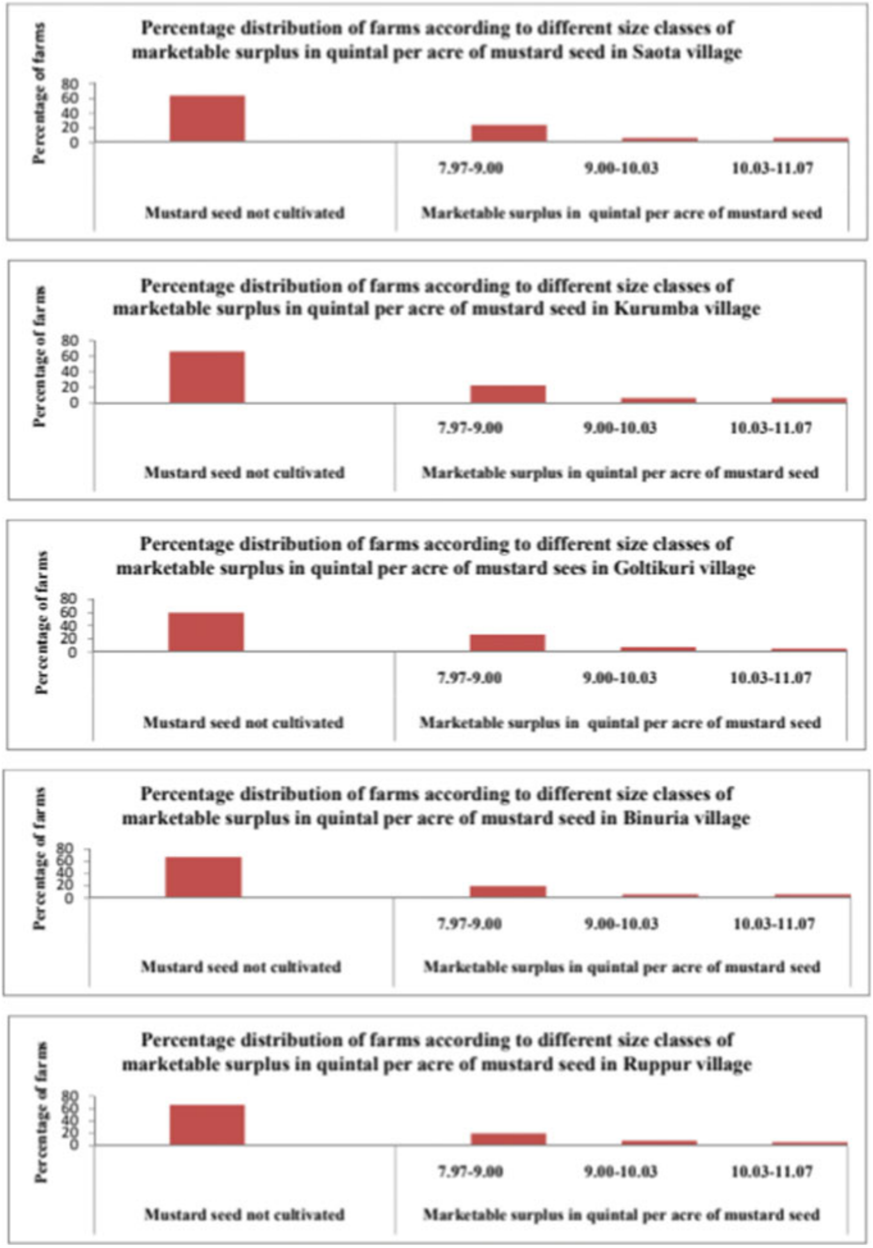


Fig. 5 Bar diagram showing percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Mustard in different study villages

Table 4 Percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Mustard in different study villages

Villages	Mustard not cultivated	Distribution of marketable surplus of Mustard in quintal per acre			Total
		7.97–9.00	9.00–10.03	10.03–11.07	
		Percentage of farms			
Saota	64	24	6	6	100
Kurumba	66	22	6	6	100
Goltikuri	60	26	8	6	100
Binuria	68	20	6	6	100
Ruppur	66	20	8	6	100

Source Field survey

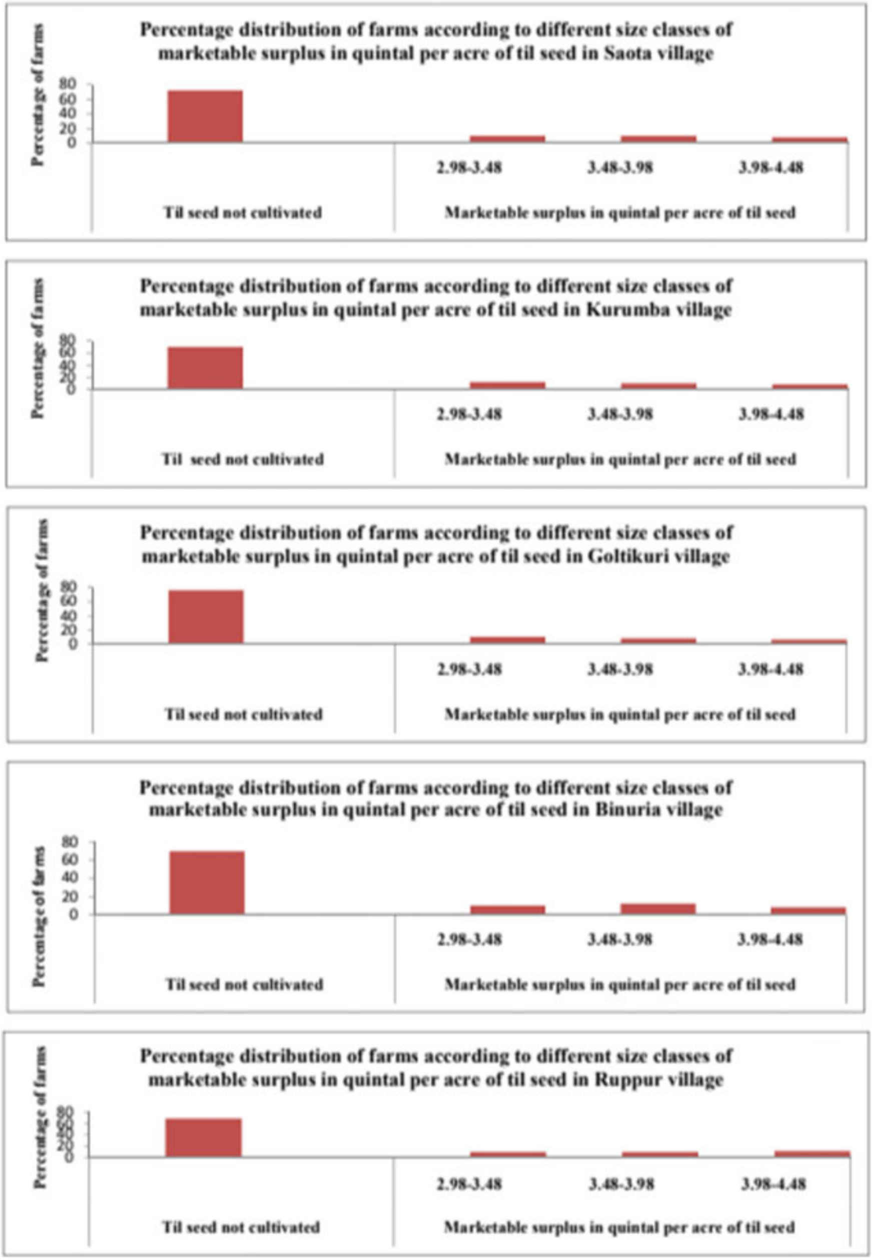


Fig. 6 Bar diagram showing percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Til in different study villages

Table 5 Percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Til in different study villages

Villages	Til not cultivated	Distribution of marketable surplus of Til seed quintal per acre			Total
		2.98–3.48	3.48–3.98	3.98–4.48	
	Percentage of farms				
Saota	72	10	10	8	100
Kurumba	70	12	10	8	100
Goltikuri	76	10	8	6	100
Binuria	70	10	12	8	100
Ruppur	68	10	10	12	100

Source Field survey

8.6 Marketable Surplus of Mursuri

Mursuri is the most important pulse crop produced in this area, and so it is largely cultivated in all the sample villages. After little consumption, farmers totally sale it. The study shows the marketable surplus of Mursuri seed of farmers at the rate of 3.88 quintals to 4.88 quintals per acre of land, but majority of the marketable surplus are as low as in between 4.21 quintal to 4.54 quintal per acre. Higher levels of marketable surplus of Mursuri are observed in Saota village, followed by Ruppur, Binuria, Goltikuri and Kurumba villages (Fig. 7 and Table 6).

9 Identification of Problems

Compared to the quantum of cultivable lands available in the villages, the number of pump sets and shallow tube wells required for irrigation is much less. Due to this, pre-monsoon crop cultivation is hampered. This situation is more or less same in all the five sample villages studied by the researcher. Due to heavy demand, these machineries do not get rest, and hence, machinery breakdown is a regular incidence during the peak yielding time.

Shallow tube wells and submersible pump sets are used to extract groundwater for irrigation. This mineral-rich water normally becomes very useful for agricultural lands. Due to continuous extraction of ground water, such water may contain harmful minerals like arsenic which causes damage to the agricultural lands and the crops. On consumption of these crops, these harmful elements may enter the human body and adversely affect human health. Government kisanmandi required for sale of marketable surplus of crops is much less and far away from the villages in the study area.

10 Policy Measure

Derelict tanks should be renovated. Deposit of eroded soil into these tanks should be controlled. Maintenance work should be undertaken on regular basis. Adequate numbers of submersible pumps are to be installed in places having location advantages. These submersible pumps must be operated scientifically. Alternative arrangements should be made for their running during power failure. Maintenance work should be performed simultaneously, and damages are to be repaired immediately. The river lift irrigation schemes and water lifting devices should be installed in appropriate places, and maintenance work is to be done simultaneously. There is another irrigation system suitable for the study area where water passes through channels aligned between the crop rows. Water infiltrates into the soil as it moves along the channel. The channels should be deeper so that the water can

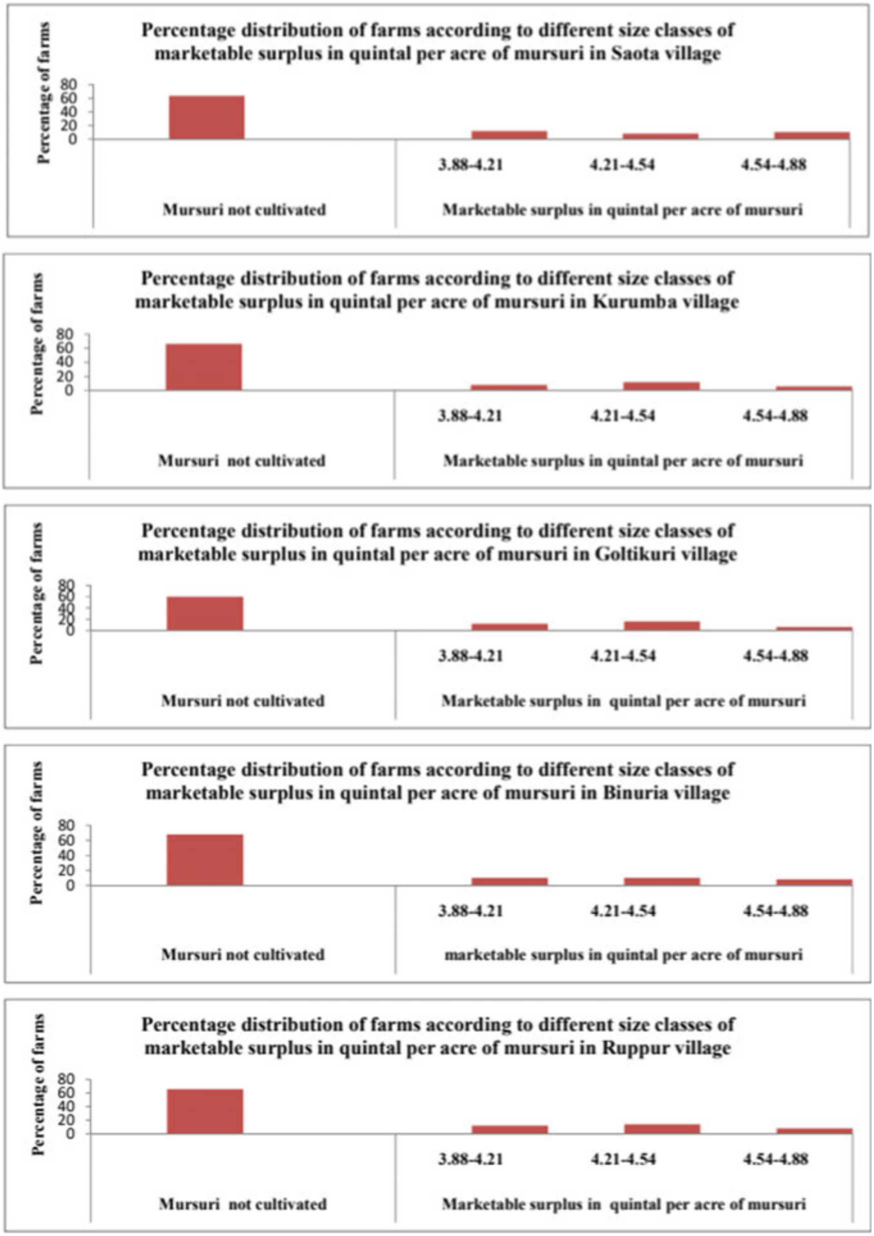


Fig. 7 Bar diagram showing percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Mursuri in different study villages

Table 6 Percentage distribution of farms according to different size classes of marketable surplus in quintal per acre of Mursuri in different study villages

Villages	Mursuri pulse crop not cultivated	Distribution of marketable surplus of Mursuri pulse crop quintal per acre			Total
		3.88–4.21	4.21–4.54	4.54–4.88	
	Percentage of farms				
Saota	64	12	8	10	100
Kurumba	66	8	12	6	100
Goltikuri	60	12	16	6	100
Binuria	68	10	10	8	100
Ruppur	66	12	14	8	100

Source Field survey

percolate to reach the root of the crop plants. Adequate number of government kisanmandi should be constructed in places having location advantages.

11 Major Findings

The marginal and small farmers sale their production to the middleman, because they get direct cash from them. Middleman purchases the production of farmers from their house by tractors and sale the purchased production to the mill. Sometime marginal and small farmers sale their production in loss because of low market value of crops at the time of harvesting. They have no interest to sale their production to government kisanmandi because governments pay the money by cheque and long process and sometime harass them to take their production. Big farmers are opportunist. They sale their production to the government kisanmandi and receive the money by cheque from bank account. Marketable surplus has been increased after the application of irrigation to the crop fields.

12 Conclusion

After consumption and keeping seeds, farmer sold their excess production to the market. Irrigation makes double and multiple cropping. As a result, productivity increases. Marketable surplus has been increased after the application of irrigation to the crop fields. Big farmers store their production long time for high value, but marginal and small farmers sold their production to the middleman after harvesting, because they pay the money their creditor. There are very few government kisanmandi in the study area and far away from the villages. As a result marginal and small farmers have no interest to sale their production to the government kisanmandi.

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A Farmer-Friendly Connected IoT Platform for Predicting Crop Suitability Based on Farmland Assessment

Jason Elroy Martis, M. S. Sannidhan, and K. B. Sudeepa

Abstract The largest area of Indian geography comprises villages in which the primary source of income depends on the agricultural occupation, which plays a vital role in establishing the country's economic growth. Crop cultivation also depends a lot on environmental factors and the fertility elements of the soil. Due to the changing weather conditions, a seasonal change transpires in the environment and the soil elements. Because of these seasonal changes, farmers face many shortcomings in selecting suitable crop cultivation in their farmland, ensuing massive imbalance in economic growth, causing an enormous threat to the agricultural occupation and the Indian economy. The aforementioned problem can be overcome by implementing seasonal cropping based on the soil elements and environmental factors. As a micromanagement solution to this problem, we propose implementing an economically innovative machine learning Internet of things platform that can closely access and deliver the information pertaining to the attributes of the environment and soil. The proposed system was tested in real time at the local district of Karnataka state in India. The system accurately predicted crop cultivation in relevance to Kharif and Rabi seasons based on local environmental conditions gathered from the data made available by the Indian Council of Agricultural Research and also enhanced soil fertility by 33%.

Keywords Internet of things · Agriculture · Soil management · Seasonal cropping · Machine learning

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1 Introduction

A very well-known fact is that an enormous landscape of Indian country comprises rural areas in which agricultural occupation derives a significant source of the country's economy. Every single Indian farmer is an asset of the government, acting as the nation's backbone. Hence, agriculture in India plays a prominent role in economically establishing the nation's growth and living comfort of the citizens [1]. One notable fact about India is that many regions, especially the belts of coastal Karnataka regions like Udupi, Mangalore, Kundapura, and Karkala, are highly prone to changing weather conditions. The abrupt change in climatic conditions includes severe drought-producing rainy and scorching summer season. Due to these reasons, farming in these regions is exposed to harsh climatic conditions and is an enormous challenge in front of the farmers [2]. As a solution to continuous weather changes, farmers in such areas need to adapt to seasonal cropping methods where suitable crop cultivation is carried out based on the support of weather conditions. However, the majority of the farmers in the country are accustomed to traditional cropping. Hence, it becomes tough for the farmers to adapt themselves to seasonal cropping as the cultivation method depends on accessing the weather conditions from time to time and selecting the right crop for cultivation based on the attributes of the climate [3]. Apart from that, the fluctuating weather conditions equally alter the soil's nourishment, indirectly affecting the growth of the crop. Due to these problems, farmers accustomed to traditional cropping face many issues in selecting and enriching the right crop for cultivation. As a result of all these issues mentioned, our nation is facing a massive inequity in the commercialization of agricultural products, causing a gigantic threat to the rural occupation and the nation's economy [4, 5].

Several actions were taken by the concerned agricultural authority, and many other agriculturists tried to successfully promote seasonal cropping to deal with the issues mentioned above. In this regard, local agricultural centers conducted comprehensive programs to educate farmers regarding the techniques followed for seasonal farming and its advantage in the maximum utilization of the farmland. But, seasonal farming itself has several dependencies concerning the varying weather aspects, selecting an appropriate crop, and nourishment factors of the soil. The Indian Council of Agricultural Research (ICAR) prepared a dataset which was also made publicly available on their website that suggests suitable cropping based on the geographical area, weather attributes, and soil parameters to address these dependencies. However, the utilization and reachability of the prepared dataset were minimal because of constraints involved within the functioning authority and the ignorance of the beneficiary. Moreover, the ICAR dataset acts as a guide. Still, the farming methodology demands accessing the required parameters that define climatic conditions and the quality of the soil to take a necessary decision as defined according to the dataset. Hence, there is a requirement for intelligent engineering technologies that could address the problem by accessing the weather's required parameters and soil attributes and suggest a suitable crop for cultivation [6].

A sizable amount of research has been carried out using Internet of things (IoT) technologies to address the issue in several different ways. Most of the previously implemented systems utilized legible sensors connected to the IoT device to gather relevant information corresponding to the farmland's weather conditions and soil properties. The executed research conquered the problem by developing a suitable solution to gather various parameters related to soil quality and climatic conditions. Few among them are (1) information gathering system to gather information corresponding to the farmland. (2) predicting suitable crop cultivation based on the quality of the soil, (3) suggesting the apposite crop based on climatic conditions, and (4) very few of them accomplished their work in predicting the proper crop cultivation based on both the climatic conditions as well as the quality of the soil. However, a significant fallacy observed in the previously implemented systems is that none of them concentrated on developing a system that could predict seasonal cropping methods based on the data gathered corresponding to the weather attributes and soil parameters. Also, the systems could not access the fertility of the soil and time-invariant prediction based on the present, past, and future data [7–9].

In this research exertion, as a micromanagement solution to the problem of seasonal cropping system, we propose the employment of a cost-effective and innovative machine learning-enabled IoT platform. The proposed approach can meticulously gather and distribute real-time information corresponding to the attributes of the environment and parameters of the soil. The collected information is then utilized to predict an apposite crop suitable to Kharif and Rabi seasons for cultivation. The prediction model of the system is designed using long short-term memory (LSTM) networks to perform time-invariant classification [10]. The LSTM network is trained using values from the ICAR dataset and local dataset constrained to Mala and Miyar villages of Karkala Taluk in Udupi District of Karnataka. The local dataset is prepared out of a deep learning prediction model. Further, the system also provides suggestions to enhance soil fertility based on local soil parameters.

1.1 Contributions

In view of fulfilling the requirements of the proposed system, the following objectives are achieved:

1. Incorporation of relevant sensors into IoT devices for sensing environmental attributes and soil parameters.
2. Setting up a centralized node and local storage to accumulate data from sensors.
3. Development of a deep learning regression model for predicting macronutrient soil parameters.
4. To design a time-invariant model using LSTM network for crop prediction based on two seasons: Kharif and Rabi.
5. To provide farmer-friendly recommendations for enhancing soil fertility.

1.2 Organization of the Chapter

This chapter is further organized into four subsequent sections. Following arrangements reveal the structure of the entire chapter: Sect. 2 contains an exhaustive literature review, Sect. 3 reveals the proposed system that describes the working methodology of an entire system in detail. Section 4 presents experimental investigations and their corresponding discussions that demonstrate the practical ability of the proposed approach. The final section, i.e., Sect. 5 depicts the conclusion and future scope of the proposed approach.

2 Literature Review

In compliance with the design of the anticipated system, an in-depth literature review focused on the fulfillment of the systems' requirements. The learning also targeted identifying the loopholes in the previously developed systems and innovative practices to overcome the same. The study area covered the assimilation of standard journal articles, various websites, and prescribed university textbooks to gather information corresponding to the concepts of the Internet of things, sensors, communication protocols, and neural network systems covering the agricultural domain. Ample research focused on exploring the prediction based on artificial neural networks and deep learning models that yield a higher level of accuracy. A sizable amount of concentration is focused on the investigation of suitable datasets that supports in upholding experimental studies of the proposed system.

In their artifact, Lee et al. (2013) proposed incorporating legible sensors for the frequent monitoring of the growth of crops and analyzing their future production. Researchers have developed an IoT-based intelligent decision-making system that could collect real-time environmental factors and suggest efficient harvesting methods that could boost up the production rate to support efficient crop cultivation. Investigations presented in the artifact prove that the implemented system has boosted up tomato crop production based on the yearly analysis [11].

Truong et al. (2017) proposed a novel IoT system design dedicated to predicting fungal disease in crop cultivation based on environmental factors. The implemented IoT system comprises the application of legible sensors to collect ecological data connected to the temperature, humidity, speed of the wind, etc. Collected data is gathered into the cloud and is later supplied into a prediction algorithm for predicting the possible fungal disease. The prediction algorithm is a machine learning system implemented via SVM regression model. Results achieved in the paper convinced that the system assists in managing the crop by providing timely maintenance based on the prediction of fungal disease. However, the prediction accuracy is in the lower side due to insufficient data supplied to the predictor [12].

Rajeshwari et al. (2017), in their research paper, successfully designed an intelligent agriculture system through the integration of big data analytics over a mobile device supported by IoT system. In this artifact, sensor-incorporated IoT device collects various data corresponding to agriculture, and later managed data is stored over a cloud storage service. The MapReduce technique is utilized to implement big data analytics over the cloud to predict suitable fertilizer applications that could boost crop production. The paper's outcomes positively suggest that the fertilizer prediction based on the soil parameters achieved a higher production rate assisting the farmers. However, observations on the paper prove that the research work lacks predicting climatic conditions, which is also one of the critical factors that decide the soil's health [13].

Guillén et al. (2017) published a research publication focused on tracking frost climatic targeting the farmland area around the Murcia region. The unexpected frosting variations in climate caused abrupt disparities in temperature change within a brief period. Henceforth, unforeseen variations in the level of temperatures primarily affected the yield in crop cultivation, predominantly affecting the production to income ratio. A well-known solution to the problem is to take preventive measures that could protect the crop from abrupt changes in climatic circumstances. To effectively implement the solution to the problem, the article's authors proposed IoT network architecture to collect the weather attributes in real time. Based on the collected data, the system estimates the occurrence of the frost with the aid of standard forecast data available. Outcomes of the work evidences the accurate tracking prediction of frost concerning the targeted area. As the future scope of the work, researchers recommend the deployment of soil sensors that could promote the system's utilization to improve soil health by predicting required nourishment [14].

Vijayabaskar et al. (2017) proposed an IoT system with NPK sensors that collect the data relevant to the nutritional contents of soil under test. The proposed technique acts as a complete agricultural solution package to the farmer where the system could predict the fertility of the soil. It could also recommend an apposite crop to enhance the production to profit ratio based on fertility level. Further to enhance the nourishment of the soil, the system performs a step ahead that also advocates the utilization of proper fertilizer. The core concept of the system's implementation relies on predictive analysis, and the researchers have taken advantage of the agro algorithm in the Hadoop technique. Results achieved through the research were promising and can open further scope for research in the area [15].

Rezk et al. (2021) developed an IoT-based intelligent system for efficient prediction of the productivity of a specific crop and the corresponding drought conditions for the same. The prediction system of the proposed methodology is supported by the incorporation of a novel machine learning technique called WPART, a novel combination of wrapper feature selector and PART classifier. The proposed work utilizes five standard datasets to test the accuracy level. Experimental outcomes and comparative analysis published in the article prove the system's higher ability in attaining the highest accuracy rate of 98%, which is way better than any other previously implemented system. As a part of the future space, researchers suggested incorporating time series-based classification and further extension by adding the soil attributes that could further boost crop cultivation in terms of investment to profit ratio [16].

Shinde and Kulkarni (2017) presented a review article covering disease detection in the crop by utilizing a machine learning-based IoT model. The author's incorporated the usage of relevant sensors for collecting data pertinent to atmospheric factors. Cloud storage is efficiently used to gather the collected data. It is fed into the machine learning algorithm on a real-time basis to predict the possible crop disease based on the climatic conditions. In their research artifact, researchers have focused on analyzing the prediction accuracy for predicting a leaf rust disease using three regression algorithms: GPR, SVR, and PLSR. Experimental investigations positively emphasized that GPR achieved a higher rate of accuracy for identifying the suitable disease. Further, authors have concluded by motivating that the problem can be further prolonged to include the apposite prediction fertilizer that can further enhance the crop yield [17].

Pravallika et al. (2020) proposed a cost-efficient smart IoT system for predicting crop cultivation based on the fertility level of the soil. The research work focused on boosting seasonal cropping due to the variation in the soil fertility in the regions, largely depending on climatic factors. In this regard, relevant sensors were used to collect data corresponding to the soil nutrients and compared in real-time with the organized values obtained from standard datasets. Based on the comparison, a suitable crop for prediction is identified. On carrying out the exhaustive investigation, it is found out that the work exposes the gap for incorporating classification algorithms that can perform an accurate prediction [18].

In their research artifact, Reshma et al. (2020) implemented an IoT model to continuously gauge the quality of the soil in terms of its fertility level and predict the suitable crop. To measure soil attributes, suitable sensors were employed to collect data concerning humidity, PH, moisture content, etc. For the efficient processing of the collected data, the cloud storage technique is incorporated into the proposed approach. To further enhance the accuracy of prediction, the technique also employed the usage of SVM classifier and decision tree systems. Experimental consequences attained from the proposed approach uphold the system's accuracy for ably predicting the relevant crop based on soil factors. However, the proposed concept lagged in using modern machine learning classifiers that could better predict time-invariant datasets [19].

Priya et al. (2018) recommended an IoT model coupled with big data analytics and machine learning systems for predicting the suitable crop that could gain higher productivity based on the geographical factors across the farmland. As a part of their study, researchers have targeted real-time conditions in connection to Telangana farming to boost the income to profit ratio of the farmers of that region. Data pertaining to the suitable farmland is accumulated through sensors connected to dedicated IoT systems, which are then loaded over cloud storage systems. To efficiently process enormously gathered data, big data analytics is applied in terms of the map-reduce tool. Further required prediction on the processed information is performed through the incorporation of the naïve-Bayes classifier. For the able training of the classifier, researchers have utilized the real-time data obtained from the agricultural sector of Telangana. Experimental outcomes were promising and motivate the further utilization of the technique to a specific region of interest to uphold the farming profession [20].

Nikhil et al. (2020) articulated their research work using the combination of IoT and machine learning techniques that offer essential farmer-friendly services. The application eases the overhead of the farmers by providing necessary information frequently and also taking specific preemptive measures. Suitable sensors connected to the Raspberry Pi system collect the relevant data that characterize the crop's health and atmospheric conditions across the farmland. Accessing the gathered data, a designed SVC classifier performs the prediction of suitable crops based on frequently collected data. A notable factor of the claimed research work is that researchers have ensured the frequent training and testing of the model by utilizing 80% of its own collected data for training and the rest for testing. Further, the authors have also incorporated trained CNN models to recognize any animals' intervention into the farmland captured via a connected camera as an add-on to the system. To alert the intervention and activate the camera, suitable IR sensors have been incorporated. Results projected were promising, but the system fails to predict the crop based on time-invariant climatic conditions, which is a gap to be addressed [21].

In a research exertion published by Munoz et al. (2020), they have proposed an innovative technique using an IoT device applicable for crop production in the greenhouse area. The proposed methodology was implemented to underlying cloud-oriented REST Web services for collecting data relevant to the greenhouse cropping system. Specific greenhouse models were designed considering the suitability of the greenhouse cropping system and are connected to the IoT systems monitoring the farm area. Data acquired by the IoT systems are mapped to specific greenhouse models to predict the relevant model for greenhouse cropping. Over the Web, any registered farmers can benefit from the services connected to their farmland geographical area. Even though the system acts as a service-based application for the connected farmers, the system fails to prove its accuracy. Moreover, it fails to track many real-time factors relevant to time-invariant climatic conditions. Considering the backlogs of the system, there is a scope to incorporate machine learning models that could learn the behavior on a time series basis and provide better predictable results [22].

Priya and Yuvaraj (2019) proposed the implementation of IoT connected to a class of artificial neural network systems known as multilayer perception models meant for crop prediction to promote the productivity of the agriculture yield. The proposed model consisted of a dedicated IoT system with the relevant sensors mounted for collecting the data connected to the geographical factors like temperature, moisture content, humidity, etc. Acquired data is classified using a trained artificial neural network model for predicting the suitable crop that can enhance the yield. Each time on a prediction, the model is implemented to get retrained with the recent data gathered. As a standard, to validate the model each time, researchers have dedicated 80% of the data for training purposes and the rest for testing purposes. Experimental investigations presented an accuracy level of 97%, which upholds the able usage of neural networks and artificial intelligence. However, as a part of future enhancement, researchers suggested the extension of work to even predict the application of suitable fertilizers for enriching soil nourishment, and the personal review widens the gap for using time-invariant classification that could perform the prediction by even considering climatic variations [23].

In their research artifact, Venkatesan and Anandhi (2017) proposed an IoT-based automated agricultural monitoring system capable of automatically controlling the irrigation system based on certain factors accumulated via connected sensors. Sensors are used to gather the attributes deciding the hydration level of crops, and suitable actions are taken to irrigate the crops frequently. The system was the first of its kind, which is farmer-friendly and also eliminates a lot of farming overhead by not having to keep an eye on the status of the water supply. Apart from that, the system acts eco-friendly by preventing unnecessary water wastage by not supplying above the requirement. The outcomes presented to meet the purpose of the research. Still, based on the data being gathered through the sensor, there is a vast scope to extend the work further to predict the soil's required nourishment across the farmland geographical area. Thus, the proposed idea opens a wide door to advance the research in the lagging area [24].

Gupta et al. (2020) developed an IoT system that monitors environmental factors affecting crop yield and predicts the harvesting of a suitable crop by employing statistical data mining techniques. The method comprises a simple node MCU with the sensors connected to acquire the soil's temperature, PH, and moisture. Received data is then classified using trained statistical data mining models like the random forest, SVM, and KNN to predict a suitable crop based on statistical parameters. One of the best things about the conducted research is the utilization of real-time datasets accessible by the agricultural board over the public domain. Experimental investigations recorded a better performance by the KNN with a prediction accuracy of about 88%. On analyzing the research article to the fullest, there were slight lags in the research work that failed to cover the prediction of time-invariant data. But as a future opportunity, researchers have indicated the incorporation of artificial neural networks to gain a higher prediction accuracy rate [25].

3 Proposed System

Addressing the various pitfalls mentioned in our literature review, we have designed our proposed system to overcome them. Our proposed system is diagrammatically represented in Fig. 1.

The system is broadly divided into three main units. They are the (1) Edge devices (2) Relay units and (3) Intelligence unit. The three units work in tandem with each other to achieve a perfect symphony of recommendation-based rules. The units are explained in detail under the subsequent sections.

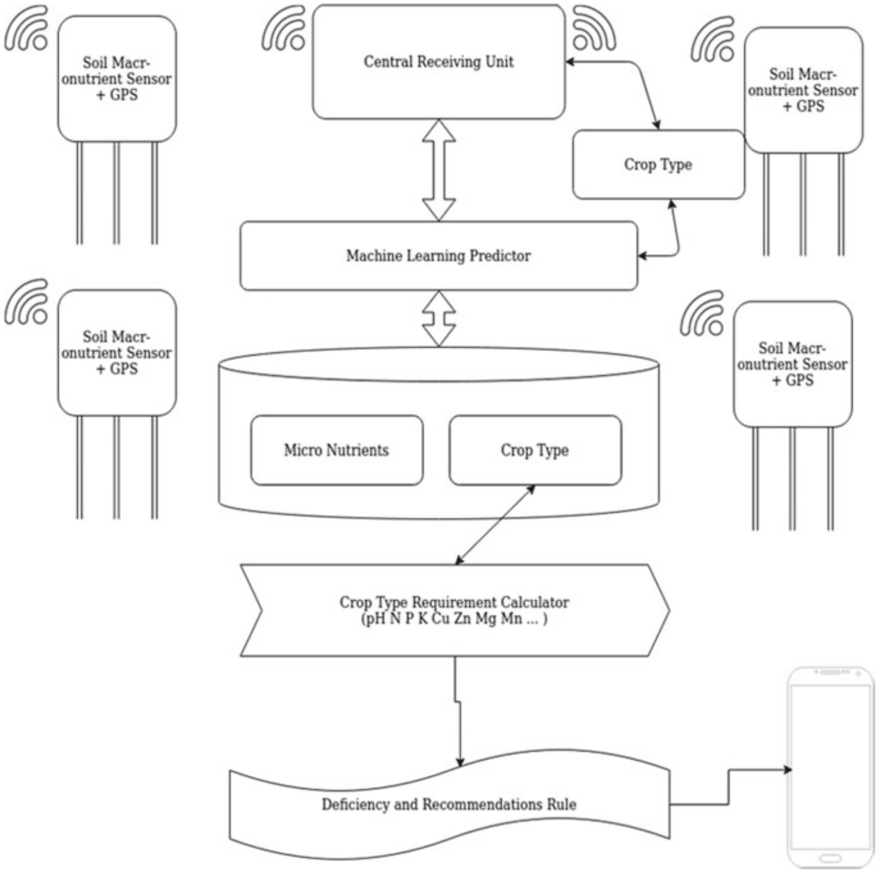


Fig. 1 The architecture of our proposed system

3.1 Edge Units

The edge units are the end units of the entire system. These devices gather data from the environment as well as relay their location. The end units consist of the following sensors.

3.1.1 Macronutrient Sensor

The main job of this sensor is to sense soil macronutrients in a detailed fashion. The primary macronutrients sensed are nitrogen (N), phosphorous (P), and potassium (K). The data received from this sensor will be in the form of milligrams per kilogram denoted in SI form as mg/kg. It is noteworthy to assume that the reading will not remain the same since the soil is overly complex and has many parameters that drastically vary. In addition to that, the reading from the sensor is subjected to environmental noise. To avoid these conditions, we take average and median readings along a specified time interval. The mathematical formulae governing these are shown in Eqs. (1) and (2).

$$\mathrm{Avg}_{\mathrm{frame}} = \left\{ \frac{\sum_i^n \mathrm{Reading}_i}{n} \right\} \quad \text{for } t_i \in (i\ldots n) \tag{1}$$

$$\mathrm{Med}_{\mathrm{frame}} = \{\mathrm{med}(\mathrm{Reading}_i)\} \quad \text{for } t_i \in (i\ldots n) \tag{2}$$

where $\mathrm{Avg}_{\mathrm{frame}}$ and $\mathrm{Med}_{\mathrm{frame}}$ denote the average and median reading from the sensors in a particular time frame, respectively.

3.1.2 pH Sensor

The functionality of this sensor is to sense the acidity of the soil. The pH value calculates the amount of hydrogen ions in the soil denoted as H+. The more the ions H+, the more acidic the soil is. The pH value ranges between 1 and 14, where 1 is highly acidic and 14 to be extremely basic. Different plants need ideal conditions of pH to grow judiciously. Sensing these values from the soil is an easy task, and it does not vary suddenly until there are weather changes. To avoid erroneous readings from the sensor, we calculate the modal reading, which is governed by Eq. (3)

$$\mathrm{Modal}_{\mathrm{frame}} = \mathrm{Max}\left(\overbrace{\mathrm{Reading}_i}^{\text{count}} \right) \quad \text{for } t_i \in (i\ldots n) \tag{3}$$

3.1.3 GPS Sensor

The GPS sensor's job is to find out the absolute location of the sensor on planet earth. Creating a relative location is exceedingly difficult to support since it requires the usage of trilateration and the creation of a zero point. With the help of the absolute definition, it becomes easy to pinpoint this location on the map and the de-facto standard for coordinate access. This only happens once during the lifetime of the installation because the sensor box does not move. If there was movement, the GPS calibration is performed again to get accurate coordinates. The circuit diagram of the data collection setup for the end nodes is shown in Fig. 2 [26].

Our end node also reads the acidity and the electrical conductivity of the soil. We accomplish this by inserting a pH meter and a capacitive soil moisture sensor into the soil. Unlike the NPK sensor, these reading is fast enough and supply less

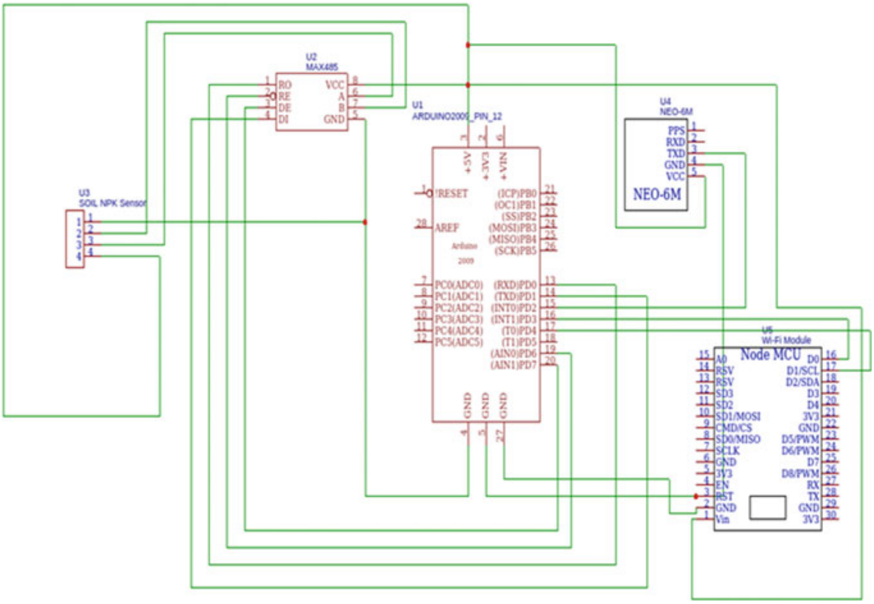


Fig. 2 Circuit diagram of edge unit with sensory setup and the communications unit

accurate readings. We compensate for this by taking mean readings in large intervals to reimburse spikes and faulty pH and water conductivity readings. The circuit diagram for the pH and soil moisture sensor is revealed in Fig. 3.

As we can observe from the above diagram, the pH sensor cannot directly read values from the soil and requires a special breakout board to communicate between the sensor and end node. Hence, the readings required must first be calibrated by installing the container in some standard pH solution. We perform this act by adding the sensor to a solution of lime water for about a minute.

3.1.4 Battery Module

The sensors provide the job of providing the technical specifications of the soil and its surrounding environment. The sensor cannot function on their own and require power. Though batteries provide sufficient juice to build up the sensors' capabilities, it is not enough and must be replenished. This makes the application very tedious and cumbersome. To aid and hasten the replenishment, we have added solar panels that help charge batteries in the day. The detailed layout of the charging unit is shown in Fig. 4.

Here, we have used a charging module called TP-4056, which is a low-cost IC-based comparator charger that supports batteries up to 9v. It is a LiPo battery charger that uses solar energy and compares battery voltage. It also has an inbuilt

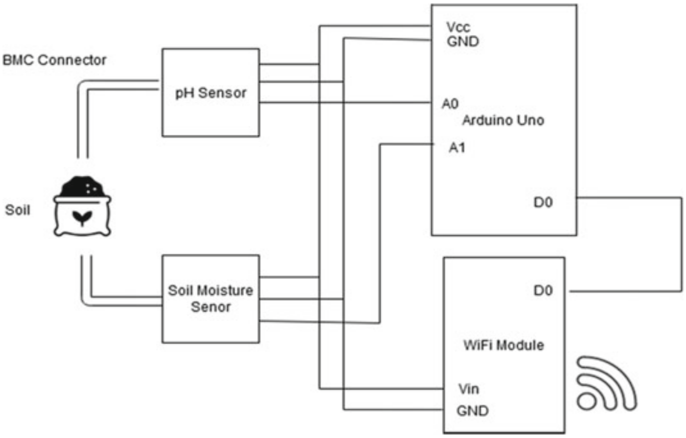


Fig. 3 Architectural setup of the pH and the soil moisture sensor

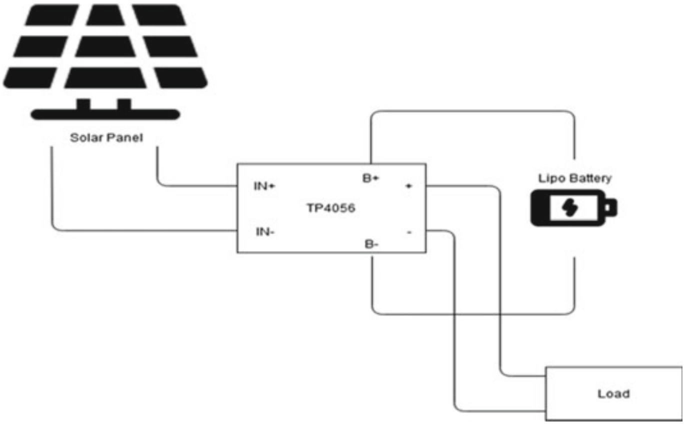


Fig. 4 Working model of TP-4056 module with solar panel and battery connected

charge compensator and voltage regulator to manage load fluctuations. The supported panel voltage ranges between 6v and 12v. This setup can last for up to three years with minimal interaction, thus making it one of the best module for running independent sensors in the field.

From the above figure, we have used a charging module called TP-4056, which is a low-cost IC-based comparator charger that supports batteries up to 9v. It is a LiPo battery charger that uses solar energy and compares battery voltage. It also has an inbuilt charge compensator and voltage regulator to manage load fluctuations. The supported panel voltage ranges between 6v and 12v. This setup can last for up to three years with minimal interaction, thus making it one of the best module for running independent sensors in the field.

3.2 Relay Units

The relay unit's primary function is to act as a centralized medium to collect data from various sensors and collate them in one single location. The edge unit communicates using Wi-Fi and LoRa. The centralized unit acts as a Wi-Fi repeater as well as a router for LoRa communications. When data is collected in the relay unit, it becomes difficult to assess the sensor's location where the data originated. Hence, we resolve this confusion by adding IDs as GPS coordinates to locate the signal and identify and authenticate the sensor providing the reading. The relay unit authenticates by creating a general look-up table for all the sensor entries for wrong entry flagging. The relay unit uses a protocol that allows for flexible subscribing of end nodes called MQTT. All this is accomplished by using a custom-made IoT framework done by us. The data collected by each node is sent from an end node in a prespecified frame format. This data is then passed on to the next unit, the intelligence unit, and is explained in Sect. 3.3.

3.3 Intelligence Unit

The intelligence unit forms to be the brain of the system. It runs various machine-level algorithms and certain deep learning algorithms to assess the best possible prediction of crops. Note that the data is also fetched from the ICAR site for cross verification and assessment of micronutrients. The algorithms used are regression type, and the assessment is performed using all related data from the sensors. We have also constructed custom-made neural networks of three main categories: the long, short, and medium networks, representing the number of hidden layers in the network. The assessment of the crop type is performed using the data provided by ICAR, and deficiency analysis is performed using rule-based signatory assessment. The equation governing this is shown in (4).

$$\text{Deficiency}_{\text{rule}} \overset{\text{def}}{=\!=} \coprod_{1}^{n} \left(\overbrace{\text{Prediction}_i}^{\text{LookupTableRules}} \right) \tag{4}$$

The rule-based signatory assessment is performed using various machine learning techniques grabbed by human experts in the field of agriculture. It forms to be the knowledge base of our system.

As mentioned earlier, our custom-made deep neural networks are constructed using regression-based dense architectures shown in Fig. 5.

As shown in Fig. 5, our deep neural network is a regression-type network that accepts inputs as NPK values and outputs predicted NPK values over a specified location. The same is performed for soil pH and electrical conductivity. We use polynomial regression as our model to fit the eccentric values. The term long, short,

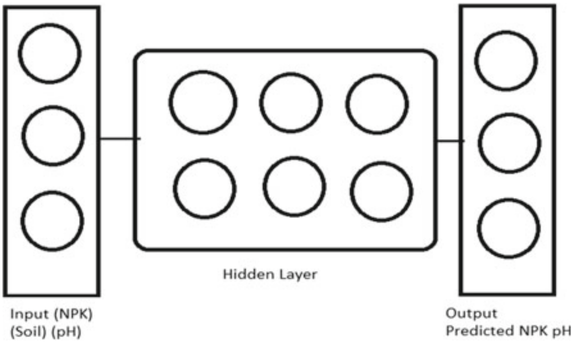


Fig. 5 The architecture of the custom-made deep neural networks

and medium networks only indicate the number of hidden layers used in the network. A typical short network means it only has less than ten layers of hidden dense functions. A medium network has more than ten and less than twenty layers, and a long network has a minimum of thirty layers. The number of hidden layers choosing is entirely trial-based and purely experimental. Each layer has a minimum of fifty nodes that are densely connected with a sigmoid and a ReLU tangent function acting as a threshold.

3.4 Crop Prediction

We have also used time-invariant classification for crop prediction since crops depend purely on climatic conditions of the locale. Performing this task using normal dense networks deems impossible since they are time-variant and require too many inputs. To achieve this, we use a time-invariant network called LSTM, abbreviated as long short-term networks. These networks observe time series and predict the classified output based on the current trending line. LSTM comes from a family of recurrent neural networks that observe time series data. The architecture of LSTM is shown in Fig. 6.

The input for the network is soil parameters, i.e., NPK, pH, EC, temp, rain, humidity, and macronutrient factors over location and time. The hidden layers are interconnected over a sequence node in a recurrent fashion, creating a time trending series. We have also implemented a forget function to forfeit older trends in time trending series. The network outputs a classified response of the crop type used in the current locale.

The training data obtained for the neural networks are taken from the local data collected and the data from the ICAR dataset. We have split our data into 80–20 for prediction, which indicated that 80% of our data is used for training and 20% is used for testing. The system is then validated on the real-time dataset obtained solely from local data.

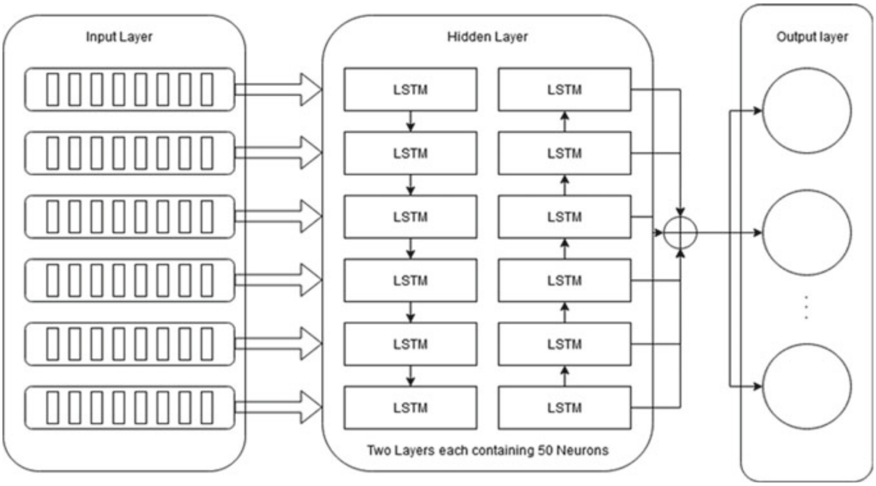


Fig. 6 LSTM network model used for classification

4 Results and Discussions

This section gives an elaborate discussion on the results and the graph obtained on the implementation of our system. The section is divided into two subsections as shown below.

4.1 Hardware Equipment's Used

To demonstrate our proposed system, we have used the following hardware which is divided into three units.

1. The primary data collection unit is custom-made by installing GPS NEO06MV2 and JXBS-3001-TR, a soil macronutrient detector from JXCIOT. Along with these, we have also retrofitted a soil pH sensor module from Think robotics and an electrical conductive ORP sensor from ROBU electronics.
2. The central processing and receiving station is an edge device on a Raspberry Pi running Raspbian OS. The transmitting and the receiving stations communicate using a custom-made framework implemented on the framework platform [27, 28].
3. The intelligence unit runs as a service on Dual Intel Xeon ES-2609V48C 1.7 GHz 20M 6.4GT/s with 128GB RAM possessing Dual Nvidia Tesla p100GPU with 3584 Cores having a maximum operating speed of 18.7 Tera Flops [29, 30].

4.2 Datasets Used and Locale Data Collection

The agricultural database shown in the methodology is taken from the ICAR dataset possessing details on the average macro and the micronutrient reading of a particular region. The location used was Karkala, which falls under the Udupi district of Karnataka.

4.2.1 Local Data Collection

The results obtained from our soil NPK sensor are susceptible, and values are sent only when inquiry frames are sent to the sensor via the MAX485 module. The frame format corresponding to inquiry and response frames related to different sensor nodes are presented sequentially in Tables 1, 2, 3, 4, 5 and 6. In each of the tables, AC represents address code, FC stands for function code, RSA abbreviates to register start address, and RL denotes register length. The CRC values are used to verify the data integrity of the reading. The response frame value is hexadecimal in nature and must be converted to digital.

On conversion, from the experimental findings, obtained values from the nitrogen sensor is 33 mg/kg, phosphorus sensor is 37 mg/kg, and potassium sensor is 49 mg/kg of soil.

For testing purposes, we have recorded the macronutrient readings through one week of fifteen-minute intervals. The different sensor readings were collected from January 12, 2021 to January 18, 2021 in Karkala Taluk of Udupi District. A total of 12 end nodes were placed across a distance of 500 m in gardens, fields, and dry vacant areas. The sample reading from one sensor placed in Mala at 13.2391°N, 75.1068°E is shown in Fig. 7.

As we can see can observe the readings of nitrogen (N) varied across 86.704 mg/kg to 100.705 mg/kg, phosphorous (P) varied across 23.572 to 53.811, and potassium (K) varied across 49.882 to 53.591 mg/kg. The summary of the collected samples is shown in Table 7.

Similarly, the resulting graph of the pH and the electrical conductivity values of the same sensor is shown in Figs. 8 and 9, respectively.

As we can see, the pH and EC readings varied across (5.71, 5.76) and (0.03, 0.04), respectively. The statistical summary of the readings is shown in Table 8.

Table 1 Inquiry frame format for neitrogen

AC	FC	RSA	RL	CRC_L	CRC_H
0x01	0x03	0x00 0x1e	0x00 0x01	0xE4	0X0c

Table 2 Response frame format for nitrogen

AC	FC	Number of bytes	Nitrogen value	CRC_L	CRC_H
0x01	0x03	0x00 0x02	0x00 0x21	0xb9	0X9d

Table 3 Inquiry frame format for Phosphorous

AC	FC	AC	Phosphorous value	CRC_L	CRC_H
0x01	0x03	0x00 0x1f	0x00 0x01	0xb5	0Xcd

Table 4 Response frame format for phosphorous

AC	FC	Number of bytes	Phosphorus value	CRC_L	CRC_H
0x01	0x03	0x02	0x00 0x025	0xb5	0Xcd

Table 5 Inquiry frame format for potassium

AC	FC	RSA	Potassium Value	CRC_L	CRC_H
0x01	0x03	0x00 0x20	0x00 0x01	0xb5	0Xcd

Table 6 Response frame format for potassium

AC	FC	Number of bytes	Potassium value	CRC_L	CRC_H
0x01	0x03	0x02	0x00 0x031	0xb5	0Xcd

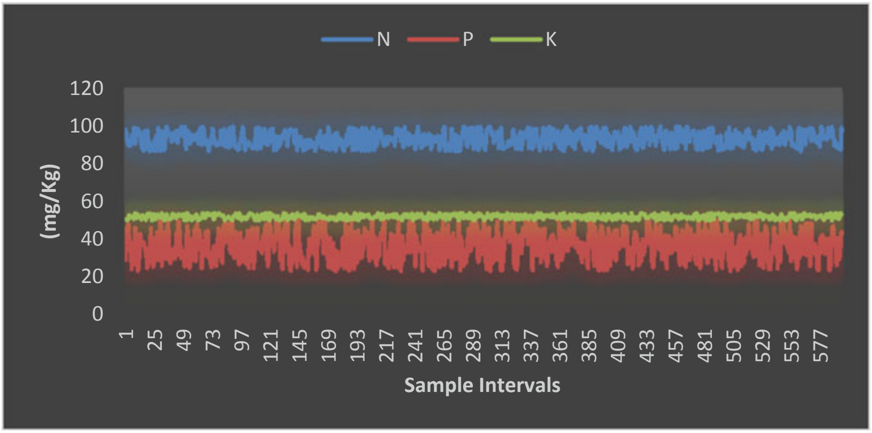


Fig. 7 Graph showing the typical NPK values of a single sensor

Table 7 Statistical summary of NPK values obtained from sensor

Parameter	Nitrogen (N)	Phosphorous (P)	Potassium (K)
Min	86.704	23.272	49.882
Max	100.015	50.811	53.951
Average	93.20474	36.66649	51.94183
Std dev	4.064269	8.010896	1.153863
Variance	16.51828	64.17446	1.331401

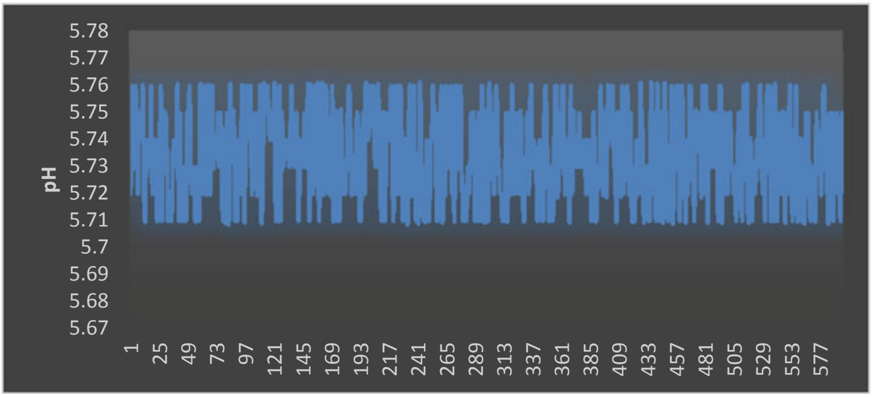


Fig. 8 Graph showing the standard pH values of a single sensor

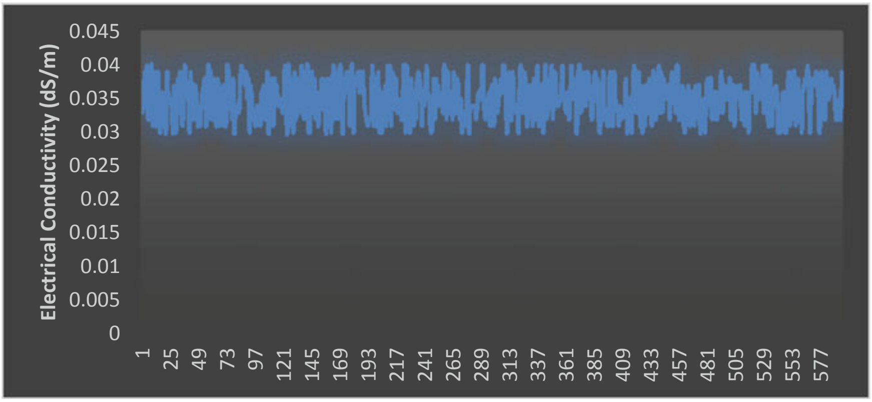
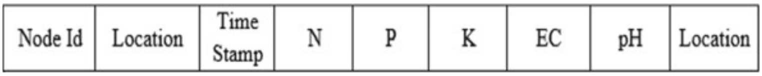


Fig. 9 Graph showing the standard electrical conductivity values of a single sensor

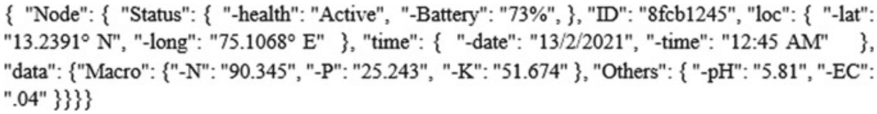
Table 8 Statistical summary of pH and electrical conductivity values obtained from sensor

Parameter	pH	Electrical conductivity (dS/m)
Min	5.71	0.03
Max	5.76	0.04
Average	5.734343	0.035002
Std dev	0.017036	0.003062
Variance	0.00029	9.38E−06



Node Id	Location	Time Stamp	N	P	K	EC	pH	Location

Fig. 10 The frame format of the data received to the central accumulator



{ "Node": { "Status": { "-health": "Active", "-Battery": "73%", }, "ID": "8fcb1245", "loc": { "-lat": "13.2391° N", "-long": "75.1068° E" }, "time": { "-date": "13/2/2021", "-time": "12:45 AM" }, "data": {"Macro": {"-N": "90.345", "-P": "25.243", "-K": "51.674" }, "Others": { "-pH": "5.81", "-EC": ".04" }}}}

Fig. 11 Sample data format to the central receiver

Table 9 A brief summary of the neural network models used

Neural network type	Number of hidden layers	Average nodes per layer	Total parameters
Short	5–7	220	300,345,23
Medium	15–20	300	700,325,256
Long	35–50	300	1,345,456,234

4.2.2 Central Station Data Collection

The data received see from the end sensors are collected at the central station, which is an edge node. The station receives data from each node in a frame, as shown in Fig. 10, and Fig. 11 presents the data sent from a sample end node to the central receiver.

4.2.3 Intelligence Unit Calculations

The data received is served as a training resource to predict the soil type of the area. We perform this task by rigorously training with pre-set machine learning models. The training is committed by extracting the data from the ICAR dataset with soil types of various taluk spanned across India. We have used KNN, linear regression,

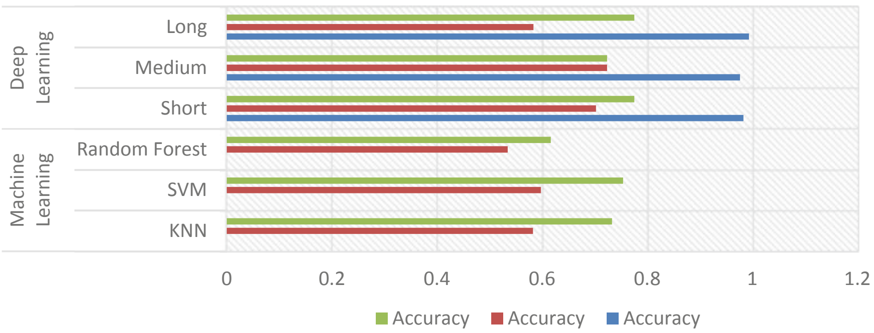


Fig. 12 Graphical representation of the accuracy analysis of different machine learning models

Table 10 Accuracy of the predicted soil parameters for different machine learning models

Model		Accuracy		
		Training (%)	Validation (%)	Real time (%)
Machine learning	KNN regressor	–	58.25	73.28
	Linear regression	–	59.75	75.42
	Polynomial regression	–	53.45	61.64
Deep learning	Short	98.32	70.23	77.56
	Medium	97.65	72.35	72.36
	Long	99.37	58.35	77.54

polynomial regression, and custom-made deep neural classifiers of three variants to categorize soil types. Our custom model consists of three feed-forward artificial neural networks varying in the hidden layers. We classified them as short, long, and medium networks. The overall structure of the three networks is shown in Tables 9 and 10 gives the summary of the obtained accuracy of the different models tested under standard conditions. The graph plotted in Fig. 12 presents the graphical analysis for the data presented in Table 10.

As observed from Fig. 12, it is proved that the overall accuracy of our custom-made networks performs better in terms of real-time accuracy with a short neural network topping with an accuracy of 77.56%. The training accuracy of our long deep neural network tops at 99.37%, showing overfitting of data.

We have also performed mapping of soil types to crop type mapping by creating a long short-term neural network for classification in terms of time series. Our LSTM network consisted of a total of 200 neurons flattened across a dense classification to different types of crops in the Kharif and Rabi seasons. The LSTM neurons are bi-directional and flattened at the output layer to classify the crop types. We have chosen a total of six crop types spanning across the Karnataka state. The selected crops are rice, ragi, areca nut, coconut, cashew, and banana. We have

Table 11 Accuracy of the LSTM for crop prediction

Network type	Training accuracy (%)	Validation accuracy (%)	Evaluation accuracy (%)
LSTM custom defined	89.32	85.46	83.32

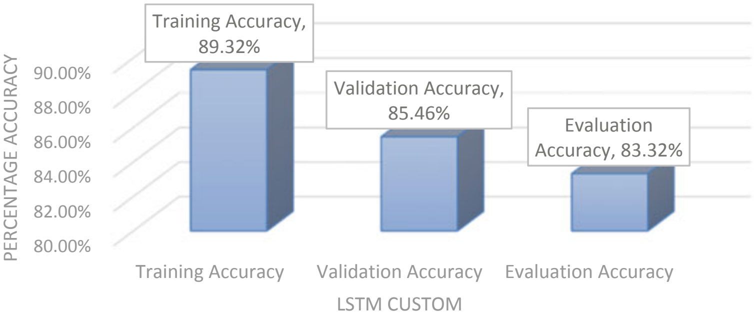


Fig. 13 Graphical representation of the LSTM model accuracies

Table 12 Confusion matrix data of various crop types used for classification under LSTM

	Rice	Ragi	Arecanut	Coconut	Cashew	Banana	Precision
Rice	**800**	100	0	0	50	0	**80%**
Ragi	50	**700**	50	50	100	50	**70%**
Arecanut	25	125	**800**	25	16	9	**80%**
Coconut	9	50	56	**800**	50	25	**80.8%**
Cashew	6	25	25	0	**779**	1	**93.19%**
Banana	0	0	16	10	5	**900**	**96.67%**
Recall	**89.89%**	**70%**	**84.48%**	**90.39%**	**77.9%**	**86.96%**	**Overall 83.32%**

The bolded values indicate that they are prominent and higher compared to other obtained values

rigorously trained our network using the ICAR dataset of crops grown in each taluk with respect to soil types. Our validation split is thirty percent of the standard dataset. The resulting Table 11 shows the overall accuracy of our network.

From Table 11, we can deduce that the LSTM network is able to accurately predict the exact crop types with a whopping accuracy of 83.32%, which is fairly accurate. Figure 13 shows the graphical representation of the same.

We have also computed a confusion matrix across all six basic types of crops to calculate the overall classification scenario. Table 12 shows the results.

It is evident from Table 12 that classification of crop type with respect to seasonal soil type performed very well with banana plantation backed up by cashew, coconut, rice followed by ragi.

Table 13 Confusion matrix for Indian seasons: Kharif and Rabi

	Kharif	Rabi	Precision
Kharif	**750**	50	**93.75%**
Rabi	50	**750**	**93.75%**
Recall	**93.75%**	**93.75%**	**Overall 93.75%**

The bolded values indicate that they are prominent and higher compared to other obtained values

Considering the seasonal classification of crops, we have also used the same LSTM network to classify Indian seasons, i.e., Kharif and Rabi. Table 13 depicts the confusion matrix of the Kharif and Rabi seasons.

As per our observation made in Table 13, we can infer that our trained network was able to classify our local seasons with an overall accuracy of 93.75%.

In order to increase soil fertility, we have designed a rule-based recommendation system that uses the aforementioned predicted parameters and decides what content needs to be added to the soil. This information is deduced from experts in the field of agriculture and is tabulated in the rule table. The classes of values used for macro and micronutrients are adequate, surplus, deficient and too deficient. The categories of pH are acidic, basic, and neutral. The various categories are decided from the values predicted by the agricultural expert domain. Table 14 presents the snapshot of the rules constructed.

As said before, we have deployed this rule policy in the village of Miyar in Udupi district and have calculated reading values over a period of six months. The values of these are tabulated in Table 15.

From Table 15, we can infer that there is a significant change in the percentage level of macronutrients. The overall change observed is about 44% which is significant for crop and soil fertility. Similarly, taking an overall reading from various sensors, we see that the global change of the proposed system comes to around 33%.

5 Conclusion and Future Scope

Agriculture in modern India is very important for the development of its GDP. However, farmers in India have a large co-dependency with traditional farming techniques. Though these techniques were in practice ages ago, too many seasonal changes caused havoc, thereby increasing crop losses and soil fertility. Recently researchers have gained a lot of interest in increasing crop yield by micro monitoring soil and seasonal changes. In this same spirit, we have proposed a system that allows a farmer to increase soil-crop output. We accomplish this by merging two leading technologies, namely the Internet of things and deep learning. The prior deploys sensors in every field to collect soil and environmental data later to be agglomerated and fed to the latter. The intelligence unit performs detailed

Table 14 Rules constructed for the nourishment of soil fertility

Rule Tag	pH	Nitrogen (N)	Phosphorous (P)	Potassium (K)	Sulfur (S)	Zinc (Zn)	Boron (B)	Iron (Fe)	Copper (Cu)	Manganese (Mn)	Solution
1	Acidic	Surplus	Too deficient	Too deficient	Surplus	Deficient	Deficient	Surplus	Surplus	Surplus	**General**: Add 5 g of zinc sulfate and 2.5 kg of lime per liter of water **Optimal**: Urea 435 g/plant, rock phosphate 556 g/plant, potassium chlorate 585 g/plant
2	Neutral	Surplus	Deficient	Deficient	Surplus	Deficient	Deficient	Surplus	Surplus	Surplus	**General**: Add 1 g of zinc sulfate and 0.5 kg of lime per liter of water **Optimal**: Urea 235 g/plant, rock phosphate 256 g/plant and potassium chlorate 285 g/plant
3	Basic	Deficient	Surplus	Surplus	Surplus	Deficient	Deficient	Deficient	Deficient	Deficient	**General**: Add 1 g of zinc sulfate and 0.5 kg of copper sulfate per liter of water **Optimal**: Spray micronutrient concentrate mix minimum twice in a day

Table 15 Macronutrient value readings obtained in Miyar village

Reading value	Nitrogen	Phosphorous	Potassium
Beginning	87.323 (adequate)	23.56 (too deficient)	30.23 (too deficient)
+2 months	94.323 (surplus)	30.453 (deficient)	38.56 (deficient)
+2 months	96.323 (surplus)	40.453 (adequate)	45.46 (adequate)
Summary	Increase	Increase	Increase
Percentage	10.3%	73.9%	49.6%

analysis on collected data and predicts the accurate crop to be planted in the appropriate season. It also predicts farmer-friendly solutions to the farmer to provide adequate soil fertility. We have rigorously tested our system by installing it in the coastal villages of the Udupi district of Karnataka state. Observational results revealed that our system granted an 83% overall accuracy in predicting seasonal Kharif and Rabi crops. The system also provided farmer-based solutions also increased the soil fertility rate by a factor of 33%, thereby increasing crop yields.

Though our system proves to fulfill farmer's needs at present, it still needs further development. In the future, we can enhance crop yield by focusing on pest management and organic farming techniques. Furthermore, early disease detection and prevention are also trivial for dealing with sudden crop devastation. Hence, there is a decent scope to extend the work by incorporating a deep learning module that could possibly monitor the crop's health. Another primary concern in many areas is the threat of wild animals destroying the farmland without any premeditation. However, precautionary measures were incorporated to avoid their entry through the usage of certain life-threatening ailments considered as inhumane practices. In this regard, our system can also be integrated with Infrared sensors that can sense animal intervention. A threatening noise can be produced to keep away the animals.

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Smart Farming with IoT: A Case Study

Roopashree, Kanmani, Babitha, and Pavanalaxmi

Abstract The agriculture sector contributes a great role in the Indian economy. The major problem encountered by the farmer is low yield due to varying infrastructure, poor storage, inadequate access to the market, and timely delivery. The digital transformation is required to change traditional farming to a smart agriculture system using IoT. There are different areas in which IoT can be applied in the agricultural field such as to know the weather conditions, to observe and monitor the field, to analyze the crop health, planting, spraying the fertilizers, etc. By using a huge amount of data, accumulated by IoT smart sensors, the farmers can monitor the weather and soil condition. Sophisticated decisions can be taken to choose the precise fertilizers and pesticides to get a high yield. IoT-based smart farming improves the entire agriculture system by monitoring the field in real-time. Examinations are made on those sensor-empowered IoT frameworks that offer shrewd and keen types of assistance toward smart farming The objective of this chapter is to report a case study of the application of IoT in the agriculture field. Research papers on applications of IoT in the agriculture sector from different publishers are referred to prepare the chapter.

Keywords IoT · Smart agriculture · Wireless nodes · Drone technology · Precision agriculture

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1 Introduction

Agriculture has been the most basic practice from the earliest starting point of human progress. Over 70% of the Indian populace relies upon agriculture for their day-by-day work. As the commitment of agribusiness to Gross homegrown items is declining these days, it is crucial to help crop profitability with productive and compelling water use. In agriculture, the water system is a significant factor as the storm rainfalls are inconsistent and not certain. Agriculture notwithstanding water shortage has been a major test. There exists an interest for monstrous specialized information to make water system systems more productive.

Weather forecasts play a major role in agriculture. Changes in climate impact majorly on food harvesting and security. Nearly, 1 billion people are in the need of healthy food. The global food production sector needs to be updated in terms of food harvesting and production by double in another 30 years.

The increase in population in the world is enforcing a shift toward an internet-based agricultural system. Reduction in the human powers in an agricultural field forcing us to think toward the automated system which could be used to control, monitor, analyze the fields. Diminishing natural resources makes renewable energy resource usage in many developing countries. Therefore, the utilization of the Internet of Things alongside different advancements is utilized to improve the operational effectiveness and profitability in the horticulture area. The Internet of things has renovated real-world objects into smart devices. The Internet of Things connects each object of the world in a way the people can control them over the internet. Web server IoT assumes a significant part in the agriculture business which can take care of 9.6 billion individuals on the Earth by 2050.

As the world population increasing exponentially, the production of quality food in more quantity is essential. Agriculture is the source of food, where only human intervention is not satisfying the world's demand in producing subsistence. Also, the farmers are facing huge challenges in growing crops. Deprivation of crops happened due to various reasons like an improper selection of soil for a particular crop, loss of crops during manual harvesting, lack of finding plant diseases in early stages, pests, etc. Most of these issues can be resolved by involving Robots and UAVs with the Internet of Things control in the field of agriculture. Robots and UAV's play a very important role in watering the field, harvesting/cutting the yields with a fewer number of laborers and less cost. Drones are used in the agricultural field to detect pests, plant disease with the image of crop leaves by applying artificial intelligence and machine learning techniques. The role of Robots and drones along with IoT technology is increasing in the production of quality and quantity food in the world.

1.1 Internet of Things: An Overview

IoT is a computerization and analysis structure that adventures consolidating, identifying, enormous facts, and artificial reasoning revolution to carry entire structures for an element. These structures control and execute the activities of the industry. IoT structures can be used in any climate due to their adaptability they upgrade facts collection, automatic control of activities using intelligent appliances.

Internet of Things allows the customers to perform automation, examination of the structure so that accuracy can be improved. Future technologies like artificial intelligence, robotics will use IoT for the monitoring of the systems. Connectivity, AI, sensors, and small devices are the main features of IoT. Artificial intelligence is used by IoT for electronic gadgets to make certain decisions. IoT creates low-cost network connectivity between the devices to maintain the systems. Sensors that are used by the IoT systems will convert the inactive network devices to active network devices in real-time. IoT uses small devices to make the system is available to the common people so that the accuracy of the system should not be altered.

1.2 Internet of Things in the Field of Agriculture

IoT finds its application in various sections of the agriculture sector. The application of sensors and the internet can be found during cultivation, irrigation, water management, temperature management, production, storage, processing, transportation, and sales. There are loads of sensors available which are used for agriculture applications. In usual IoT applications, the sensors are placed randomly in the field, greenhouse, storage house, transportation systems, etc. The information gathered from these sensors can be stored in the cloud or it can be used to perform necessary actions.

A few works have shown that IoT can be utilized in changing over the conventional water system measure into a keen water system. Among the different works completed by different analysts, the vast majority of them focus on controlled water systems by checking the various conditions, for example, soil type, kind of the yield, the temperature of the encompassing, the stickiness of the climate, and so forth a portion of the creators have applied AI alongside IoT to anticipate the dirt dampness content all the more precisely.

Precision agriculture (PA) is a method of managing the agricultural field through the internet, which ensures that the harvests and soil get precisely what they need for ideal well-being and efficiency. IoT can also be implemented to test the levels of nutrients present in the soil. Many sensors are used to measure the soil parameters. These sensors collect all the soil-related information and transmit it to the intended user/system over the internet. The greenhouse system utilizes sensors using which temperature, humidity, CO_2, lighting, water levels could be measured and controlled through the internet.

Drone technology in food cultivation plays important role in precision farming. Quality effective farming makes use of different sensor data, the real-time image to increase farm production. To support quality effective farming, drones can be used in testing the soil and to monitor the crop, assist in planning water irrigation auto control, manage fertilization, calculate and identify yield data and provide valid information for climate and weather analysis. Multiple factors should be considered in terms of the Drone revolution which includes regulations, drone technologies, communication technologies, Sensor platforms, space technologies, and IoT usage. They are,

A. Automatic aircraft in agriculture
B. Drone technology in increasing the crop productivity
C. Analysis of agriculture field data
D. Hardware technology in Drones

2 Organization of the Chapter

This chapter has an outline of various IoT-based methods used for smart agriculture. The main aim of this chapter is:

1. In Sect. 1, we discussed about IoT
2. Section 3 describes different types of IoT techniques used in the automation of agriculture and how drone technology is used in agriculture along with that we have reviewed some of the IoT-based papers in the field of agriculture

3 Case Studies

Ferrández-Pastor et al. [1] have designed a hydroponic crop production in a greenhouse and tried it utilizing ubiquitous sensor network observing and edge control on the IoT standard. A novel way of information access is provided in the proposed system. The information obtained through sensors can be used to control the actuators. Based on the environmental conditions, type of crops used, and information received from the sensors the way of actuator response also can be adjusted in the system. A low-cost sensor/actuator network platform, integrating machine-to-machine and human-to-machine interface protocols was developed and tested. Edge computing utilizes this multiprotocol method to develop control procedures on PA situations. They demonstrated added benefits in terms of cost, energy, smart development.

Venkatesh et al. [2] propose a cold storage management system for farmers that protects foodstuffs and food grains from decaying. Monitoring nodes in a system have sensors, which collect temperature, humidity, lights information and sends these to the central node wirelessly. The central node, an application in a mobile, sends the information to the management node, laptop, or PC. The proposed system used preserves the quality of the crop and improves storage capacity. The condition of the crop obtained through sensor parameters can be analyzed and appropriate measures can be taken to prevent crop loss. This system designed is used for managing items stored in the warehouse.

In a precision agriculture system developed, [3] temperature and soil moisture sensors are placed in the crop which collects related information in analog format. The system is used to estimate the amount of water required. Collected analog information is transformed into digital information and transmitted wirelessly to the cloud. The data is compared with the threshold value. The threshold value varies with crop fields with seasons. Depending on the results obtained, the motor is turned on/off through Raspberry Pi. With the assistance of this methodology, the irrigation system automated additionally gives constant data about the lands and crops that will help farmers settle on the correct choices. The system maximizes the yield of the crops, helps in examining the climate conditions of the field, and optimizes the usage of water fertilizers.

Dholu [4] developed a sensor node capable of measuring agriculture-related parameters like temperature, soil moisture, light intensity, humidity, etc. The captured parameters are saved to the cloud and are also used to control the actuators. The parameters are visualized through a mobile application.

Sushanth and Sujatha [5] proposed to develop a smart agriculture system that uses advantages of cutting edge technologies. The plant root regions utilize a wireless network used in the photo voltaic-powered computerized irrigation structure that measures the soil dampness in the plant root regions. The developed system can monitor temperature, humidity, moisture. The presence of animals in the agricultural fields was identified using the motion sensor. Notification through an SMS or application developed will be sent to the farmer to take appropriate actions. The system schedules irrigation based on the data received from the sensors which are programmed through an android application.

By tracing and tracking the food conditions and real-time sharing of acquired information with the customers or the food supply chain (FSC) administrators the quality of life is supposed to be improved by employing the Internet of Things in the FSC. The FSC system with IoT uses heterogeneous devices with ubiquitous data exchange, tracking, and localization systems. Using IoT, the quality of the food can be monitored regularly, can manage factory staff and check their safety, provide useful information about the food to the customers. Witjaksono et al. [6] have explored the use of an IoT to monitor the quality and safety of the food. The freshness of the food can be investigated using a mobile application that was developed by the authors. The freshness of food is tested through a mobile camera. Using the IoT technology the data obtained could be imparted to every one of the shoppers and the chiefs.

Hardyanto et al. [7] have developed a smart aquaponics system using IoT technology. Cultivating plants along with fish in a container using IoT tools is known as Smart aquaponics. This system is very profitable because the land used will not be too large. Sensors will work as observers and actuators in aquaponics.

Smart devices are used to control the actuators and they can also function as monitors.

Khoa et al. [8] proposed an innovative topology of sensor nodes based on the use of economical and highly effective sensors. LoRa LPWAN technology-based transmission module is used which improved the performance of the system. By combining layers of IoT, the system is optimized in terms of hardware and even software. The manual and automatic controlled cellular application is developed by the sensor networks and it has been tested successfully in the research lab.

Zhang et al. [9] have used innovation of farming IoT for continuous observing of citrus mud dampness as well as supplements to examine the coordination of treatment and water system decision support scheme. A few accomplishments were acquired including citrus mud condition as well as moistness discovery remote sensor hubs and citrus accuracy handling and H_2O management scheme. The framework plan objective is the continuous observing arrangement of citrus mud dampness also supplement is intended to screen the soil dampness as well as supplement condition in the citrus plantation, so that organic product ranchers can get a handle on the condition of plantation on schedule, and under the direction of decision-making support system can change treatment water system methodology. Incorporate wireless sensor organization of citrus soil supplement and dampness and distant data the board framework and clever decision support system dependent on ZigBee innovation. The IoT stage plan thought is applied to the constant checking arrangement of citrus soil dampness furthermore, supplement. The moisture, temperature as well as supplements are provided based on the single-point multi-layer recognition technique.

Khoa et al. [8] proposed another geography of sensor nodes dependent on the utilization of economical and profoundly productive parts, for example, H_2O level, mud dampness, moistness, and rainfall detectors. Also, to ensure great execution of the framework, the pre-owned transmission unit depends on LoRa LPWAN innovation. The fundamental circuit is advanced by joining dual layers to carry out encoding development. The continuous checking of H_2O supervision that advances power utilization is planned. An extra objective is to reduce expenditure in smart horticulture. The sensor node influences energy dissemination in the communicating unit. At long last, the assurance of viable information move innovation is equipped toward executing an energy-effective sensor node. The framework can persistently notice the deliberate qualities and impart them to clients through the cellphone.

Muangprathub et al. [10] proposed a framework ideally watering horticultural yields dependent on a remote sensor network. Proposed work planned to design and build up a mechanism for utilizing node sensors in the harvest field with information on the board utilizing a cell phone and a web application. The three parts are hardware, web application, and portable application. The main segment was planned and executed in control box equipment associated with gathering information on the yields. Soil dampness sensors are utilized to screen the field, associating with the control box. The second segment is a web-related application that was planned and carried out to control the subtleties of crop information and field data. This segment applied information mining to examine the information for anticipating reasonable temperature, moistness, and soil dampness for the ideal future administration of harvest development. The last part is predominantly used to control crop watering through a portable application in a cell phone. This permits either automatic or manual control by the client. The programmed control utilizes information from soil dampness sensors for watering. Notwithstanding, the client can pick manual control of watering the harvests in the practical control mode. The proposed framework can utilize IoT gadgets to gather information on moisture got from the DHT22 sensor, soil dampness got from the soil dampness sensor, and the temperature got from the web administration of the Thai Meteorological Department Homepage. This data can be shown on a cell phone to the rancher and is utilized via programmed on/off control of watering. In addition, the rancher can physically turn on/off the watering. The practical status can be informed through the LINE Application.

Burton et al. [11] propose the monitoring of situ N in the field using remote potentiometry. A reusable IoT planting soil sheet is used for investigating continuous soil nitrate content during irrigation occasions. An IoT empowered mud sensor sheet sensor can do electrochemically distinguishing NO_3 leachates. The sensor sheet was inkjet imprinted on a paper substrate and altered through electrodeposition. Sensor crumbling can be expected for different reasons, like a convergence of soil supplements, pH, ionic structure, vague adsorption on the outside of the terminal, climate conditions, also mud microbial association.

Navulur et al. [12] proposed the model to concoct a versatile-related sensor robotization framework for deciding the soil condition such as moisture, soil pH value, H_2O levels in the field. A significant benefit of the gadget is to create different creature/bug sounds. Based on the earth's vibration, the elephant entering the area can be found. The sensor is modified to impersonate the sound of humming honey bees which won't just stop elephants from entering the field, however, will set off a caution to alarm the observing staff. Essentially, bird examination is averted from ruining crops before they collect by setting sensors that will make reasonable sounds to freeze them. To stay away from any disappointment of its capacity because of force disappointments and floods, the gadget is made with sun-powered battery-powered batteries. This gadget additionally deals with turning on or off the watering frameworks distantly which assists ranchers with accurately observing and set clocks for the water siphoning frameworks utilizing the shrewd application in the cell phone.

Vaishali et al. [13] proposed a Mobile Integrated and shrewd water system utilizing IoT dependent on application controlled observing system. This task controls the water supply and screens the plants through a Smartphone. This system comprises the Raspberry Pi board, water siphon, dampness sensor, and temperature sensors. The yields or plants are inundated concerning the water prerequisites at various phases of their development. The cell phone is associated with a Raspberry Pi board through Bluetooth. The engine is constrained by the cell phone by the qualities ON and OFF. The sensor innovation to computerize the water system improves water utilization proficiency. The Raspberry Pi has been utilized as a PC where outside memory can be utilized and it has four ports where any info gadgets can be associated. This venture utilizes Raspberry Pi for simple interaction and establishment. Sensors are the gadget which changes over the actual boundary into the electric sign. The system comprises soil dampness sensors. The yield of the sensor is a simple sign; the sign is changed over into a computerized sign and afterward taken care of by the processor.

Rajalakshmi et al. [14] created a system to computerize the water system measure by checking the various parts of the yield field, for example, soil dampness, temperature, mugginess, and light with the assistance of various sensors. The information from sensors is shipped off a web worker data set utilizing remote transmission. The watering cycle will start just if the dampness and temperature of the field fall beneath the limit. The notices, for example, regardless of whether the watering interaction has begun or halted are shipped off farmers' versatile occasionally. The farmers are ready to screen the field conditions from any place with the assistance of their cell phones. The web application is planned to dissect the information got and to check with the limit upsides of dampness, moistness, and temperature. The dynamic is done at the worker to mechanize the water system. On the off chance that dirt dampness is not exactly the edge esteem the engine is turned ON and if the dirt dampness surpasses the edge esteem, the engine is turned off. This technique can likewise be utilized in nurseries where what's more light force control can likewise be controlled and robotized. The sensor is interfaced with an Arduino microcontroller and customized. Whenever it is customized, it is put inside a case and kept in the field. Sensors persistently screen the field and send it to the webserver play helps in using the water assets all the more proficiently keeping away from any water wastage.

IoT-based shrewd water system proposed by Rawal et al. [15] screens and keeps up soil dampness content utilizing programmed watering. Microcontroller ATMEGA328P on the Arduino UNO stage is utilized to carry out the control unit. The arrangement utilizes soil dampness sensors which measure the specific dampness level in the dirt. This value empowers the system to utilize a suitable amount of water that stays away from the over/under water system. IoT is utilized to keep the farmers refreshed about the situation with sprinklers. Data from the sensors is routinely refreshed on a page utilizing a modem. A farmer can check the condition of the sprinkler through this page at some random time. Additionally, the sensor readings are sent to a Thing talk channel to create charts for examination. The system is a mix of equipment and programming parts. The equipment part comprises an implanted system and programming is the page planned to utilize PHP. The website page is facilitated on the web and comprises a data set in which readings from sensors are embedded utilizing the equipment. Depending on the water level the sprinkler has to work automatically based on the decision done by the sensor to maintain the moisture content in the mud. Data acquired through sensors empower the system to turn the sprinkler on and off. A farmer can distantly screen the water system measure on the homestead. Subsequently, the system was added to make a smart system.

The financially savvy and solid system created by Thakur et al. [16] expects to inundate fields just when there is a water prerequisite. This system likewise recognizes interruption in the horticultural field. The data about the water system and interruption location is shipped off by farmers with the assistance of cloud applications. This system utilizes Arduino IDE for transferring the code into the Arduino board. Python language is utilized to put play away that information in a dominant bookkeeping page, which helps get to the information from distant areas without any problem. With the assistance of the dropbox application, farmer can check the situation with the fields whenever. The distinctive equipment parts utilized in this system are the Arduino board, soil dampness sensor, Passive Infra-Red (PIR) sensor, and water siphon. The job of the dirt dampness sensor is to detect the dampness of the dirt and give its separate yields to the client. The water siphon will inundate the field just at whatever point the dampness of soil goes underneath the ideal edge worth and it quits working when the ideal limit worth of dampness is accomplished. The recognition of interruption is estimated with the assistance of an uninvolved infrared sensor (PIR) at whatever point there is any location of interruption in the field the clients will become acquainted with it as allocated values.

The brilliant homestead water system proposed by Saraf et al. [17] utilizes an android telephone for distant checking and controlling of trickles through a remote sensor organization. The system has a programmed and manual mode. The constant detected information is put away on the cloud worker for dynamic and controlling activities. The client can screen the controlling activities taken at the homestead just as control the water system through an android application on the farmer's cell phone. The proposed system assists the client with improving the quality and amount of their ranch yield by detecting surrounding temperature and dampness esteems soil dampness worth, and water level of the tank from the field with no human mediation. The android versatile application is utilized to give clients a literary and graphical portrayal of the data obtained by the remote sensor organization, which is put away in the cloud stage. This portrayal incorporates readings of every sensor just as the water system periods. The versatile application additionally gives alarms to the client to the utilization of composts and pesticides relying on crop determination.

Anandkumar et al. [18] proposed an IoT-based soil investigation and the water system to assist the farmer with diminishing the exertion in physically turning on and off the water siphon. The cultivating field is dissected by three distinct boundaries. To begin with, the water substance of the dirt is estimated. This fills in as a critical worth in working the engine. Estimating the water amount is finished utilizing a dirt dampness sensor. It is important to consider factors like the fast fire that jeopardize crops and the field. For this reason, a smoke sensor is utilized. When there is a fire in the field, the gas particles overpower and the sensor esteem continues high. The temperature sensor is kept in the field to survey the encompassing temperature. This estimation is an additional worth to the farmer. Because of this temperature sensor, the farmer can conclude if to water the harvest. The information in the sensor dwelling in Arduino will be communicated through a devoted channel to the following stage. The sensors read the accumulated information from the field ceaselessly and send it to Arduino which has a different port for perusing sensor simple information guaranteeing the rightness of information. The gathered information from Arduino is sent for preparation the field is dissected consistently and information is communicated. All the information read by Arduino is sent and put away in Raspberry Pi. The information is examined by Raspberry Pi. If any of the sensor information meets its limit, the comparing esteem is accounted for by the farmer. The warning will be sent provoking the farmer to react if to inundate the homestead. When there is a deferral or no reaction from the farmer, the Raspberry Pi will deal with turning on the engine, for example, the force control is mechanized at this stage. The undertaking of flooding the field is straightforward as the farmer gets a message when the water content is low in the dirt. The engine is initiated by just tapping the ON button through a portable application, in light of the farmer's reaction. On account of an unforeseen circumstance like an abrupt fire in the field, the engine is actuated consequently and a crisis message is shipped off the farmer. The water measure and surrounding temperature are accounted for by the farmer occasionally. This system helps the farmers via mechanizing the water system measure.

Kamaruddin et al. [19] proposed a system that oversees plants watering rate as indicated by the harvest necessity. The proposed IoT-based water system, the executives, and observing system consist of reconciliation work between equipment, programming, and sensors/actuator parts which satisfy the goals of this exploration. One Arduino UNO functions as a sensor hub and the other as a base station. The base station will get the information from the sensor hub and send it to the cloud worker. When the water system is empowered, the small water siphon will siphon the water from the water tank and play out the watering cycle. The created Android application is utilized to get the information from the equipment system and screen the capacity of the watering system. The proposed system additionally can be observed at an extremely significant distance through a cloud worker. Other than that, the client likewise can set a caution for the dirt dampness level limit to advise them that their plants are in a basic circumstance. Accordingly, they will realize that the watering system had an issue because of a disappointment of siphon, tank, or nonappearance of water. Clients can decide to physically play out the watering interaction by tapping the watering button on the android application.

One more comparable system proposed by Pawar et al. [20] has the goal of controlling the water siphon consequently without human obstruction and checking the development of harvests utilizing the webcam. Farmers can watch the live spilling of homesteads with the assistance of portable applications created with this system. This system utilizes various sensors like soil dampness sensors, temperature sensors, and ultrasonic sensors. The system is instated on Raspberry Pi. The USB camera introduced with the Raspberry Pi gives the total post of the field and this can be observed in the interior organization system. The sensor continually faculties the temperature and dampness of the field and updates the information in the webserver. If the allowable degree of water is diminished, the hand-off which is associated with the Raspberry Pi will turn ON the engine. Essentially, if the dirt becomes dry, the engine which is associated with the transfer will be gone ON to wet the field.

An open-source innovation-based shrewd system is proposed by Goap et al. [21] to find the importance of the water system for the detection of moisture content, temperature, and condition of the soil using the internet. The rain, temperature of the air, humidity are used for the shrewd calculations. The data collected from the sensors are stored in the cloud and will be used by the system for making the decisions to perform the specific task. The automated water supply is controlled by the system known as shut circle control. The engineering of the proposed IoT-based keen water system has seven fundamental parts, viz., Field information assortment gadget with hand-off switch; Web administration for gathering field sensor information; Web administration for gathering climate data accessible on the web; Web administration to control water engine; Soil dampness forecast calculation; Responsive online interface for ongoing checking; IoT empowered engine siphon. These parts are gathered into three distinct layers, for example, the information assortment and transmission layer, the data handling, and knowledge layer, and the application layer of IoT.

Vij et al. [22] proposed a smart irrigation system that utilizes AI and IoT to give a best-in-class answer for cultivating needs. This system considers the way that Irrigation needs to shift with crop types and season. Water systems or fewer water systems both would influence the yield and nature, so mechanization of Irrigation systems is vital. The proposed arrangement depends on the 2 sorts of microcontrollers, the decision of the microcontroller depends on their computational force, price, and simplicity of accessibility. With the utilization of different sensors, the variable boundaries will be continually observed and the water system reasonable to and explicit to the sort of harvest will be finished.

The smart multi-level irrigation system proposed by Salvi et al. [23] enhances the yield of harvests with decreased water utilization and better force use. This system goes about as another structure for staggered cultivation in a metropolitan territory where development space is restricted. It is given the neighborhood hub for each level with its nearby dynamic system, sensors, and actuators which are modified to the chosen crop. This system incorporates distinctive equipment and programming parts, for example, the Arduino Uno board, soil dampness sensor, temperature, and stickiness sensor, light power sensor, Ultra Violet (UV) LED, and Bluetooth module. Diverse information gathered from the sensors is put onto the cloud where the customers can undoubtedly see it by signing in to the record on the cloud. This information is dissected and the measure of water needed for the yield is determined.

Internet of Things (IoT) is one of the evolving technologies used in many areas like healthcare, agriculture, etc. Smart agriculture needs remote monitoring of the field using Internet of Things technology and wireless sensor networks. This remote monitoring of the field requires the installation of the increased number of sensor nodes in a wide agriculture area. This requirement in multiple sensor nodes is reduced by giving mobility to these sensor nodes with the help of moving robots [24] and the overall system cost can be reduced. The Master robot is equipped with a camera to capture the image, which is then processed using deep learning algorithms to detect the weed and non-weed and other sensors to find the atmospheric parameters like moisture, temperature, humidity, etc. The slave robot's sensor will also have these sensors and can collect instant atmospheric conditions in the wide agricultural land. The slave sensors send this information to the master using NRF protocol, and the master robot communicates these data with the server using WIFI.

With the increase in population worldwide the demands of food production require automated and intelligent robots, unmanned aerial vehicles (UAV) working with artificial intelligence (AI), data analytics, and the Internet of Things (IoT). UAVs are playing one such significant role in smart agriculture which reduces working hours, increases productivity and accuracy. Two types of UAVs are used in agriculture: fixed UAVs and rotary-wing UAVs. The fixed UAVs are the larger size aircraft appears like airplane used for spraying pesticides, monitoring, and protection of plants in precision agriculture [25]. The rotary-wing UAVs are lightweight aircraft used in spraying crops seeds and aerial view photographic [26].

The typical control technology is necessary for controlling these UAVs to control altitude and attitude, obstacle detection and avoidance, navigation by decision making. This is still a challenging research area using three different kinds of control methodologies as linear, nonlinear, and learning-based control [27]. The linear control system is applied in UAVs for stable flight. Nonlinear controlling is often used in quad rotors for sliding motor control, back stepping, and feedback linearization. The learning-based control use strategies like fuzzy logic, model prediction, and neural network controllers and hence provide very powerful and intelligent control over the UAVs.

4 Conclusion

Agricultural fields can be made smart with IoT-enabled technologies. This chapter presented a review of IoT applications for the agriculture sector. This chapter includes different complications faced in different sectors of agriculture along with its solution which is based on the internet and sensors. Most of the system developed for agriculture field uses heterogeneous components and wireless networks. Water control and management, soil testing, greenhouse systems, drone farming, precision agriculture are the sectors that are reviewed and presented in this chapter. These days smart agriculture uses the IoT framework, yet the harvest buildup is as yet a significant issue for climate, for this issue, we can implement an IoT System mixed with biotechnology that can assist with getting the data to determine the issue of harvest buildup and give a solution for disintegrate the harvest buildup in documented that will make the land rich and decrease the contamination.

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Blockhain Solutions for Agro-Food Chain Systems

Mustafa Tanrıverdi

Abstract The agro-food chain is a very important area providing consumers with safe, sustainable, affordable, and sufficient food. It is critical that all stakeholders on this chain trust each other and that the food data can be monitored smoothly and securely. Due to food scandals and epidemics frequently encountered in recent years, people's demand for safe and traceable food increases. Despite the continuing trend of digitalization of the economy, sufficient digitalization in the field of agro-food could not be achieved. Blockchain technology, which has become popular in recent years and plays an important role in the implementation of solutions that make life easier in many areas, also has an important potential in the field of agro-food chain. Blockchain technology enables secure data sharing thanks to its distributed, transparent, unchangeable structure. With this study, the rapidly spreading blockchain and the opportunities it offers will be mentioned, and the studies using this technology in the field of agro-food will be examined. This study will focus on the challenges faced in this industry and the potential of blockchain technology in combination with advanced information and communication technology and the Internet of Things (IoT) devices to overcome these challenges.

Keywords Blockchain · Smart contracts · Agro-food · Supply chain · IoT devices

1 Introduction

Thanks to the developing technology in the past years, improvements have also been made in the field of supply chain. The supply chain is a network service that involves production, processing, and delivery of goods to the customer. At the end of this process, a quality problem may arise in the goods offered to the customer and it is extremely difficult to identify the source of the problem in traditional supply chain systems. Recently, with the improvement of living standards, food safety has

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become important for people. the Mad Bee Disease outbreak in the United Kingdom in 1996, Bird Flu in Hong Kong in 1997, Swine Encephalitis in 1998, Screed Disease in South East Asia, Europe, SARS scandal in Hong Kong in 2001, Sanlu milk scandal in China in 2008 caused people worry about safety of food. People even worry that there may be hormones, chemical additives in all foods. These incidents revealed that there are problems in food production and supply chain processes [1]. After the food scandals, consumers became more interested in data within the supply chain and began to demand better quality foods. In addition, governments attach great importance to the monitoring of food products. The Food Law [2], enacted by the European Union in 2002, stipulates the need for a comprehensive monitoring system to provide timely and accurate information to consumers. The Food Safety Law [3], which has been implemented by China in 2009, requires food manufacturers and businesses to establish a product tracking system for food safety. For these reasons, it has become important and mandatory for supply chains to follow the entire process, from the production of food to the delivery to the customer.

Today, data on processes such as production, food processing, and distribution in traditional agri-food supply chains are stored paper-based or in special databases. This situation causes serious difficulties. Some of these include [4]: (i) Data stored in private and central databases may be manipulated and may cause trust issues among stakeholders. (ii) The supply chain may become inoperable as a result of a single point of failure. (iii) Centralized databases vulnerable to attacks by hackers may be destroyed or confidential data may be stolen. (iv) High costs may occur if a third party is included for data verification and monitoring. To overcome these problems, studies involving distributed databases and cryptography have been carried out over several decades. Among them, blockchain has come to the fore with its services in response to trust problems [4].

In blockchain technology, many advanced computing and cryptographic techniques have been integrated into the distributed data structure to achieve a digital trust system in an untrusted environment [5]. Thanks to its distributed, unchangeable and transparent structure, the blockchain can create an environment of trust among the actors in the supply chain. With smart contracts running within the blockchain, many transactions such as asset transfer, data exchange, and data monitoring can be automated. There are concerns over the deterioration and alteration of the data obtained from IoT devices in the current agricultural food supply chains in the central data structures. Thanks to the integration of IoT devices into the blockchain, it is possible to manage data collection and data monitoring in a transparent and distributed manner.

2 Blockchain

Blockchain technology was first introduced by an author called as Nakamoto, whose actual existence is unclear [6]. The blockchain, which became known with crypto coins in the early days, pioneered solutions that made life easier in different areas thanks to its features in the following years. Blockchain technology has revolutionized distributed applications with the opportunities it offers due to its nature. Many definitions of blockchain have been made by researchers. Some of them are as follows; Beck described the blockchain as a database that enables secure, consistent and transparent transactions between many participants in a computer network [7]. Reyna et al. defined blockchain as a data structure in which the reliability of the data transactions performed is provided by stakeholders in the network [8]. According to Zheng et al., transactions approved by the participating nodes are stored in blocks on the blockchain and new blocks are created as new data is added. Blockchain has been expressed in this way as a growing data book [5]. From a technical point of view, blockchain can be defined as a combination of decentralized consensus methods, cryptographic algorithms, and a distributed, transparent and immutable database. We can list the advantages of blockchain technology as follows [9]:

- Distributed structure: Stakeholders do not have to rely on a central authority or third-party applications.
- Transparency: Nodes in the network can view the actions of other nodes.
- Autonomous Operation: The blockchain network does not have an owner, if any node goes off, the chain/the network will continue to run.
- Resistance to attacks: A lot of computational power is required to -attack compromise mechanisms such as Proof of Work (PoW).
- Error traceability: Error points in the blockchain can be detected.
- Immutability of historical data: It is not possible to change or delete a data in the blockchain.

One of the important services offered by blockchain technology is smart contract. Smart contract is a transaction protocol that executes the conditions for the occurrence of a series of events on the blockchain [10]. In other words, smart contracts consist of transparent, immutable pieces of software code that are stored within the blockchain network and run when triggered. Smart contract ensures that the agreements between the parties are carried out in an electronic environment in a transparent and secure manner. Many blockchain systems offer smart contract services with support for different software languages. For example, it is possible to create smart contract with the Solidity software language on Ethereum system. Thanks to smart contracts, useful studies have been carried out in many different fields. Some of the features of smart contracts are:

- Smart contracts promise to replace the traditional contracts used today, thanks to their distributed and secure structure being independent from the central authority.
- Smart contracts are transparent and unchangeable pieces of software code that are machine-readable and running on the blockchain network.
- Once created, smart contracts run automatically without the need for monitoring.

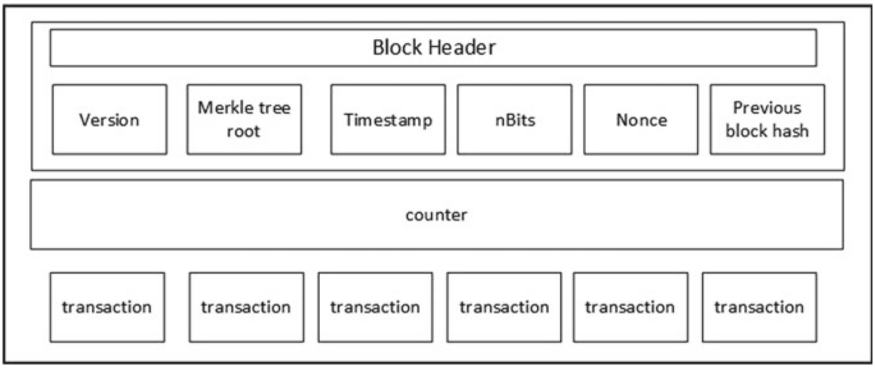

Fig. 1 Block structure

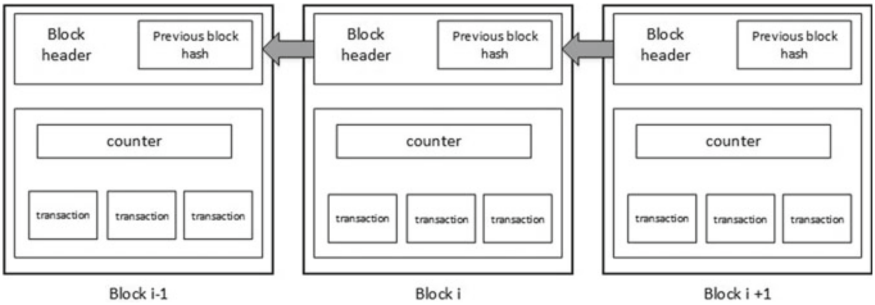

Fig. 2 Blockchain structure

The blockchain consists of interconnected blocks that increase according to the size of the transactions made. A block contains information such as values of the previous block, time stamp, block version, and transaction counter, as shown in Fig. 1. By connecting the blocks together, a chain similar to the blockchain structure shown in Fig. 2 is formed.

Existing blockchain systems are classified into three categories: Public Blockchain, Private Blockchain, and Consortium Blockchain [11]. The Public blockchain provides an open platform that allows anyone or any institution to participate, add records, and mine. There are no restrictions on such blockchains, and therefore they are called unauthorized blockchains. Blockchain structures managed by one or more groups that allow data sharing and exchange between participants are called Private blockchains. A stakeholder’s participation and access to the network become available according to the rules set by the group that manages the network. Consortium blockchain can be defined as a partially private and authorized blockchain in which a predetermined group of stakeholders is involved as decision makers in block validation and consortium processes instead of a single organization. These stakeholders manage who will participate in such networks and who can mine. Examining the studies in the literature, it is seen that private blockchain is usually used in the solutions presented.

3 Blockhain Solutions for Agro-Food Chain

The introduction of IoT devices in agricultural activities has provided many conveniences in areas such as planting, irrigation, data collection, data monitoring, transportation, and paved the way for smart agriculture. Friha et al. conducted a study on the use of IoT devices in smart agricultural applications [12]. In this study, survey studies conducted in recent years have been evaluated according to criteria. In one section of this study, 14 survey studies on the use of IoT devices in agricultural activities were examined. One of the evaluation criteria of these studies is the state of working on blockchain. Looking at the evaluation results, it was stated that only two of the 14 questionnaires focused on blockchain technology. It is seen that these two surveys were conducted in 2020. Again, in this study, the literature review about the applications developed on the use of IoT devices in agricultural activities is included. In this review study, recent studies to monitor, control, warn plants and animals, manage disease and damage, monitor the supply chain, reduce waste and pollution, and save money and time are examined. It is determined that only two of the 18 applications examined work on the blockchain. In a different part of this study, studies on the use of IoT devices in the agricultural supply chain are evaluated. Examining 17 studies, it is seen that 10 of them were blockchain-based. In this review study conducted by IoT devices on smart farming applications, it was stated that blockchain-based applications are rare among the studies on smart agriculture. Small number of these blockchain-based applications have also been developed in recent years, as it is expected in the field of supply chain, the abundance of blockchain-based works draws attention. It is thought that the number of blockchain-based supply chain and other smart agriculture efforts may increase as a result of the development and widespread use of blockchain technology.

The study conducted by Lin et al. included a comprehensive literature review of blockchain-based agricultural applications [4]. In this study, 24 applied blockchain-based agricultural applications were examined. These include applications that track the process from the production stage of foods such as meat, fish, vegetables, and eggs to the consumer using RFID and IoT devices, smart agricultural applications such as irrigation, storage, and time estimation, and financial applications where digital payment, insurance, and credit transactions are made. Considering the implementation issues, it is seen that most of the work done is on the supply chain and monitoring. In this literature study, the blockchain system used for each study examined is also included. Analyzing the blockchain systems used, it is seen that Hyperledger fabric and Ethereum-based applications are in the majority. In addition, there are few applications developed with MultiChain and Quorum systems. Considering the date of the studies, it is seen that the majority of the studies have been carried out in last 2 years. It is expected that the number of studies to be carried out in this field will increase in the future, as this is an area of interest to researchers and companies.

Some of the current blockchain-based studies on the supply chain and traceability of agricultural foods are.

A blockchain-based system was proposed by Caro et al. to monitor the supply chain of agricultural foods [13]. This system, called AgriBlockIoT, is based on monitoring agricultural food with IoT devices in all processes such as production, transportation, and transferring data to the blockchain of these devices. In this system, the importance of using IoT devices in all processes of the agricultural food supply chain has been emphasized. It is stated that IoT devices can be used for seed tracking with QR codes, agricultural area tracking with cameras, product development tracking with photos, collection of data on water and chemicals in the soil with sensors, transportation and packaging data with GPS sensors. Data collection and sharing were done through smart contracts, so that necessary warnings were received in case of inconsistency, such as between the amount of seed and the product obtained. The proposed system was developed on Ethereum and Hyperledger environments and the performance of these two environments was compared.

Yang et al. proposed a blockchain-based secure traceability system for vegetables and fruits [14]. In this study, the traceability of agricultural products is divided into four phases as production, processing, transportation, and sales. The production phase includes planting, irrigation, and fertilization. The processing phase includes weighing, packaging, production environment information, inserting product information, barcode, and key information. In the transportation and sales phases, products are traced by IoT devices. It is ensured that the data related to these processes are managed digitally and that the data sources in the supply chain become a participant on the blockchain. In this way, with a complete monitoring system, a trusted environment has been created where customers can query the products. It is stated that, thanks to this system, security and judicial units can make the necessary examinations regarding the quality or health problems that may arise and responsible person can be easily identified. As the number of participants on the blockchain increases, the size and query times of the data kept in the chain also increase. A participant in the blockchain can also access all the data in the chain. In this study, “database + blockchain” solution is proposed to solve this problem. In this solution, a data belonging to the product is added to the local database, and the encrypted form and hash code of this data are kept in the blockchain. Keeping the data encrypted in this way and verifying an issue when necessary is done with smart contracts. The application and evaluation results of the solution presented in this study are also included. Hyperledger fabric as the blockchain system, Go as the smart contract language, Linux and Docker support for the blockchain environment, CouchDB as the local database and C # ASP.NET MVC and Java Script for application development are chosen. With the application developed, all processes of fruits and vegetables from production to sales can be traced. The performance of the developed application is evaluated with the Hyperledger Caliper tool and information is given about the times of adding data to the blockchain and reading data. Finally, it is included in the comparison of traditional monitoring systems with blockchain-based monitoring systems.

Shahid et al. proposed a complete supply chain system for agricultural foods [15]. In this study, the authors handle all tracking, distribution, and payment tasks from manufacturing to the customer. These tasks are managed transparently and automatically with smart contracts. In addition, comments and scoring information about the participants such as farmers, logistics, and retailers are kept and an evaluation score is calculated for the participants. This score is offered to customers as an important criterion for subsequent purchases. In this study, as in many similar studies, the files of data such as sensor information and production pictures are kept on the central file server in order to alleviate the data load on the blockchain and the encrypted key information required for the verification of these data is kept on the blockchain. Creating the encrypted keys of the files and then verifying them are also carried out with smart contracts. In the proposed system, the farmer, the transporter, the retailer, and the customer are participating in the blockchain. The farmer transfers the sensor data and production pictures of the agricultural foods to the transporter with a single key data, then the retailer pays the price of the products selected from the transporter in cryptocurrency and gains access to the production data. In this way, the end user can access the production data of the food he intends to buy. These transactions between the participants are carried out automatically with smart contracts. In the smart contracts made in these transactions, a certain amount of deposit is received from the parties and this deposit can be used when the physical exchange is completed. In the event of any mishaps, the depository of the offending party is blocked as a penalty. After these exchanges are made within the supply chain, the parties can add comments and point information about each other. This information is used to form the evaluation score of the relevant participant and is considered as an important criterion for the selection of the relevant company for future purchases. The proposed system has been simulated in the Ethereum environment. In the study, information about the technologies used in the simulated environment is provided as well. The simulation results include the duration of operations such as product registration, data, verification, evaluation, and the amount of "gas" required for these tasks.

Wang et al. [4] and Salah et al. [16] also provided solutions for the safe and transparent monitoring and management of agricultural foods from the farmer to the customer with smart contracts. Vanany et al. proposed a similar blockchain-based supply chain against the difficulties of tracking halal food [17].

There are many studies in the literature similar to mention above. These studies are generally based on the distribution and tracking of data in the entire supply chain, from production to the customer, as distributed and unchangeable. Recently, IoT devices, which have become widespread rapidly, are very useful for monitoring agricultural foods. Saving the data obtained from these devices directly on the blockchain provides a safe and transparent environment for the participants in the supply chain. Keeping all the data produced in the supply chain distributed on the blockchain can cause a large amount of data to accumulate in all stakeholders and increase query times. In addition, this distributed structure causes some private data of the participants to be shared with all stakeholders. In parallel with the developments in blockchain, studies in the field of supply chain have been carried out on keeping data in cloud environment or central file servers and keeping hash codes and encrypted key values in blockchain, which prove the accuracy and immutability of this data. In most of the work done, the exchange of products in the supply chain and data verification processes were carried out automatically with smart contracts.

3.1 Real-Life Applications

In addition to the solution proposals presented in the literature in this field, it is possible to find real-life applications. Motta et al. conducted a study on real-world applications built on the blockchain-based agricultural food supply chain [18]. Some of these applications include:

Tuna Tracking and Certification (Provenance)

An application named Provenance has been developed in Indonesia in cooperation with NGO Humanity United and International Pole and Line Foundation to monitor the caught tuna until it reaches the customer. When the fisherman catches tuna, he must register the QR code or RFID information placed on the fish by SMS. The factory and the customer can now monitor this fish, which was recorded in the blockchain. In this way, it is ensured that the customer questioned the fish he wants to buy and identifies the fish that was not known where they were caught [19].

Olive Oil Tracking (Ambrosus)

In France, a tracking system has been developed to track olives from the fields to the warehouses and from there to the packaging factory and retailer. Unlike the existing tracking systems, Ambrosius enables the tracking of olives with RFID technology using the “hardware-in-place” method. The exchange of olives has also been done through smart contracts on Ethereum [20].

Celeia Dairy (OriginTrail)

OriginTrail ensures that data such as images and sensor information are kept distributed on the Ethereum blockchain in the dairy supply chain operated by many companies, instead of being kept separately in each company and the transactions are verified through consensus transactions [21].

Pork Meat Traceability (Te-Food)

Te-Food application has been developed to follow the process of pork from production to the customer. With this application, the farmer registers the pigs associated with RFID and QR code to the blockchain with his smartphone. Later, it is ensured that the trucks used for transportation can also be monitored with RFID. Slaughter of pigs in the truck arriving at the slaughterhouse and quality control by the veterinarians are identified with a QR code. In this solution, the token technology is used for exchanges between companies and product comments made by the user. The system was launched in South Vietnam at the beginning of 2017 and more than 6,000 companies have been trained to use it. It has been reported that 25 thousands chickens and 2 million eggs are monitored daily on Te-Food, which has been used for chicken and egg tracking since September 2017 [22].

After the recent food scandals, Walmart followed pork in China and mango in America using the Hyperledger-based supply chain monitoring system offered by IBM in 2016. With this method, presented as a “farm to table” approach by Wallmart, products can be followed transparently. Food safety has been increased and the amount of waste has been reduced [23].

4 Proposed Solution

The previous sections covered current studies and real-world applications of the use of blockchain technology in the supply chain of agri-food. Considering the studies conducted, it is obvious that each study brings different solutions to different problems. In this study, an ideal system proposal is provided in which innovative solutions presented in existing studies are included. The general structure of the proposed system is shown in Fig. 3.

In most of the studies conducted in this area, it is stated that agricultural food should be traced from “farm to customer” in the supply chain. For this, the use of IoT devices in agricultural areas is very important. Figure 4 shows an agricultural area proposal in which IoT devices are used for the proposed system.

In order to monitor agricultural food in the supply chain, it is important to monitor the transportation and factory process as well as agricultural areas. It is thought that the ideal method to solve this problem is to use IoT devices and blockchain technology together. For this, the products identified with RFID and QR code in the agricultural field should be taken to the factory environment by carriers equipped with RFID, GPS, and thermometer devices. Operations such as cutting and packaging in the factory must be monitored by responsible people and recorded with a camera. Then, the products obtained can be traced to the market shelves by associating them with RFID or QR codes. Figure 5 shows an example of how foods can be traced in the transport and factory process.

Information was given about an ideal structure, agricultural area, transportation, and factory processes to monitor agricultural foods in the supply chain above, sample figures were also shown. The proposed structure should have the following features;

- The farmer, transformer, factory, supermarket and the customer, who are participating in the supply chain, should know that all data of a product is stored in

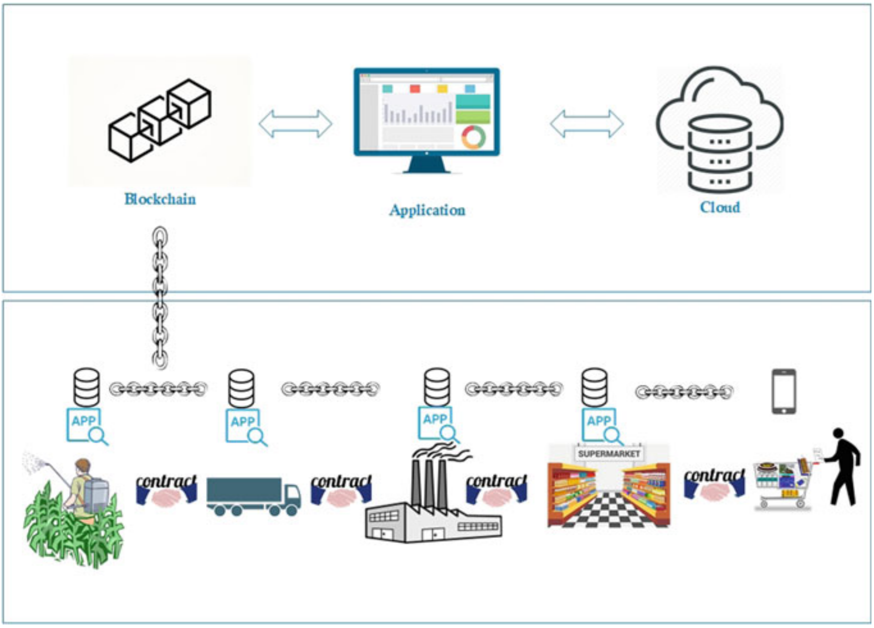

Fig. 3 General structure of the proposed system

Fig. 4 Proposed agricultural area

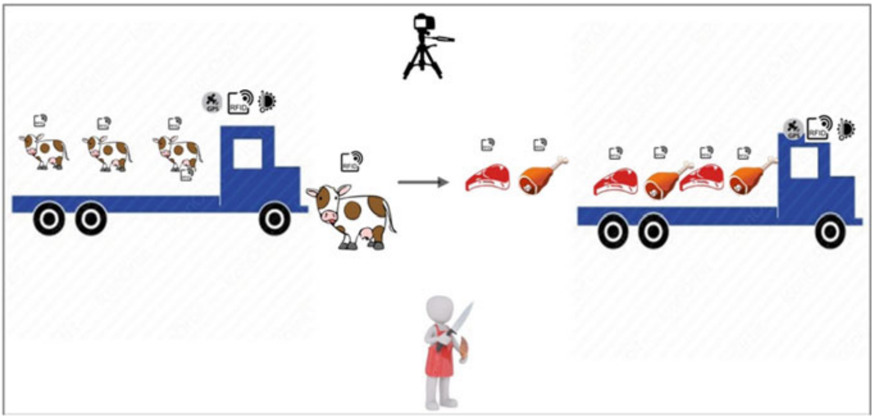

Fig. 5 Tracking of food transportation and factory processes with IoT devices

a distributed, transparent and unchangeable manner in the process from production to the market shelf. An environment of trust should be created. For this, the system must be developed on a blockchain basis.

- The use of IoT devices in agriculture is a great innovation. But ensuring the reliability of the data obtained from these devices is another important issue. For this, IoT devices such as RFID, camera, moisture meter, sensors that measure the chemical status of the soil, and GPS used during transportation should be directly connected to the blockchain.
- Purchases between supply chain participants should be made with smart contracts. In this way, both the process will be automated and inconsistent operations can be prevented. For example, if too many products are obtained from an agricultural area than usual and delivered to the shipper, the system can block this purchase by issuing a warning.
- It should be ensured that the products are tracked by means of technologies such as RFID and QR codes during the exchange between participants. For example, when a cow arrives at the slaughterhouse with RFID, it should be ensured that the meat is slaughtered under the supervision of the camera and the veterinarian and the meat obtained is associated with the animal slaughtered with the QR code.
- Each participant of the supply chain will also work as a node of the established blockchain. Since the amount of data recorded in the supply chain will increase over time, storing all of this data distributed over the nodes will cause too much disk need and private data of the participants to be included in the entire supply chain. This causes a scalability and data security issue. To prevent this, an application developed for participants should ensure that the full data of the products are uploaded to the server located in the cloud. The hash code and private encrypted key information of the file in the cloud should then be saved to the blockchain network.
- An application must be developed for data management and data validation between blockchain and cloud database. Thanks to this application, all

participants will be able to access the exact data they want with the hash code and encrypted key in the blockchain. In addition, customers should have access to all data related to a product through a web interface available in this application.

The general structure and main features of the system proposed above are given. The proposed system has been designed taking into account the current needs and the latest technological developments in this field. It is thought that this recommendation will be a useful guide for future studies.

5 Conclusion

Due to the rapidly developing technology, the usage routines and expectations of the customers are changing. Today, distributed and transparent structures are emerging as an alternative to central structures in many areas. The emerging food scandals and the desire to access quality products have created the need for access to all data of food products starting from the production environment. Thanks to the blockchain structure and features, it is thought that it can make important contributions to the supply chain of agricultural products as in many areas.

This study is based on blockchain-based solutions for tracking agricultural products in the supply chain. In this context, the current situation was evaluated and it was stated that food products should be monitored. General information about blockchain and smart contracts, which are new technologies, is given. Current studies in the literature and real-world applications in this field are mentioned. Finally, an ideal system has been proposed in which different solutions presented in the current studies are presented together.

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Efficiency and Reliability of IoT in Smart Agriculture

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Abstract Farmers need agrarian data and relevant information to settle on proficient choices and to fulfill enlightening necessities. In the agribusiness area through the improvement of information the board framework, requests of farmers can be replied to with the assistance of mixed media which is effectively open. The utilization of Information and Communication Technology (ICT) has demonstrated for extending the chances to advance farming on a few angles and areas in agricultural nations. Innovation has crossed obstacles by utilizing remote innovation, organizing, versatile, and so on to conquer the utilization of energy, force, and cost devouring types of gear which was useful in the horticultural turn of events. The improvement of ICT in different areas has driven considerable premium in rising speculations by private areas towards the development of ICT in Agricultural exploration. It is fundamental for increment the profitability of rural and cultivating processes to improve yields and cost-adequacy with new innovation, for example, the Internet of Things (IoT). Specifically, IoT can make rural and cultivating industry measures more proficient by decreasing human intercession through robotization. IoT is a blend of overall information, web-related things or things, and is a fundamental segment of things to come web. IoT centers around the robotization of cycles by diminishing human connection. During the time spent robotization, IoT gathers information utilizing sensors and cycles the information utilizing regulators and finishing the mechanization measures by utilizing actuators. Recent concerns, for example, cell phones, insightful administration of Wireless Sensor Networks, middleware stages, incorporated Farm Management Information Systems across the inventory network, or self-ruling vehicles and advanced mechanics stand apart due to their capability to lead arable cultivating to shrewd illustration cultivating. During the execution, various difficulties are experienced, and here interoperability is a key significant obstacle all through all the layers in the design of an Internet of Things framework, which can be tended to by shared guidelines and conventions. Difficulties, for example, reasonableness, gadget power

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utilization, network dormancy, Big Data investigation, information protection, and security, among others, have been recognized by the articles looked into and are talked about in detail. Various answers for all distinguished difficulties are introduced tending to advancements, for example, AI, middleware stages, or intelligent information the executives.

Keywords IoT · Agriculture · Information and communication technology (ICT) · IoT agricultural network topology · IOT agricultural network platform

1 Introduction

Cultivating and farming are vital for the achievement of society overall. Without cultivating, everybody would be compelled to chase and accumulate food, and it isn't workable for the total populace to make due off such an eating style. Mechanical cultivating methods and hereditarily adjusted harvests permit ranchers to create a lot more noteworthy measure of food than previously, in any event, when utilizing a similar measure of land, which keeps food on tables. Mechanical cultivating additionally utilizes numerous individuals, including hourly specialists, part timers, and logical analysts who try to improve cultivating procedures. Family cultivating is significant on a lot more limited size. Family cultivating gives neighborhood nourishments to the local area when there is overabundance delivered, and it accommodates a large part of the family's food admission in any case. This permits the family to set aside cash and diminishes reliance on modern cultivating. Little family cultivates additionally keep the land fit as a fiddle through normal plowing and care, improving the general wellbeing of the nearby biological system [16].

Agribusiness somehow related to fundamental food crops. As of now, agribusiness far in excess of developing, dairy, natural item improvement, poultry, beekeeping, mushroom, etc. Today, planning, publicizing, and scattering of harvests and tamed creatures things, etc. along these lines, agriculture could be suggested as the creation, dealing with, progression, and allocation of agrarian things. Agriculture expects an essential part of the entire presence of a given economy. Cultivation is the establishment of the financial plan of a given country. Notwithstanding giving food and crude material, horticulture additionally gives business freedoms to a huge level of the populace. Below are some listed points which will demonstrate the importance of agriculture [17].

- Origination of employment
- Addition to national credit
- Stockpile of Food and Grain
- Implication to the International business
- Paternity of Raw material
- Marketable Surplus

- Overseas exchange resources
- Significance in Transport
- Food security
- Economic development
- Source of saving
- Employment Opportunities

In the context of food supply, it is important as Farming is the world's driving wellspring of food things. All the food substances that are fundamental Agriculture produces vegetables, proteins, and oils. The sugars furnish all living creatures with energy. These are delivered as grains that fill in ranches, for example, rice, wheat, and potatoes. It's useful to assemble our body with proteins. They are circulated by farming as grams and other leguminous merchandise. Such items incorporate beans, heartbeats, for example, dark gram, Bengal gram, green gram, and so forth. Other protein sources, for example, meat, fish, and dairy are additionally reliant on cultivating. Protein from veggie lover sources is modest and sound without the danger of illness. Individuals, in this way, depending on protein from agribusiness for their everyday needs. It is fundamental for supply energy, body construction, and warmth with fats and oils. These can be acquired by developing sunflower, groundnut, mustard, sesame, and so on from horticulture. Natural products: natural products have natural and unblemished food content since they don't have to cook. Kids, the older, and debilitated individuals make them absorbable. Grapefruits are additionally used to make wine [19].

While discussing the roles of agriculture in medicine it Papain compound is acquired from the product of papaya. This papain is utilized as a catalyst that is natural. It is utilized as a substitute for acid reflux for one of the stomach related catalysts. Particularly valuable for the older and debilitated. This papain is acquired by the development of papaya for an enormous scope. Like a medication, most alkaloids are utilized. Opium alkaloids, for example, morphine calm serious agony, hack, and loss of developments too. These are acquired in ranches through the development of opium poppy plants. Moreover, cultivating gets alkaloids, for example, hyoscine, ephedrine, physostigmine. These are some significant standards of medication. Models incorporate cardiovascular breakdown heart glycosides, for example, digital is Senna is a glycoside utilized in obstruction treatment. Steroidal glycosides for the creation of steroid drugs in the heart [20].

As per agrarian bio variety Agricultural biodiversity is a wide term that incorporates all segments of natural variety identified with food and agribusiness, and all parts of natural variety that make up rural environments, otherwise called agro-ecosystems: the assortment and variety of animals, plants, and miniature creatures at the hereditary, species and biological system levels expected to support key habitats. Agricultural biodiversity is the consequence of hereditary asset connections, the climate, and farmers the executive's frameworks and practices. This is the result of the century's long improvement of both common determination and human inventiveness. Plant hereditary capital is including crops, wild plants gathered and kept up for food, ranch trees, fields, and types of rangeland, Microbial, and contagious hereditary assets.

Animal hereditary assets, including tamed animals, food chased wild animals, wild and cultivated fish, and other oceanic organic entities. These are the principal creation units in farming, including developed and trained species, overseen wild plants and animals, just as developed and tamed species, wild family members. Biodiversity parts that help environment benefits that depend on farming. These incorporate various species that add to supplement cycling, nuisance and illness the executives, fertilization, contamination and dregs guideline, hydrological cycle protection, disintegration control, and environment guideline and carbon sequestration at different scales. Human exercises and the board rehearse structure and save agrarian biodiversity, and countless individuals rely upon farming biodiversity for feasible livelihoods. Such measurements incorporate customary and neighborhood consciousness of rural biodiversity, participatory cycles, and social variables, just as the travel industry related to farming landscapes. Agriculture depends on biodiversity. It has encouraged the improvement of cultivating frameworks since the principal advancement of horticulture approximately 10,000 years back. Biodiversity is the root and variety inside all plant and tamed creature species. It is likewise the base of significant environment administrations for keeping up farming and the prosperity of individuals. The biodiversity of the present harvests and animals is the consequence of millennia of human mediation. Biodiversity and agribusiness are emphatically interrelated, as while biodiversity is vital for horticulture, farming can likewise add to biodiversity protection and maintainable use. Truly, both empowering and improving economical farming through biodiversity. Keeping up this biodiversity is fundamental for the economic creation of food and other farming items and their advantages to humankind, including food security, nourishment, and jobs [21, 22].

1.1 Contribution to GDP Over the years

Sector	1980	1990	2000	2003
Agriculture	38.1	31.1	24.7	22.2
Industry	25.9	29.3	26.4	26.8
Service	36	39.7	48.8	51.0

Cultivating expects a central part in the economy of non-present day nations and gives the fundamental wellspring of food, pay, and work to their typical masses. As shown by FAO (2000), it has been set up that the segment of the agrarian people in the hard and fast individuals is 67% that cultivating records for 39.4% of the Gross domestic product and that 43% of all tolls include plant items. It has gotten dynamically obvious over a few years that the beginning of the two monetary investigators and policymakers regarding the piece of cultivating in financial headway has gone through a critical turn of events. Around one-fourth of the

World's terrestrial surface is presently being worked on in the field of changing of land and managing in the 30 years after 1950 than in the previous 150 years. In various regions—including Europe, North America, Australia, and actually Brazil, China and India-humankind have furthermore gotten skillful at growing yields by using inputs like agricultural instruments such as pesticides and regular composts. Other terms, various less lucky countries with low repo rates and creating peoples, agriculture continues wandering into minor and fragile landscapes [20, 21].

1.2 Importance of Agriculture on Economy

- Contribution to domestic revenue
- Origination of Food Supply
- Pre-imperative for the crude material
- Provision of excess
- Shift of labor
- Creation of Framework
- Reduce of disparity
- Relief from deficiency of capital
- Based on fair ideas
- Create viable interest
- Helpful in Eliminating Financial downturn
- Source of Unfamiliar Trade for the Country
- Contribution to Capital Development
- Employment Openings for Country Individuals
- Improving Rustic Government assistance
- Extension of Market for Mechanical Yield

In the farming field, there are numerous applications, conventions, and models. IoT agribusiness research patterns incorporate organization stage, network design, applications, security, and difficulties among others. Besides, in numerous nations and associations over the globe diverse IoT strategies and rules have been executed in the agribusiness field. Anyway, in IoT farming climate a sensible measure of work done and a requirement for intensive investigation on IoT in agribusiness setting to comprehend the momentum research status. Figure 1 depicts the different trends in agricultural fields incorporation to IOT.

2 Significant Parts of IOT-Based Cultivating

There are 4 major components involves in IOT-based Smart farming which is listed below.

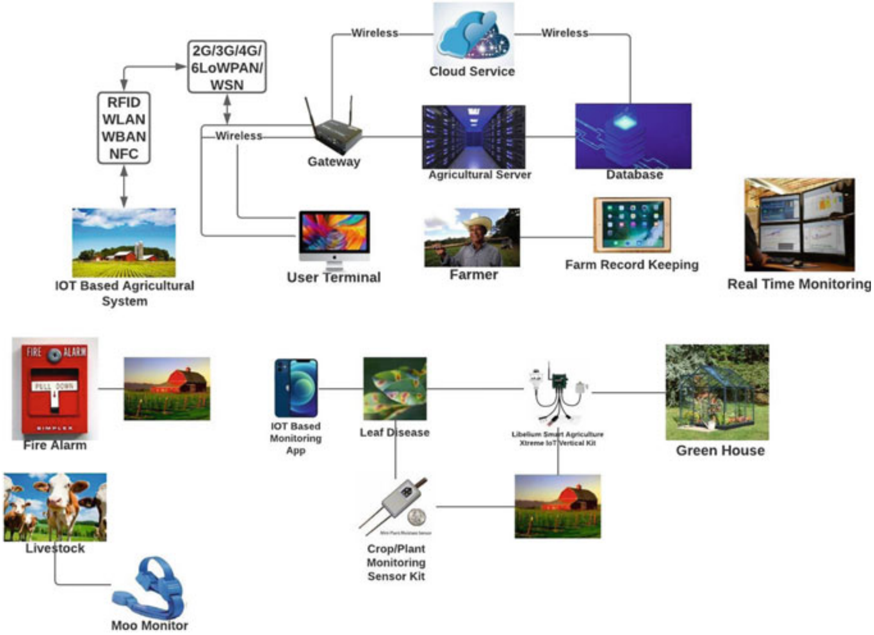

Fig. 1 Agriculture trends using IOT

- Physical structure
- Data acquisition
- Data analytics
- Data Preprocessing

The actual design is the main factor for exacting farming to stay away from any undesirable occurring. The entire framework is planned in such a manner that controls the sensors, actuators, and gadgets. A sensor plays out numerous assignments like soil detecting, temperature detecting, climate detecting, light-detecting, and dampness detecting. Additionally, gadgets perform many control capacities like, hub disclosure, gadget ID and naming administrations, and so forth Every one of these capacities is performed by any gadget or sensor which is controlled through a microcontroller. This controlling activity is performed by any far off gadget or a PC that is associated with the Internet. Information Acquisition is additionally partitioned into two sub-segments specifically: IoT information obtaining and standard information procurement. IoT information procurement segment comprises seven conventions that are Message Queuing Telemetry Transport (MQTT), Websocket, Advanced Message Queuing Protocol (AMQP), Node, Constrained Application Protocol (CoAP), Data Distribution Service (DDS), and HyperText Transfer Protocol (HTTP). Contingent upon the necessities and conditions more conventions can be utilized for the execution of shrewd cultivating. Though, in the standard information obtaining ZigBee, WIFI, Long Range Wide Area Network

(LoraWan), SigFox, and ISOBUS conventions have been utilized. Information handling comprises numerous highlights that are picture or video preparing, information stacking, choice emotionally supportive network, and information mining. As per the framework necessities, any element might be added that may work in corresponding to offer different types of assistance. Information examination comprises of two principles includes that are observing and controlling. Checking includes three fundamental application in shrewd horticulture that are Live Stock Monitoring, Field Monitoring, and Greenhouse Monitoring. IoT empowers ranchers to screen animals by means of various sensors that are utilized to screen distinctive animal illnesses like temperature, pulse, and processing, and so on. While field observing applications expect to report various states of the field like soil extravagance, temperature, dampness, gas, pressure (pneumatic stress and water pressing factor), and harvest sickness checking. A keen nursery configuration disposes of the manual mediation and measures diverse environment boundaries by clever IoT gadgets and sensors as indicated by plants' prerequisites. Data acquisition basically alludes to the way toward getting, investigating, fathoming, and reviewing data through the most amazing aspect of many existing solid strategies. Here, information is procured from solid sources by building up a model coordinating ranchers, horticulture organizations, Ministry of farming, Agricultural Universities, and establishments alongside Rest API administrations [3, 5]. Here Fig. 2 represents the different kinds of data Acquisition techniques in the agriculture field, how data is transferred from various parts to the research center the price inflation, and all.

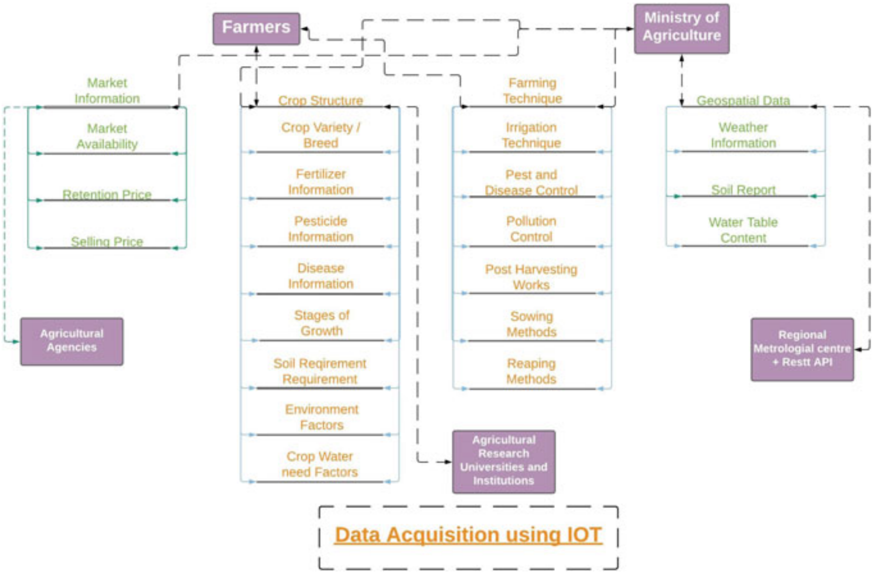

Fig. 2 Data acquisition using IOT

3 IOT Agricultural Network Architecture

The IoT agricultural organization is the primary factor of IoT in agribusiness field. IoT Agricultural organization design proposes a blueprint for the detail of an IoT horticultural organization's actual components just as their working standards, and procedures. A large portion of the IoT applications normally follows the four layer engineering, i.e., Network Layer, Application layer, Physical and Mac Layer, and Transport Layer because of the fame and interoperability of IP. Figure 3 depicted below gives an overview of the different network platforms and its protocol in IOT agriculture network.

3.1 Application Layer

Because of the energy imperatives and tough calculation required by the IoT gadgets, there are numerous lightweight conventions on application layer, for example, CoAP, MQTT, AMQP, and HTTP. These conventions can be expanded or diminished by the framework prerequisite. CoAP convention runs on UDP and chips away at the rule of solicitation or reaction engineering. AMQP convention runs over the TCP convention by following distribute/buy in design non concurrently and use TSL/SSL for security confirmation. MQTT is a data transmission

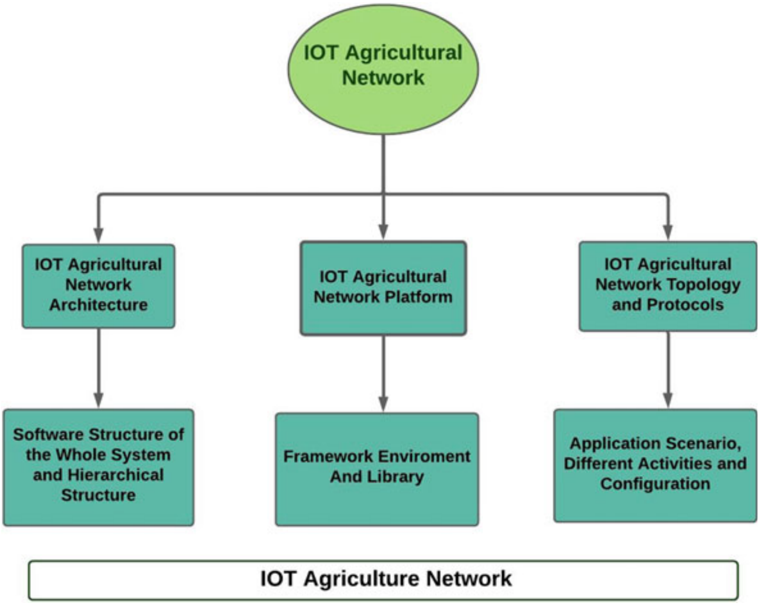

Fig. 3 IOT agriculture network

effective convention that utilizes little battery power and is intended for accepting and sending sensor information. HTTP is a notable web informing convention which dependent on the solicitation/reaction engineering [1, 2].

3.2 Transport Layer

This layer is likewise called host to have transport layer and is straightforwardly moved from IP to IoT space. The primary errand of organization layer is to gather and typify the horticultural data which is acquired through sensor layer. There are two conventions that are transmission control convention (TCP) and client datagram convention (UDP). TCP is an association situated convention that guarantees the dependability of conveyed information. TCP information transmission speed is low in contrast with UDP. UDP is an association less convention which doesn't guarantee dependability of information. Its information transmission speed is high when contrasted with TCP. Both of these conventions are utilized in various applications in light of the fact that their decisions rely on the necessities of use.

3.3 Network Layer

This layer is a basic innovation for accuracy cultivating and capable to communicate agrarian data at application layer. IP is the significant decision with the current two forms that are IPv4 and IPv6. IPv4 appeared because of expanding the enormous number of addressable gadgets. While creation of IPv6 was normal which step by step build up on all systems administration gadgets. Directing convention for Low Power and Lossy Networks (RPL) is considered as the fundamental convention while applying steering on 6LoWPAN. RPL comprise of distance vector steering convention which utilizes Destination Oriented Directed Acyclic Graphs (DODAG) to determine courses. To help various progressions of traffic RPL change itself as per network speed and recognize directing measurements, for example, status of the battery utilized in gadget, connect quality, and higher computational expense trade [1, 4].

3.4 Adaption Layer

Adaption Layer (AL) point is to guarantee the interoperability and execute fracture, pressure, and reassembly system. In spite of the fact that AL accomplished numerous advances yet at the same time, there is an intricacy for IPv6 supporting since its immediate use on IoT gadgets isn't viewed as sensible. Normally conflicts were seen with imperatives which are related to IoT gadgets. That is the reason, 6LoWPAN put forth a major attempt to diminish the constraints of IPv6 and make it appropriate for IoT gadgets. Sensors and gadgets use IPv6 and 6LoWPAN to send information over IEEE 802.15.4 convention in IoT agrarian organizations [11].

3.5 Physical and Mac Layer

This is the base most layer in farming organization architecture which is mindful to detect and impel diverse rural parameters. Inside physical and MAC layer IEEE 802.15.4 is quite possibly the most well known standard which was intended for minimal effort, low utilization, and low intricacy. This standard was embraced by numerous conventions like Wireless HART, ZigBee, and ISA100. IEEE802.15.4 for the most part works in ISM band of 2.4 GHz. Besides, it likewise works 915 MHz (in United Nations of American) 868 MHz (in European nations) and supports up to 250 kbps information rates. Anyway writing shows some critical impediments of later methodologies, which are with respect to portability and organization development [10].

4 IOT Agricultural Network Platform

This network model refers to both big data analytics model and cloud model which is described briefly below. How the concept of big data and cloud models have their impact on the agricultural field. Figure 4 represents the overall model of how big data models, sensors, and certain communication protocols have their impact in this agriculture field.

The proposed network platform consists of six components.

- Farmer experience
- Big data analysis
- Sensing and monitoring
- Warehousing services
- Protocol
- Physical Implementation

The farmer experience layer is intended to assist the ranchers with observing harvest efficiency in various manners, for example, for successful development of yields ranchers are aware by recognizing the suitability of fruitful determination. Environment conditions, crop development conditions, soil quality, or steers wellbeing checking causes the ranchers to follow the condition of their business and alleviate the lower creation hazards [5, 8].

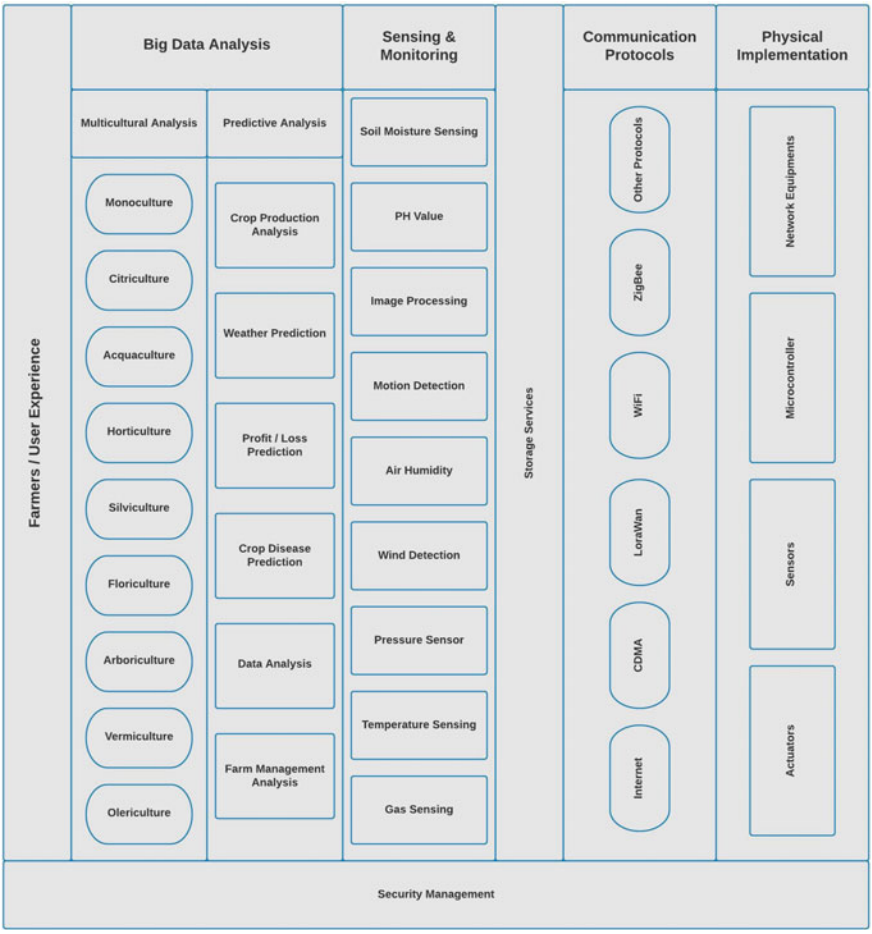

Fig. 4 Agricultural network platform

4.1 *Predictive Analysis*

This observation makes the entire climate more astute by the blend of savvy cultivating market knowledge and IoT innovation. The significant errand of prescient examination is to break down, investigate and measure the rural data for advanced mindfulness. Prescient investigation is made to check the probabilistic possibility of yield profitability up to the following season. Here various distinguishing gadgets are applied to check the Crop illness, climate conditions, and gauge the benefit/misfortune based on yield profitability. Prescient examination encourages the homestead to comprehend the ideal time for planting and reaping and different ranch the executive's strategies [9, 12].

4.2 Multicultural Analysis

Expounds the various types of agribusiness. In this examination huge information investigation limit the danger of harvest obliteration as per logical ways. To improve the development pace of water included Botanic Aquaculture layer is furnished with huge information. Other multicultural procedures like Citriculture, Horticulture, and Floriculture profit direct advantages when enabled with huge information investigation. It is useful for dynamic identified with harvest or plants occasional development, and nuisance control. Vermiculture is utilized for the development of worms. Arboriculture is essentially utilized for the development of woody plants. Olericulture is an application that is utilized for the forecast and measure the development pace of various vegetables.

4.3 Physical Implementation

Various sensors, various sorts of actuators, and microcontrollers are executed actually to monitor diverse farming applications. Numerous other organization supplies likewise executed at actual layer like switches, switches, and passages are incorporated. At this layer, while ecological conditions are detected and afterward incite as indicated by predefined directions. The microcontroller plays the director's job and performs organizing related activities and some other usefulness which are finished by sensors and actuators. An IoT-based utilitarian casing work appears in Fig. 6. The useful system shows that how agriculturists and ranchers can get to different data sets with the help of a help layer from the application layer. The business layer contains all essential activities which are significant for any IoT ranch. Information securing layer furnishes association with meeting layer through IoT conventions like MQTT, AMQP and COAP and so forth [15, 17].

4.4 Sensing and Monitoring

Detecting and checking examination is made by applying diverse detecting and observing gadgets. Sensors sense information and store the harvest infection data. Information that is handled through numerous assets is accomplished by detecting layers. The statistical examination has been made on information gotten from sensors to activate the disease. Breeders get fundamental data, for example, temperature, dampness of soil, and stickiness through web and message administration. From recent picture and video analysis on information cause the rancher to get convenient and exact data [15, 16].

4.5 Communication Protocol

Correspondence conventions gather and epitomize rural information. To measure and communicate information by using these conventions has been considered as the operational hub of IoT in farming. These conventions comprise web-related innovations like WIFI, LoraWan, and Code Division Multiple Access (CDMA) advances. ZigBee is considered as the primary empowering influence for correspondence over significant distances when outsider specialist organizations, for example, Long-Term Evolution (LTE), CDMA, or Global System for Mobile (GSM) are not accessible [18].

4.6 Storage Services

Ranchers store crop-related information to improve assessment in future and use set aside information in various seasons for more noteworthy benefit.

5 IOT Agricultural Network Platform Based on Cloud

Cloud gives a lot of capacity through enormous virtualized workers which are associated together to perform vital activities. A cloud based IoT plan for accuracy cultivating has been introduced in the chart. In which IoT procedures are applied to examine and oversee information from ranches through sensors and gadgets to create data for dynamic. Stage has been proposed based on four layers which are Cloud Storage, Gateway, Fog Computing, and equipment modules. Distributed storage layer centralized the all-agrarian related information, for example, climate related, soil, preparation, crop, and rural advertising in the cloud and gives on-interest assets through organized framework [16, 17].

Analytics assets and web administrations are additionally introduced on cloud or web which is available by cloud administrations. The vast majority of the gadgets or sensors are not planned in such a manner that can associate with web with the end goal of information sharing. To determine this information sharing issue neighborhood passages are planned which go about as extension between all equipment gadgets and sensors for availability, security, and controllability. Execution of doors in nursery or field improves the capacity of computerization and control the ongoing nursery observing framework. Equipment modules and cloud administrations are conveyed though assets are coordinated through mist figuring. Mist registering decreases the computational heap of cloud and guarantees ongoing preparation. Essential reason for haze registering in this proposed network stage is to use the on-interest versatility of distributed computing assets by exploiting both cloud and edge figuring. In equipment modules, different actuators, sensors, microcontrollers, and focal preparing units have been executed to screen and detect different agrarian factors. Equipment modules are conveyed worldwide or nearby organizations and used to make administrations or cycles. For the usage of keen cultivating quick reaction time and capacity to trade data is important. Both of these prerequisites (quick reaction time and ability to trade data) are satisfied by two conventions that are Representational State Transfer (REST) and Message Queuing Telemetry Transport (MQTT). Rather than utilizing enormous server farm conveyed framework is more powerful for savvy cultivating in light of the fact that it separates huge calculation into simple and more modest errands like: Crop, Temperature, supplements, energy, environment, dampness of soil and so forth [15, 16, 18]. Figure 5 represents the impact of cloud computing how the data has been store and from which sources it comes from in the agriculture field is represented clearly.

5.1 IoT Agricultural Network Topology and Protocols

IoT horticultural organization geography shows the game plan of various components of an IoT Agricultural organization and addresses an ideal situation for keen farming. The below figure describes how a heterogeneous registering matrix gathers important sensor information by utilizing numerous detecting gadgets such as moisture sensor, stickiness sensor, temperature sensor, gas sensor, PH sensor, bright

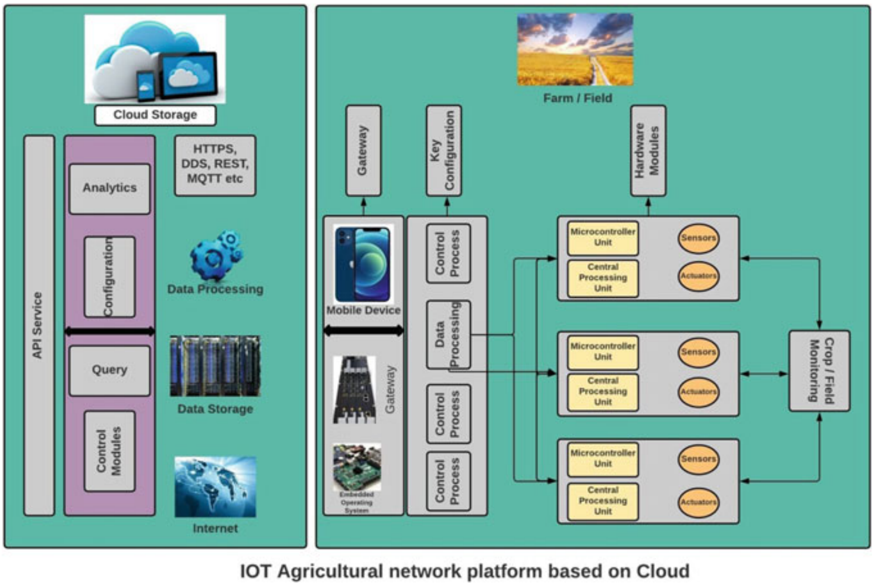

Fig. 5 IOT agricultural network platform based on cloud

sensor, etc., and structures an IoT rural organization geography. This pervasive Agricultural arrangement changes the capacity limit of various electronic gadgets like smartphones, Laptops, and horticultural terminals into mixture processing grids. The sensed information is then breaking down and put away, and put away information from different sensors and gadgets gets valuable for accumulation. Based on collection and examination agriculturists/ranchers can screen the diverse yield factors on the whole over the field from anyplace. In addition, geography comprises a legitimate organizational arrangement for the real-time agrarian recordings. For instance, uphold the spilling of nuisances by means of an interconnected organization with a web convention (IP), GSM, WiMAX, and access administration network door [5, 6, 8]. Figure 6 represents the role of task manager, scheduler how the data suppliers are working in the agriculture field, and from where the data has been utilized how the users are going to access it is represented.

Figure 7 represents the role of user, farmer and how the data is captured through sensors, how it supplies to any network is depicted clearly as the overview represents the overall model of remote monitoring in the crop field. Low power WSN innovation is a topology where low power remote sensor network has been intended to screen and control the different cultivating factors. In this framework, ZigBee is being utilized for information transmission which comprises numerous end gadgets and switches to proliferate the data on bigger distances. End gadgets that are dissipated in the field comprise various sorts of sensors like temperature, gas, dampness, soil, Motion indicator, PH, UV, PIR sensors, and a microcontroller. End gadgets are straightforwardly associated with the switch and regulator, where

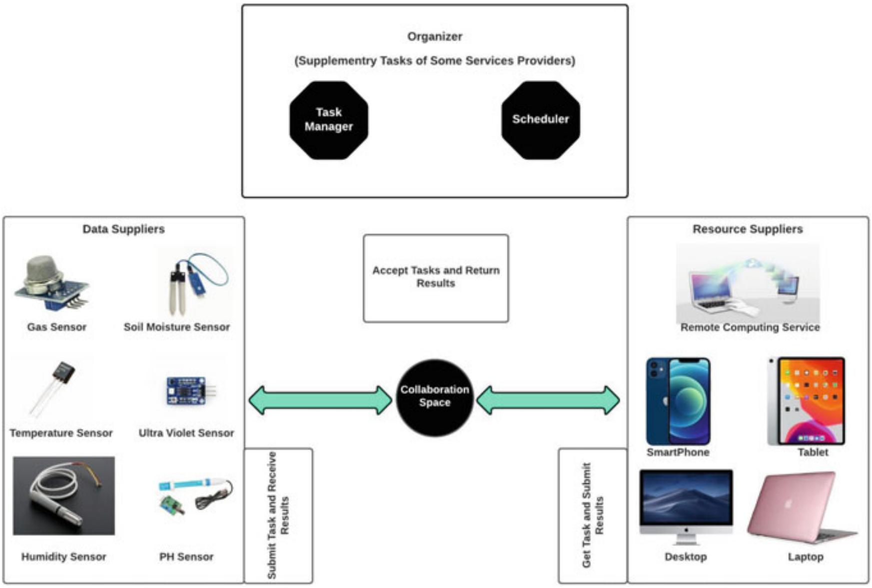

Fig. 6 IOT-based Ubiquitous agricultural solution

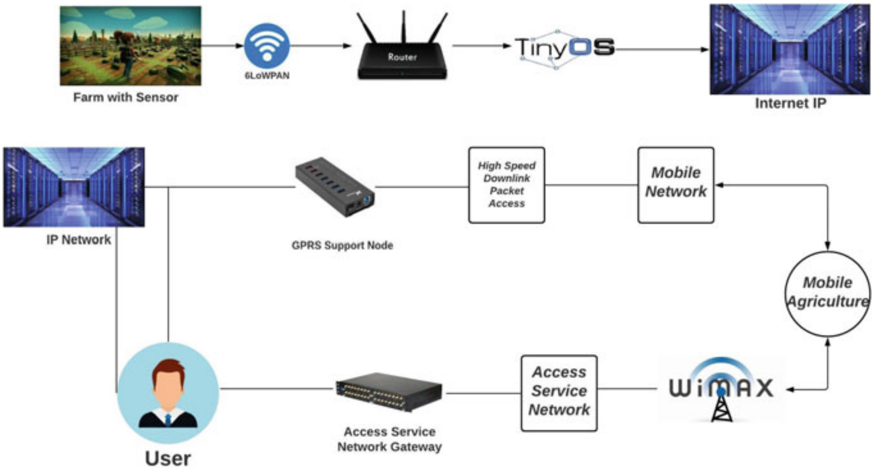

Fig. 7 Farm remote monitoring in agriculture

regulator speaks with base station by utilizing sequential port to examine the got data. As per programming checking point of view, each end gadget is appropriately instated and connected sensors are enacted in a proper manner. When the sensors are actuated then every gadget follows the switch to interface similarly as indicated by which they have been planned. After affirmation end gadget may associate with the WSN by utilizing indistinguishable keys. Information that is gathered through sensors is shipped off the base station which takes examination on got information. At the point when the sensors joined with end gadgets are being perused then information is communicated through ZigBee to the Controller or switch. Significant preferred position of this net geography is its bi-directional correspondence by utilizing ZigBee [13, 14].

5.2 IOT Protocols for Agriculture

There are numerous IoT correspondence protocols that are generally utilized in horticulture with the end goal of keen cultivating. By utilizing these conventions ranchers can impart in a more helpful manner and settle on more effective choices for shrewd cultivating to upgrade and screen the development of harvests. Most regular remote conventions which are being utilized named: IEEE 802.11 WIFI, 2G/3G/4G-Mobile Communications Standards, LoraWan, WiMax, Low-Rate Wireless Personal Area Networks, Bluetooth, RFID, and ZigBee.

IEEE 802.11 is an aggregation of correspondence principles Wireless Local Area Network that is 802.11a, 802.11b, 802.11g, 802.11n, and 802.11ac. Every one of these principles works in various data transmissions that are 5 GHz, 2.2 GHz, 2.4/5 GHz, 60 GHz, and 5 GHz. Information move scope of these norms is from 1 Mb/s to 7 Gb/s. Its correspondence range is from 20 to 100 m.

LoraWan is a long reach correspondence convention that is created by an open and non-benefit affiliation specifically Lora TM Alliance. The fundamental motivation behind this LoraWan convention is to guarantee interoperability between various administrators.

Information move scope of Worldwide Interoperability for microwave access is from 1.5 Mb/s to 1 Gb/s. Yet, presently a day with the headway of innovation information move rate has been changed. WiMax gives broadband multi access availability that incorporates fixed, versatile, traveling, and portable correspondence through wired or remote networks. Both WiFi and WiMax advancements have been sent to the Ministry of Food and Agriculture, Ghana (MOFA) which empowers client to associate either WiMax organizations or building Wifi [5, 15, 18].

Low-Rate Wireless Personal Area Networks sort out the detail of significant level correspondence guidelines like ZigBee. Information move pace of LR-WPAN comprises of 40 Kb/s-250 Kb/s. The significant property of this standard is that it gives low speed and minimal effort correspondence administrations. LR-WPAN is generally utilized for indoor horticulture like home nurseries or in little ranches.

RFID chips away at the head by appointing an interesting number independently to each protest to record data. RFID comprises of perusers, hosts, and labels where labels get and send radio waves because of which it is otherwise called responder. RFI labels comprise dynamic labels and detached labels which are accessible in various sizes and shapes. Detached tag is more beneficial in contrast with dynamic tag since it is modest than dynamic labels. Labels have remarkable ID numbers and natural data, for example, dampness level, temperature condition, and moistness, and so forth these labels are inserted and appended in numerous items to distinguish that object.

ZigBee is on the highest point of IEEE 802 principles made by ZigBee Alliance. It is a bunch of determinations for gadget-to-gadget networks having low force information rates. With the headway of innovation and expanding the interest of throughput, there is a need for quicker and low force utilization innovation. These prerequisites are satisfied by more settled advances which gives quicker information move. In agribusiness climate, IoT sensors sense the information and move it towards far off workers. In the wake of detecting, gathered information is analyzed for choices making.

MQTT is an informing convention in IoT that is mainly designed for distant associations. It’s a transfer speed proficient convention and uses little battery power. MQTT is utilized for nonstop examination and sends a keen framework for agribusiness area. An easy online IoT arrangement has been introduced by utilizing MQTT for checking, following, and dissecting rural information and gather information from field mood and improve ecological conditions. By utilizing MQTT a minimal effort water system framework has been proposed for accepting and sending sensor data [18].

5.3 Agricultural Application Domain

IoT agriculture framework has a major role in all aspects which are listed here, Precision farming, livestock monitoring, and greenhouse monitoring. Several IoT agribusiness applications are being utilized to make more proficient assets for horticulture efficiency. Primary areas of IoT agribusiness applications are accuracy cultivating, animal checking, nursery observing, and horticultural robots. The accompanying subsection comprises different sorts of horticultural applications.

5.4 Precision Farming

Precision cultivating assists the breeder with improving, mechanize and advance all possible headings to upgrade the rural efficiency and make editing framework savvy. Diverse IoT sensors are sent to gauge soil quality, climate conditions, dampness level, and adequately plan to advance gathering procedures to support the harvest creation a connection examination between rural climate data and yield measurable investigation has been created to gather crop information. In an IoT-based stage has been produced for exactness agribusiness and environmental observing. IoT-based climate gauges help to streamline profitability and take expectant investigation to keep the harvest from any losses. There are different kinds of sensors are there which will predict the bug or any kind of pest symptoms and behavior in seconds before they harm crop. Farmers use IoT-based irrigation system answers to oversee and investigate crop water systems a prerequisite during a far off rural checking stage has been introduced on observed information. An in-depth design comprised of digital frameworks and programming characterized set works has been introduced for precision cultivating. This smart farming depends on various observing and controlling applications, for example, environment conditions checking, soil designs checking, vermin and yield illness observing, water system, decide the ideal opportunity to plant and reap, and chasing [4, 5, 15].

5.5 Climate Conditions Monitoring

Where it requires performing any outdoor activities or anything important it is always worth monitoring the weather beforehand so that further activity can be planned accordingly similarly in farming also monitoring of weather is an essential and most important part. For monitoring any weather conditions there are many gadgets available nowadays. Weather stations are the most well known contraptions inside the field of horticulture that are utilized to find out any distinctive environmental conditions. Climate stations are liable for noticing consolidated temperature, tenacity, wind heading, and pneumatic pressure, etc. Situated across the field, environment stations assemble the natural data and send it to the cloud. Accumulated data is used for environmental assessment to design climate conditions, and give new pieces of information to take anticipated that actions should improve cultivating benefit. US Food and Agribusiness Association (FAO) has been described an environment related system called Climate Smart Agriculture (CSA) which helps the customer with changing the cultivation structure by perceiving climate conditions. A distant sensor network has been sent by using IoT development to recognize any environment changes by joining the sensors and gadgets [17, 18].

5.6 Soil Monitoring

Monitoring of soil has become an important practice in agriculture field that will be beneficial both for farmers and industry. In soil checking, there are numerous natural issues which influences crop creation. By chance that it experiences a few issues are recognized information precisely, the cultivating patterns and cycles can be seen without any problem. Soil designs that are being checked comprise of Soil Mugginess, dampness, treatment, and temperature. Soil moistness and dampness sensors are sent to analyze the dampness content in the dirt. A satisfactory measure of preparation in the field likewise expands crop yield. Soil checking test reports increment crop profitability and prescribes best treatment answers for the rancher. Additionally, the recognizable proof of debased soil by utilizing IoT advancements shields the field from over-treatment and yield misfortune. Nuisance and Yield Infection Observing Main drivers of income and creation misfortunes are crop illnesses. Because of the blessing of IoT horticultural framework has been changed into the computerized framework which assists the rancher with shaping educated choices. Forecast of harvest sicknesses at beginning phases assists the ranchers with creating more income by saving yield from bother assaults. Here IOT protects the crops from any unwanted issues in various ways by identifying diseases at earlier stage and from unnecessary animal attacks [12].

5.7 Pest and Crop Disease Monitoring

Yield assaulting is the major concern as it involves withdrawal of land into various untamed life frequents. Detecting the location of crop diseases or infection at beginning phases is very hard to find out in a crop field. While, programmed identification of illnesses is extremely valuable, exact, and less expensive for ranchers when contrasted with manual perception by specialists. Image processing procedure is an essential part of the previous identification of infection. Disease detection while sensing information by means of detecting gadgets is changed organization through distant worker at that point put away into a data set which is shown through a User

Interface. After analyzing the data for these we can easily identify the possible disease (bacterial, parasitic, viral, and so forth) examination [5, 7]. Figure 8 represents the role of different sensors, how it detects the disease in the agriculture field overall it is a disease and pest detection scenario in the crop field.

5.8 Irrigation Monitoring System

IoT seems to be a boon in every possible field in agriculture it improves the current scenario in a more innovative manner. A rancher can enhance water framework in his field in different manners while observing the current state of climate and soil types. IoT innovation analyzes water system framework in four different ways like climate determining information, control, and screen entire field from anyplace, Ethernet association and WIFI. This advanced framework works with the ranchers by introducing various sensors, decreasing rancher's system cost, and breaking point water assets. In a smart irrigation system, the executive's framework has been introduced by utilizing coordinating with other innovations which sense distinctive soil and climate boundaries. An IoT-based irrigation framework has been planned during which utilizes HTTP and MQTT conventions to illuminate the client. Water quality is observed by sensor hubs which are enabled with remote correspondence. IoT innovation measures both physical, and synthetic requirements of pH, broken down, temperature, conductivity and oxygen. Accumulated information about water the executive's framework is seen on web by utilizing distributed computing administrations. As of late different IoT irrigation system stages have been created to manage the water utilization inside the field [17, 20]. Figure 9 represents the

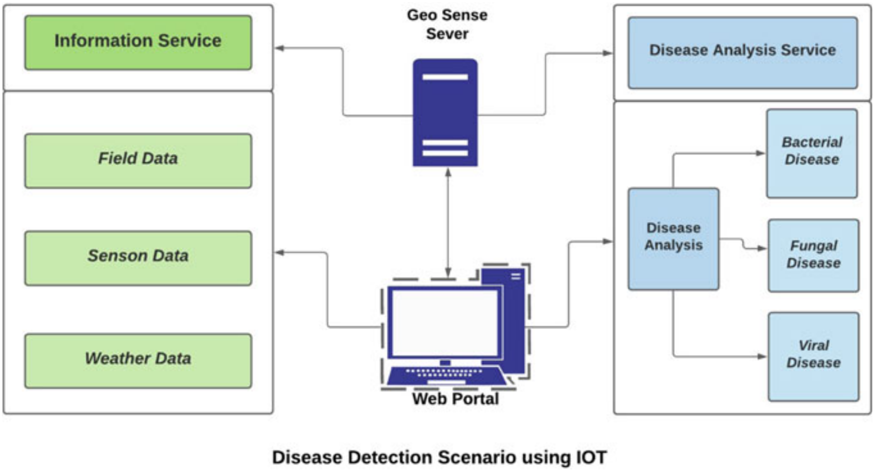

Fig. 8 Disease detection scenario using IOT

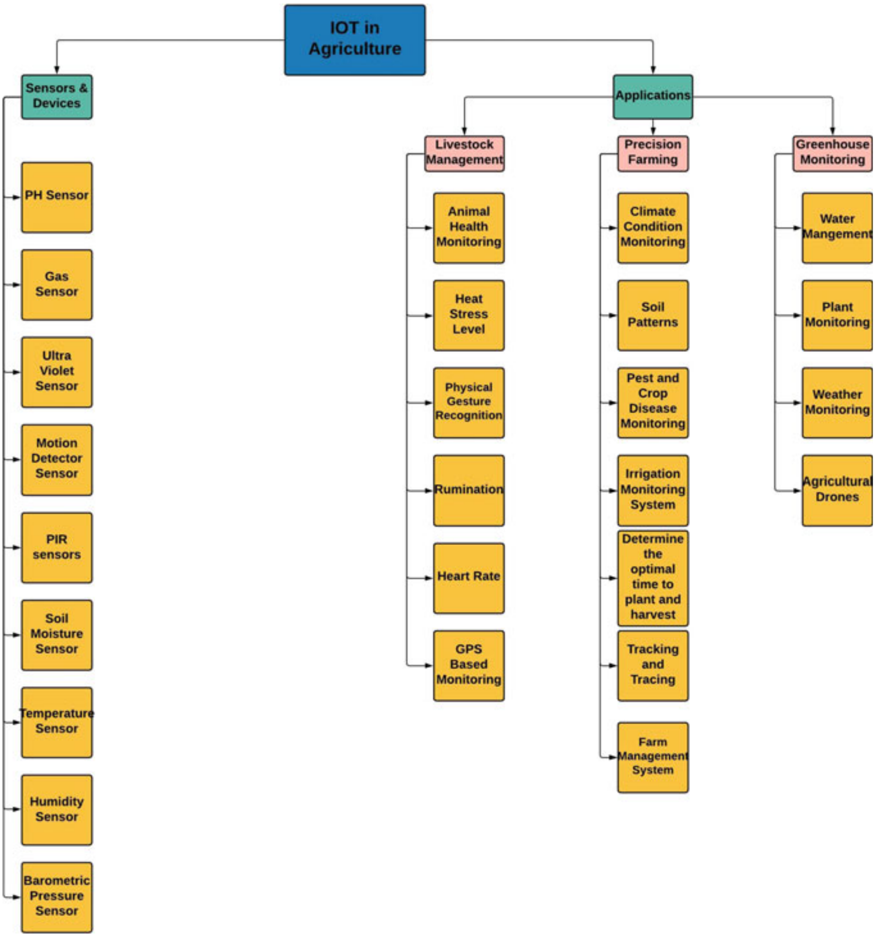

Fig. 9 Role of IOT in agriculture

overall scenario of livestock management, precision farming how it involves sensors and devices to improvise the system further is represented below.

5.9 *Agricultural Drones*

Robots are portrayed as Automated Flying Vehicles or Unmanned Aerial Vehicles (UAVs) utilized in agribusiness. These devices are controlled remotely by a regulator or self-administering redid. Cultivating cycles that are performed by meanders aimlessly are crop assessment, sprinkling, and screening, planting, and investigating reports, assessment of nitrogen in wheat, and assessment of soil conditions. Robots empower the farmers through coordination with Geographic Information Systems (GIS) arranging and collect development imaging. Robots are for the most part sent in tremendous farms where issues related to miniature life forms are difficult to manage and require standard noticing. These robots are responsible for detecting any micro organism's growth which is otherwise very hard to identify. Close by cultivating pesticides and excrements are essential for crop yield. Cultivating robots are accomplishing this work capably by virtue of their high speed and ampleness in the sprinkling action. In like manner, they moreover shipped off screen forest areas, creatures, and aqua-farming. An affiliation Accuracy Falcon is using drones for significant data gathering through sensors for examining arranging, and imaging of rustic land. They act in-flight checking, farmers enter the data in regards to which field to contemplate and pick a ground goal. To meet the targets set by the farm, Agrarian robots are consolidated with GPS devices cameras, and sensors to monitor crop successes, like planting, crop showering, screening, and assessment of soil, and more. We can use robots for various purposes like yield prosperity imaging, plant checking, and the proportion of nitrogen in wheat, plant height, leakage arranging, and weed pressure, and many more [20, 21].

5.10 Green House Monitoring

In a controlled and monitored environment, green house plants are raised. The benefits of this glasshouse are that a breeder can raise a plant anytime and anywhere while adhering to certain environmental factors else there is no specific rules attached to it. But there are certain facts that need to be remembered that greenhouse is intense while cultivating here it requires high precision which makes it different from traditional crops production. For monitoring of greenhouse and the climate and factors underneath several studies has been done in the field of WSN. Ongoing investigations show that how IoT can be executed in the farming industry to limit the man forms of collecting data and gives an immediate connection of the field from farmers to clients. A large portion of the examinations has zeroed in just on remote monitoring and neighborhood. Moreover, with the end goal of high accuracy, there have been great deals of studies that incorporate data to move through the remote infrastructure with information through the web. By applying all around assessed crop models, evaluation of the yield status assists the farmers with settling on better choices. Information can be gotten by sensors and identifiers and afterward moved to the main server for preparing. In actual execution, the significant segments are the sensors and network for exact data transmission. Cultivators set up the diverse observing gadgets and sensors as per the particular necessities and track or record the necessary data. Agriculturists settle on better choices by dissecting the data and accomplish explicit objectives by acquiring ideal information. There are numerous IoT-based farming applications, for example, irrigation systems, plant checking, and environment observing, and so on [1, 5, 7].

5.11 Livestock Monitoring

Perfect climate or conditions that ingest an unreasonable measure of environmental conditions leave an adverse consequence on daily performance of animals which is a huge concern for some researchers. Yearly farmers lose a lot of benefits because of animals' sickness. But IOT-based Livestock Management has the answers for this problem for improving living conditions, improving the cultivating standards, animals' conditions, and dairy items. Somewhat like yield checking sensors, distinctive domesticated animals observing sensors likewise are appended to the animals to monitor their execution. Domesticated animals observing variables changes on the various factors of animals viable like milk, bug assault, stickiness, and water quality. By labeling RFID to singular animal permit ranchers to follow their area, consequently keeping animals from robbery. Connected sensors and wearable's are inside the animals permits the rancher to monitor generally speaking animals' exercises and information is gushed to the cloud straightforwardly that assists the ranchers with recognizing the issues that have been underlying. Cowlar and SCR by All flex are utilizing shrewd agribusiness sensors to analyze animals' wellbeing, action, temperature, nourishment and gather data on every individual likewise as about the crowd. Inside the field of domesticated animals, a few investigations have been figured out. Remote Sensors have been utilized which are generally favorable for breeder.

Here distinctive IoT detecting gadgets have been conveyed to keep an eye on the climate conditions through meteorological perception posts and sense different conditions inside the field by any remaining information sources which have been executed in the entire field or farm. Detected information is put away on the cloud, which client can use for dynamic purposes and uses remotely when he wants. Recognition of any disease its associated symptoms and avoidance is the primary function for animal wellbeing observing. Typical blood warmth of dogs is 38.3 °C–39.2 °C and cow's is 38.5 °C–39.5 °C. At the point when the internal heat level is expanded or diminished from the ordinary internal heat level then it shows that creature is influenced by any sicknesses. Warmth or Body heat stress diminishes the cow's milk profitability with same dietary information, because of which ranchers face the profitability issues. In summer season dampness content turns out to be low in weather on account of which anxiety in animals expanded, as a result of this animal might die too. Proper gesture analysis can be made for the animals in support with the IOT automation which helps to find out the abnormality soon. Animal's motion conduct is surveyed into various gatherings, for example, in cows; this conduct comprises of two classes that are voyaging and fixed. Voyaging conduct comprises of creature's strolling, running, and brushing while fixed conduct is creature's sitting, dozing, and standing. Rumination screen detects the processed food by animals and it is recognized by mounting a screen inside the animal's (cows) nose. In this manner, ranchers can get precise signs about animal's wellbeing.

Estimation of pulse is an aberrant strategy that impacts because of the unsettling of cow. Typical pulse rate of cow ranges between 43 to 84 bpm through calf's ordinary pulse is 100 to 140 bpm [16]. By utilizing IoT gadgets and sensors beat rates are regularly checked continually. GPS framework is utilized to get the detail of ranch and sends the checked boundaries to local observing station by utilizing remote sensor network. To stop these creatures from burglary, wild assaults or climate conditions a repulsing framework has been given by utilizing remote advancements like Zigbee, WIFI, and LoWPAN.

5.12 Security Issues

IoT agricultural ideal models are not yet solid however kept on making up because of which as of now it's hard to get every single imaginable danger and weaknesses in IoT farming field. In any case, when specialists discover the security answer for tackle the evident security dangers by then they ought to can relieve the secret issues. To achieve a security arrangement, security checks ought to be sent with changing environments. Assuming a structure during which security instrument contains various frameworks which can recognize and forestall IoT agrarian framework from assaults. Presently consider, that an assailant produces a substitution kind of assault on farming applications gadgets and organizations to take agricultural data honesty. In such conditions, existing security procedures ought to identify this new assault by utilizing dynamic calculation. Security framework is intended to relieve the assault while diagnosing framework gathers action information from rural applications, organizations, hubs and dissects recognized farming information. Response framework is intended to help the agrarian substances endure a wide range of assaults. Entire framework has been planned by following unique calculations. To keep from present, plausible, and covered up assaults this procedure has solid coordinated effort. Upon interruption, location framework gives an activity order and store in response framework where they can post their queries that have received after experience with security framework to keep from additional assaults. Activity order get reaction from recognizable proof assistance, response framework eliminates the framework disappointment dangers and afterward pass out its involvement in other two frameworks that are security and diagnosing frameworks [2, 3, 5]. Figure 10 represents the IOT security model in the agriculture field for any data breaches. As everything, whatever improvement can be done but the security of our data is foremost important for us so that it can't be misplaced or modified by any intruder. Here we have tried to give an overview of security model for smart farming.

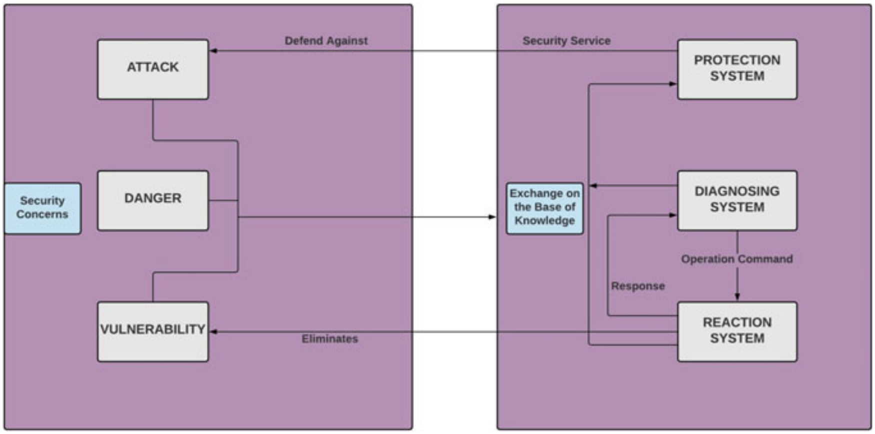

Fig. 10 Intelligent IOT security model for smart farming

6 Conclusion

Over the world, different data analysts and analyzers are exploring different types of solutions to increase the productivity of agriculture in a method that enhances existing methods by using IOT. Here a small yet detailed and comprehensive detailed analysis is presented on the progressive for IOT in agricultural domain. Here we have tried to focus on the different types of agricultural networks its associated architecture, existing platform that plays a great role in this field. This text provides an in-depth summary of the existed methodology in comparison with the recent development and the future of this methodology using Agricultural sensors, protocols, and all the available technologies. We have tried to give insight knowledge on various challenges and security threats involves in IOT farming. Finally, it is expected that this survey results into a really helpful piece of knowledge for researchers, professionals, agriculturists, and policy manufacturers who are collaborating and dealing in IoT field and agricultural technologies.

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Architecture, Security Vulnerabilities, and the Proposed Countermeasures in Agriculture-Internet-of-Things (AIoT) Systems

Nancy Kansal, Bharat Bhushan, and Shubham Sharma

Abstract In recent years, along with the rise in the population, the demand for food has also increased which led to the need for industrialization as well as intensification of agricultural sector. The Internet-of-Things (IoT) has been a promising technology that offers extended solutions towards the development of agriculture. Various research institutions and scientific groups, as well as industries, are trying to cope with the challenges by delivering more and more IoT products for agricultural sector. In this paper, we aim to provide a survey of IoT systems, its enabling technologies, and communication technologies. Moreover, we provide insights into IoT enabled agricultural applications along with its architecture and research challenges. Finally, we discussed the security and privacy issues that occur in agriculture IoT along with some cybersecurity attacks.

Keywords Internet-of-Things (IoT) · Agriculture · Security · Privacy · Attacks · Industry

1 Introduction

The term IoT was first coined in 1999, by Kevin Ashton, a British visionary. IoT standard is considered to provide global technological system that is equipped with many physical objects/things like everyday tools, sensors, etc. and these things play a vital role either as distributed or as a single unit having enhanced networking capabilities and computing power. These objects collaborate to form the swarm of heterogeneous devices. Moreover, as the things are associated over the network via Long Term Evolution (LTE), Near-field communication (NFC), Bluetooth,

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Wireless Sensor Networks (WSN) [1, 2] Radio-frequency Identification (RFID), and other communication technologies, IoT can also be summarized to be defined as "the association of things over the internet" [3, 4]. Advanced IoT has highly influenced agricultural sector. In 2009, The Food and Agricultural Organization (FAO) of the united nation predicted that world population will grow up to 8 billion by 2025 and can further grow up to 9.6 billion by 2050. Therefore, it can be said that by 2050, there must be a 70% increase in food production. The rising demands of growing population for high-quality products are responsible for intensification and modernization of agricultural practices. Moreover, it is mandatory to achieve high efficiency in the utilization of water and other resources. Precision Agriculture (PA) is a promising concept which is contributing a lot to increasing food production in a natural and balanced way [5]. PA aims to improve and optimize the agricultural processes in order to ensure high productivity and gives the farmers a more detailed perspective of current situations in their agricultural field. Furthermore, PA required distributed, reliable, and fast measurements in order to coordinate the automatic system/machine to optimize water use, energy consumption, and chemical use for plant growth and pest control [6, 7]. The algorithms that are used to handle the big data that are distributed over several nodes in the network practically are too complicated to be implemented on low-power wireless sensor nodes. However, when IoT is used, the things of the network will be interconnected, hence, the computation overhead will be distributed among the devices or will be shifted to the cloud [8].

Throughout the years, many eminent researchers have also written survey articles focusing on the usage of IoT in agricultural field. However, in reality, technology is dynamic and ever enhancing expectations and constants achievements from an existing methodology keep on motivating the researchers and scientists to obtain novelty further. Besides, over the past few years, there has been a noticeable increase in many new technologies such as big data [9], cloud computing [10], IoT [11], etc., in agricultural as well other fields. Owing to this advancement, there is a dire need to revisit the state-of-the-art capabilities and standings of IoT in agricultural sector. This study highlights the agricultural requirements in modern life and their alternatives that are precise to give the solutions based upon the expectations with the use of modern day IoT concepts. Paustian and Theuvsen [12] presented the relevance of several techniques that are used in PA. Their study also gained insight into the important attributes to adopt PA in Germany by several farmers based upon the farmer demographics and other several characteristics. They performed the regression analysis on the adoption of PA by the farmers and depicted a positive influence. Their experimental results provided manifold initial points to proliferate PA further in numerous directions. Balducci et al. [13] focused on the management of non-homogeneous data gathered from sensors. They also depicted that how private, public, and small- or large-scale companies increase profitability resulting in cost reduction and determining suitable ways to utilize data that are recorded continuously and can be accessed easily in order to achieve the right goals. They suggested machine learning based models such as polynomial regression and neural networks to perform data handling and decision-making process.

Hamad et al. [14] emphasized the role to utilize smartphones to access various parameters related to agriculture and the importance of these parameters in agriculture field. They performed a survey on 230 farmers by interviewing them, also provide a structured questionnaire for them to fill. Their investigation resulted that majority of the farmers were using smartphones to acquire the data on state-of-the-art farm conditions, and they were also relying upon the newer farming techniques depicted on videos available online in AP field. Köksal et al. [15] proposed a Farm Management Systems (FMS) based on IoT. The proposed architecture performed 2 basic activities: FMS development and domain engineering. FMS model was developed using the consecutive steps taken in domain engineering. Several reusable FMSs were developed in domain engineering phase and finally, an IoT based FMS architecture was developed using these outputs of domain engineering phase. Chen et al. [16] proposed image recognition and artificial intelligence combined with IoT and environmental sensors in order to identify the pests in the farm. They performed intelligent pest identification using the environmental IoT data. They proposed a combination of deep learning and mature AIoT technique to apply to smart agriculture. Similarly, Hu et al. [17] came up with deep learning combined with IoT technology to build an automatic fine-grained disease identification system for crops using IoT. Proposed system facilitated the transfer of diagnostic results to the farmers based upon crop disease detection. Such type of significant amount of work has been performed in agricultural areas by exploiting smart IoT technology [18]. Moreover, agriculture environment has been revolutionized by examining various challenges and complications in farming [19]. Subahi and Bouazza [20] proposed IoT based greenhouse monitoring and controlling system by developing the Petri Nets (PN) system. They used the IoT sensors generated big data for analysis of energy consumption, crop growth rate, and for predicting the production. Therefore, through our study, we have presented the summarized view of some of the researches done in agricultural field exploiting IoT devices and systems. Study also focuses on the issues related to security and privacy as well as the attacks incorporated with the concept of agricultural IoT. Major contributions of our work are as follows:

- This work provides an overview of IoT, highlighting the evolution of internet to IoT, enlisting the objectives of IoT, technologies enabled with IoT, and the communication technologies that are used in IoT.
- This work presents the concept of agriculture IoT referred to as AIoT that covers the development, definition, and architecture of AIoT. It also focuses on the applications of IoT in agricultural sector by providing some state-of-the-art evidence. Moreover, it emphasized on the research challenges faced in AIoT.
- This work identifies potential security and privacy issues that are confronted in agricultural applications enabled with IoT systems.
- Finally, this work identifies potential cyber-attacks that created the barrier in the practical applications of IoT in agriculture.

Remainder of the paper is organized as follows. Section 1 presents the introduction which sheds light on IoT, agricultural applications that have been enhanced with the use of IoT. Section 2 presents the basics of IoT, evolution of IoT, objectives, IoT enabling technologies, and several IoT related communicational technologies. Section 3 introduces Agricultural IoT in detail along with its development and architecture, this section also focuses on the major applications of IoT in the agricultural field along with the corresponding research challenges. Section 4 depicts the privacy and security issues that occur in AIoT applications, finally, Sect. 5 discusses some of the attacks on the smart farming based AIoT systems. Finally, Sect. 6 concludes the paper.

2 Overview of IoT

The term internet is a refined term and has come into existence with the constant advancements in internet field with the passage of time. Figure 1 shows various phases of internet. The Pre-Internet (PI) phase was the first phase in which Short Message Service (SMS) and fixed telephone line were used for communication. Later, mobile telephony devices replaced this communication medium. Internet-of-Content (IoC) was the second phase which was able to send messages having large size, for example, an email, which was able to be sent by attaching entertainment, document, or any media information with that. Internet-of-Services (IoS) was the third phase of internet, which centered the electronic applications such as e-commerce, e-productivity, etc. Internet-of-People (IoP) was the fourth phase which was responsible for associating people with each other via YouTube, Skype, Orkut, Facebook, and other various social media platforms. Finally, Internet-of-Things (IoT) is the current phase that is responsible for device coordination over the internet. These devices are able to perform several activities and communicate with each other as programmed/directed on the basis of functional and design capabilities. However, the current phase might not be considered as the

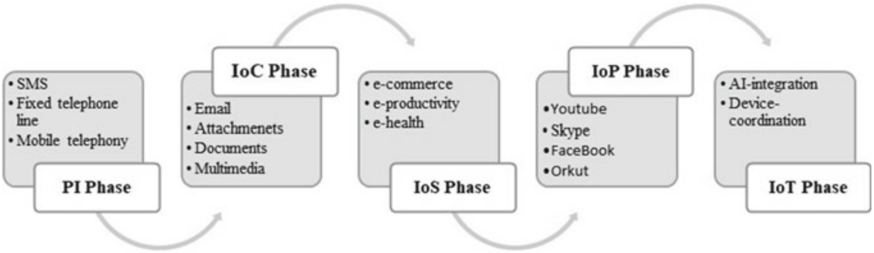

Fig. 1 Internet phases

last phase of this road map. In support of this, the researchers are trying to integrate IoT with Artificial Intelligence (AI) concepts so that necessary decisions can be taken without human intervention. Thus, it would not be incorrect to say the upcoming phase as AI empowered IoT (AIIoT) [21].

2.1 Evolution of Internet to IoT

Internet has certainly become a standard if we talk about communication. Over billions of devices are controlled using internet nowadays by incorporating the sensors on the basis of their operational capabilities. When these devices are connected over the internet through sensors, they generate a big amount of data that are processed further for keeping insights and for making various decisions. Near about 40 billion smart devices have been deployed in the world to date and the estimated incremental value for this deployment would go beyond $400 billion by 2030. Therefore, it leads to the advancement of new communication technologies and the methods to synchronize the new devices to IoT sensors [22]. Direct evaluation of operational capabilities of IoT may be incorrect, without analyzing time-to-time advancements and changes in IoT field. Industrial as well as academic sectors are greatly influenced by the research area of IoT as the results show the strong urge to find new methods to associate various devices to the sensors over the network. The development of societies leading to smart life can be looked upon by considering the IoT as a roadmap. Few examples contributing to the smart life are, independent living, agriculture, and breeding, smart buildings and home, smart grid, smart mobility, etc. [23].

2.2 Objectives of IoT

IoT aims to attain the objectives depicted in Fig. 2 by integrating the things via an Internet Protocol (IP) based interoperability of heterogeneous components that are enabled through Service Oriented Architecture (SOA).

2.3 IoT Enabling Technologies

IoT has a three-layered architecture which is namely, application layer, network layer, and perception layer for the tasks data storage and manipulation, data transfer, and sensing, respectively. IoT devices have many characteristics from which the fundamental feature is network capability, as it can also be implied by the term “Internet”. Although internet is the basically the interaction of humans where the end user is human itself, IoT is the interconnection or interaction of non-human

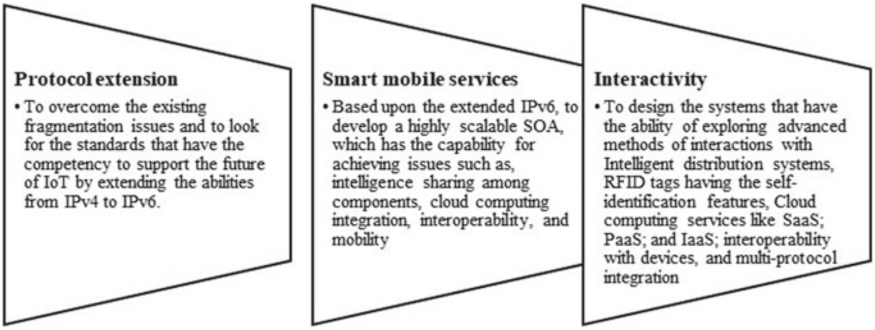

Fig. 2 IoT objectives

entities which are possibly the machines hence, the main idea is Machine-to-Machine (M2M) communication. Figure 3 shows some of the enabling techniques at different layers of IoT infrastructure.

2.3.1 The Application Layer

The application layer provides the realization facility to IoT systems. Several issues are also faced by the application layer like it has to identify the devices as unique entities. Addressing and identification of devices from all over the world will provide control and direct internet-like access to them over the internet in future. The relevant features belong to addressing schema include scalability, persistence, and the uniqueness of identity. IPv6 plays an important role from the perspective of internet mobility and could alleviate the issues related to device identification [24]. However, this problem is further amplified due to some factors such as confluence of device data, concurrent operations, variability of data types, and the non-homogeneous nature of wireless nodes. IoT is aimed to interconnect billions of

Fig. 3 IoT enabling techniques

devices having great diversity in networking subsystems, peripheral devices, computing power, and technical specifications such as compatibility, environmental capability, and power supply. There is a sublayer called middleware that is composed of several layers and is located between the application layer and the devices. This provides the developers, a set of more generic tools having the abstract technical specificities and device functionalities to build the applications. Furthermore, middleware is responsible for combining the SOA with the cloud infrastructure and sensor networks thereby providing the appropriate tools for all types of implementation and deployment [25].

2.3.2 The Network Layer

Network layer is responsible for, the communication of physical nodes with their neighboring nodes or we can say the gateways, the interaction with their environment, thereby forwarding the data towards the remote nodes by building the networks. The forwarded data can be further used for storage, analysis, processing, and extraction of valuable knowledge from those data. Several problems can be addressed by creating scientific literature on sensor networks in context of wireless communication. These problems can be such as robustness, scalability, networking features, and energy efficiency, etc. The communication gap between the end-nodes and internet-enabled gateways can be bridged by the standard protocols such as 802.15.4, build over the wireless networks. Such protocols include 6LoWPAN, ISA100.11a, WirelessHART, Sigfox, ONE-NET, and ZigBee. Also, some other are deployed recently such as low-power Wi-Fi, DASH7, LoRa/LoRaWAN, and Bluetooth Low Energy (BLE) [26].

2.3.3 The Perception Layer

Recently developed technology such as Near-Field Communications (NFC), RFID, and WSN is related to the perception layer. RFID and WSN technologies can be overlapped from the perspective that active and semi-passive RFID tags can be considered as WSN having low storage and computational capacity. Usually, a WSN node consists of an RF communication module, a low-power microcontroller, and a processing module, that support low-power WSNs [27]. Although agricultural harvesting is monitored and controlled during production itself, yet there is a need to monitor, track, and identify the livestock and agricultural products after the harvesting process. Logistics and storage facilities are widely affected by the use of WSNs for monitoring and climate controlling. The “Things” are interconnected by the RFID technology as the RFID tag contains the data in Electronic Product Code (EPC) form and RFID readers are manipulating, reading, and triggering many tags. Agricultural domain is widely affected by the use of NFC and RFID technologies as they offer the tracking, identification, and data storage facility on passive or active tags. Passive tags do not need of embedded power supply in them to work. Some of the applications include lifecycle assessment, quality control tracking, supply chain, and livestock or product monitoring [28].

2.4 Communication Technologies to IoT

Modern day applications are widely affected by the choice of options for connectivity among the devices. These choices may vary on the basis of the systems and products associated with IoT. Table 1 depicts some of the features of the presented communication technology.

2.4.1 Radio-Frequency Identification (RFID)

RFID system is the collection of several RFID tags and one or more reader(s). RFID tags are applied upon objects based upon the specific address. The principle working of RFID tags is based upon the electromagnetic field and radio frequency that is used to transfer the data from one node to another node in the network. Whenever the object has come in the RFID reader, the information that is electronically stored on the tags is read. RFID permits the objects to be monitored in real-time without the necessity of being them in line of sight. From the physical perspective, RFID label or tag is a microchip that has a compact package of antennas embedded on it. These antennas receive the signals from the reader and sent them back by adding some relevant information. An RFID tag has three configurations namely, Passive Reader Active Tag (PRAT), Active Reader Passive Tag (ARPT), and Active Reader Active Tag (ARAT). In PRAT, the reader receives the signals from active tags (battery operated) and it itself is passive whereas, ARPT tags do not have any power sources but it utilizes the energy from the signals sent by the reader and sends the data. ARPT tags are most widely used in communication. Finally, the ARAT tag is most commonly used to store the EPC data to track and identify the data uniquely [29].

2.4.2 Long Term Evolution (LTE)

Global System for Mobile (GSM) communication technology based, LTE is a high-speed data transfer wireless communication protocol that supports signals having frequency up to 100 MHz. data downloading and uploading often experience higher throughput and low latency rates.

Table 1 Comparison of various communication technologies used in IoT

Technology	Year of discovery	Description	Operating frequency (in MHz)	Range (in meters)	Downlink/ uplink	Standard
Machine-to-machine (M2M)	1973	Communication between the mobile devices, actuators, smart sensors, embedded processors, or computers	1–20	5–20	50–150 Mbps	Open to all communication protocols
Radio-frequency identification (RFID)	1973	Collection of several RFID tags and one or more reader(s)	0.125–5876	2	100 kbps	Wireless
Long term evolution (LTE)	1991	High-speed data transfer wireless communication protocol	400–1900	35	100 Mbps	4G, 3GPP, and LTE
Near-field communication (NFC)	2004	Digital wireless communication technology that is considered as assimilation of RFID reader on to the smart phones	13.56	<0.2	106, 212, or 424 Kbits	ISO 18092
Long Range (LoRa)	2012	Wireless data communication technique	169, 433 and 868 (Europe) and 915 (North America)	3000–5000	0.3 37.5 (kb/s)	Wireless

2.4.3 Long Range (LoRa)

LoRa is a wireless data communication technique that is widely used in offshore, remote, as well as rural industries for connecting various IoT devices which are in long range by distance. Besides the above application, LoRa is also utilized in several applications such as natural resource management, transcontinental logistics, supply chain management, etc. [30].

2.4.4 Near-Field Communication (NFC)

Similar to RFID, NFC is also a digital wireless communication technology that is considered as assimilation of RFID readers onto smart phones. NFC can also be considered as a radio communication device that is activated if there is close proximity between the two devices. From the technicality perspective, NFC utilizes 13.56 MHz band of radio frequency and operated on the device range of 20 cm. this range depends on the device's antenna size. Thus, NFC is considered as a low-power and short ranged wireless connection that is evolved from RFID and is able to carry a small amount of data among the close proximity devices. There are certain advantages of NFC which includes, no paring (between devices for data transfer), safe communication between smart objects, and remote communication [31].

2.4.5 Machine-to-Machine (M2M)

M2M is referred to as the communication between mobile devices, actuators, smart sensors, embedded processors, or computers. M2M communication has been widely used since last recent years. Nowadays there are more than 2.5 billion devices that are connected wirelessly (excluding smart phones). M2M communication technique has basically 5 components that are, services, applications, information processing, heterogeneous access, and sensing. M2M structure has the 5 parts that are, communication networks, gateway, area network, device, and applications [32, 33].

3 Agriculture IoT (AIoT)

Agriculture IoT is a technique for farm management that utilizes information techniques in order to ensure the optimum productivity and health of crops. Moreover, there have been numerous variations in the methodologies and techniques in order to perform agricultural activities as the farmers of modern age have moved to modernized concepts rather than traditional activities. In order to support the above statements, this section focuses on the research status of virtual reality/augmented reality, blockchain, the concepts of AI, and IoT in agricultural sector.

3.1 Definition and Development

IoT technology has been gradually penetrated into various areas since its development in 1999. All over the world, people are focusing on agriculture as it is the source of living for humans. Various researchers have presented their perspectives and have given several interpretations regarding the Agricultural IoT (AIoT) concept. AIoT has some main characteristics that have several aspects such as intelligent processing, comprehensive perception, and real-time feedback of harvesting to sales in agriculture [34]. AIoT has become a milestone since the evolution of cloud computing to edge computing models like mobile edge computing and fog computing. These techniques have completely changed the operation and management of the farms [35]. Several researches have been performed to progress AIoT methods in last few years. Xing et al. [36] developed an intelligent monitoring system that senses greenhouse information using ZigBee wireless technology. Gutiérrez Junco et al. [37] developed agrometeorological monitoring station that utilized wireless Bluetooth technology to send the data to the computer. Zhang et al. [38] realized the upload, visualization, management, and collection of actual information in paddy fields. They propounded information monitoring system that used the GPRS and solar-power panel technology. However, GPRS and ZigBee both are short-range and high-cost wireless technologies. Therefore, Zhang et al. [39] designed a monitoring system based on WSN and combination of LoRa and NB-IoT.

3.2 AIoT Architecture

AIoT was firstly dedicated to the applications of single entity leading to scalability, however, interoperability and scalability of the whole system increasingly failed to meet the ongoing demands of agricultural production. Later, based on the practical experience, expansion of IoT systems, reusability, and safety principles, new hierarchical AIoT architecture was propounded that fulfilled the special needs related to agricultural marketing and production. Figure 4 shows the architecture of AIoT that is divided into 5 layers from bottom to top, which are, sensing layer, access layer, network layer, data layer, and application layer.

Communication protocols are used to transfer the data between various layers. The bottom layer of the architecture, sensing layer, utilizes various sensing devices that use ZigBee, GPRS, and Wi-Fi technologies for data transfer and this data is further transmitted to the access layer in AIoT architecture. Further, access layer is comprised of built-in software middleware and hardware gateways. The complexity

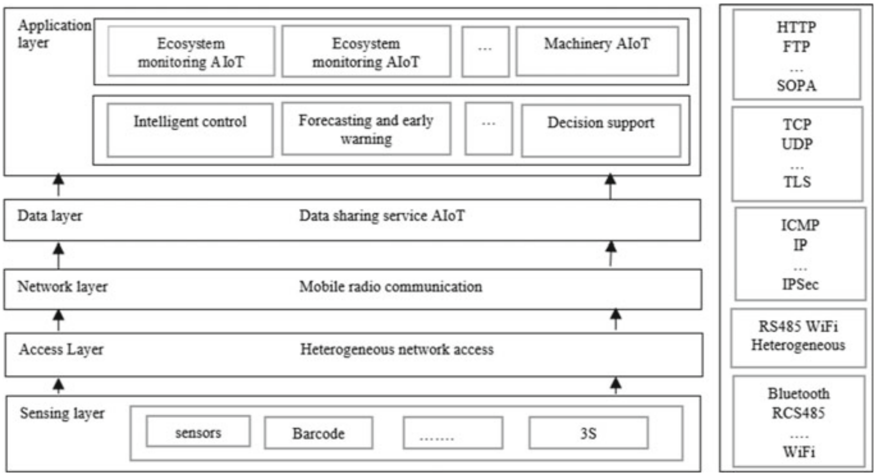

Fig. 4 Architecture of AIoT

of non-homogeneous sensing network is safeguarded using the middleware that provides the integrated abstract management interface for rapidly increasing business applications of AIoT. Network layer is responsible for data transmission to the upper layer using the mobile communication network protocol and internet protocol. The data layer in AIoT architecture behaves like a huge data pool that is responsible for the unified sharing of different sorts of monitoring data, hence is called the AIoT data sharing layer and uses User Datagram Protocol (UDP) and Transmission Control Protocol (TCP) for data transmission and sharing. The uppermost layer, application layer gets the data from the lower layer utilizing the standard protocols like FTP and HTTP to construct the corresponding AIoT system. The five-layer architecture of AIoT is more beneficial than the traditional 3-layer and 4-layer architectures in the sense that it provides a more independent and clear view of all the layers, reducing the communication burden, and providing the load balancing between the servers.

3.3 AIoT Applications

The core technology of Industrie4.0 is the IoT that is responsible for transforming various aspects of human life by creating a smartly connected world. Some of the use cases are connected vehicles, industrial internet, and smart home. Similarly, the evolving applications of IoT are encouraging the agriculture sector. The applications of AIoT include weather tracking, fishery management, smart greenhouse, livestock monitoring, and precision farming. These applications are discussed here in a more generic way, named Space-Air-Ground-Under surface Integrated

Network (SAGUIN) for global agricultural networking and sensing. SAGUIN paradigm would be recognized using the combination of mobile crowdsensing, WSNs, smart agricultural vehicles, drones, and remote sensing. Agricultural information can be provided by the remote sensing satellite constellation on the basis of commercial and national space infrastructure. This agricultural information can be relevant to pest identification, yield monitoring, crop production forecasting, etc. Moreover, in addition, the innovative automatic airborne vehicles designed using multispectral cameras, hyperspectral sensors, and other innovative instruments can improve observation precision and provide fast emergency responses through 3D monitoring at various geographical areas [40]. Finally, under surface and ground perception can be performed using various types of mobile crowdsensing devices, autonomous farm vehicles, and agricultural sensor nodes, etc. The requirements of agricultural applications can be met using advanced wireless networks such as Wi-Fi, ZigBee, Sigfox, NB-IoT, LoRa, 5G, and using communication technologies. These technologies can be applied in applications of agriculture such as high throughput plant phenotyping and real-time remote equipment controlling, for better end-to-end latency, bandwidth, and connection density [41].

3.4 Research Challenges of IoT in Agriculture

Irrespective of the rise that agriculture has been managed and automated with the use of IoT, there are several fundamental challenges pertaining to proper performance and management of AIoT systems. Various technical challenges related to AIoT are discussed in this section.

3.4.1 Professional Agricultural Sensors

Whenever there is the need to sense the agricultural environment, various issues arise. Precise agriculture needs the deployment of various sensors on agricultural equipment, animals, crop plants, and farm fields. However, the main barrier in monitoring fine-grained agriculture is the lack of professional sensors that do monitoring in plant phenotyping and livestock biosensing. This issue can be addressed by high reliable, high resolution, and high-quality professional agricultural sensors that are needed to be developed and deployed in agricultural production environments for the perception of physiological signs of plants and animals. The other solution can be the study of radio signal-based sensor-less agriculture. For example, electrical conductivity and soil moisture can be accurately measured using Wi-Fi signals.

3.4.2 Wireless Power Transfer and Ambient Energy Harvesting

Sensors' batteries are difficult to be replaced when used in agricultural environments as the sensors are installed at the places that are not easily approachable such as, on livestock, on trees, underwater, and underground. Hence low-power sensing materials are required. The solution to this problem is the used of electromagnetic waves to recharge the batteries remotely and this process is called wireless power transfer, but this method cannot hold with the situations when the sensors are put in extreme environments like underwater or underground. Photovoltaic AIoT where electricity production and agricultural activities co-exist at the same place. In this situation, the energy to sensing device can be supplied using distributed wireless chargers; however, due to varieties of sensing devices, energy transfer is to be done using adaptive task scheduling which is a major concern in agricultural applications. Moreover, sustainable AIoT can also be enhanced utilizing ambient energy harvesting method. This method can harvest the energy from various sources such as ground surface [42], movement of vehicles [43], fluid flow, and energy from rivers [44], etc. however, owing to the limitedness of electrical energy, further improvements need to be done to improve the efficiency of power conservation.

3.4.3 Cross-Media and Cross-Technology Communication

All the applications of agriculture cannot be implemented using the single standard network solution due to varieties of agricultural environments. Similarly, sensing devices that are used for agricultural purposes are distributed at water areas, underground areas, outdoor farmlands, and indoor greenhouses. Thus, due to this variation in application environments, several types of wireless communications methods can be considered such as vibration, sonar, radio frequency, and other types of signals for exchanging information. Therefore, there is a need to analyze these wireless communication methods and their performance while implemented in suitable scenarios. The incorporation of the smart sensors can also be accomplished using cross-media communication between air, underwater, and underground [45]. Different agricultural applications require different features of the AIoT network like latency, throughput, transmission distance, node density, and network size. AIoT applications ensure that the cellular technologies-based network, LoRa, low-energy networks, Bluetooth, and 802.15.4 mesh networks would be existing at the same place. Hence, the interoperability in AIoT can be further researched by enhancing the cross-technology communication techniques at various layers of AIoT architecture.

3.4.4 Robust Wireless Networks

Several challenges are imposed on wireless communication when it is applicable in complex agricultural environments. The reliability of LoRa networks and mesh networks is affected by the results of temperature variations in received signal strength and packet reception. It is also proved that relative humidity also affects the strength of radio signals. Secondly, obstacles such as, plants, animal movement, human presence, etc. are responsible for fluctuations in strength of signals on account of the multipath effect. Hence, the dynamic agricultural environment and variations in weather conditions can be managed if robust network protocols are implemented [46]. Thirdly, quality of service can also be degraded due to dense deployment and non-homogeneous AIoT networks and also would be responsible for wireless interference. In order to mitigate this issue, agricultural applications should be integrated with several effective channel scheduling between perceptive radio assisted WSN [46], non-homogeneous sensing device, and concurrent transmissions techniques should also be explored [47].

4 Security and Privacy Issues in AIoT System

The adoption of cloud supported smart applications and sensor-based technologies deployed in AIoT applications are responsible for orchestrating cyber-attacks as unleased opportunities for adversaries. Therefore, before discussing the cyber-attacks in smart farming domain, this section discusses major data privacy and security issues.

4.1 Data Security and Privacy

Various types of enormous amounts of spatial, dynamic, and complex data are generated from several non-homogeneous equipment, devices, and sensors, in smart farms. And if this confidential data is leaked or accessed by any unauthorized party, it can cause potential threats. For example, farmers can be economically affected if there is the leakage of information through hostile actors or competitors, of agriculture purchase, crop, or soil, and if the attacker bypasses the security measures and leaks the information about the anti-jamming devices used in agricultural applications. Besides this, potential threats can also arise when important agricultural information is disclosed to any different country [4]. Owing to these privacy and security threats, it is important to design a smart farming system to perform reliable operations. These systems leverage AI, state-of-the-art communication techniques, and IoT [48, 49]. These systems provide better results in case of real-time analysis contrasting to the traditional systems which take more response time as the data is first transmitted to the central server and after processing the results are got by the user in those systems. These systems often analyze the data that are collected by applying third party agronomy analytics and the analyzed information can be utilized by the researchers in various areas such as disease predictions, supply forecasts, agriculture economy, and plant genetics [50]. The smart farm data can be accessed directly by the researchers for real-time analytics. However, this advantage for researchers can also be an advantage for the attackers as they might compromise the systems of third parties injecting malicious software into their systems and steal the data. These types of attacks are not too easy to detect [51].

4.2 Authorization and Trust

In smart farming applications, the subsystems such as field sensors, flying drones, and autonomous tractors, etc., are connected to each other, interact and communicate with one another and issue control and command operations in order to prove efficient and automated experience. This type of interaction and communication can either be done via edge or cloud assisted network or direct M2M which are capable of supporting IoT communication protocols such as Constrained Application Protocol (CAA) and Message Queue Telemetry Transport (MQTT) protocol [52]. Regardless of whichever type of interaction is used, authenticity of message sending party is ensured so that no adversary can harm the system. The owner of the field or the trusted party should be responsible for authorizing the information such as breeding decision information, current location, information about crop yield, or moisture level of soil, etc. to the third party or to the cloud. The most relevant component of farmer's income is livestock. Cattles can be monitored remotely by the doctors by embedding the sensors in their body and enabling preventive actions when necessary, based upon the data collected from the sensors [53]. Moreover, the buyer can be provided temporary access to livestock data before purchasing. Although the cattle are monitored remotely, the adverse conditions and temperature of barn can impact the animals' yield and can also result in widespread disease and epidemics.

Whenever planting and harvesting are done, a bad software patch can also restrict the farmer from utilizing it in a critical agriculture environment, if Over the Air (OTA) updates are not provided by the trusted party. Multicloud [54] and cross cloud [55] models are required when various objects access the data remotely and are associated with various cloud providers. Such access should only be enabled based upon trust. This trust is most vital asset in case a doctor tries to access the cattle's data from the private cloud or an automobile engineer diagnosing an autonomous tractor. Various access models have been propounded for the systems like IoT [56, 57], however, there is the need for investigation for the feasibility of these models in dynamic smart farming. Despite being any simple task performed by the farmer such as data of a soil moisture sensing device, smart water sprinkler, or to issue a command, there is a need for proper authorization. Disclose of such type of information can cause serious issues for the farmers such as the attacker, by exploiting the sensors connectivity, may make the field parched or may flood the field of the farmers. In these types of applications, multi-level authorization may be needed.

4.3 Authentication and Secure Communication

The authenticity of the interconnected devices in smart farming needs privacy and security. Before a device is added to the smart farming system it should be passed through the levels of authenticity. Public Key Infrastructure (PKI) would not be a feasible solution for the interconnecting devices due to their limited storage capacity, memory, and limited processing power. Therefore, a more realistic solution to these smart farming environments can be, Lightweight Multifactor Authentication (LMA) [58]. Intermediary Certifying Authority (ICA) is responsible for checking the authenticity of the devices connecting to the network [59]. The authentication method provides an efficient solution by preventing unauthorized devices to be added to the system as well as providing authentication to the authorized devices without using their limited resources in processing. Furthermore, devices can also leave or join several layers of smart farming environment. This provides authentication on demand mechanism to devices allowing them access over different layers for different services. While providing on demand authentication, there is also the requirement of providing secure inter-device as well as inter-layer communication. To fulfill this requirement, the futuristic solution such as quantum-based cryptography is under investigation to provide secure inter-layer and inter-device communication [60]. However, such solutions have not been proven to be feasible for real-world situations.

4.4 Compliance and Regulations

Precision agriculture and smart farming raise numerous legal issues that stay partially unanswered. Some of the major issues have been discussed in this section.

4.4.1 Contracts and Agreements

Smart farm consists of several parties such as networking infrastructure providers, cloud service providers, farmers, etc. These parties need to agree and negotiate on several parts of the contracts such as intellectual property protection, security, and data privacy [61]. The most crucial part of the contracts for the development of smart farming is the protection of data. These contracts need to protect the confidentiality and value between the interested parties. The farmers who utilize the smart devices are also needed to negotiate on some parts of the contracts. For example, a wrong decision made for data analyzing and processing may lead to several downstream processes to be affected in the pipeline.

4.4.2 Data Security and Privacy

The fear of farmers for the data to be publicly released or stolen by their competitors leads to the concern for the security of data and specific clauses to be agreed upon by the technology providers. When non-personal data is linked to specific Personally Identifiable Information (PII), it can cause a serious concern for smart farming users. The example given in this context are, the personal details of the farmers linked with the crops conditions and livestock data that directs them to their owner. Thus, the processing of private data should be prohibited in the privacy clauses given by the technology providers. Moreover, other issues can also arise when smart farming entities such as tractors or drones are able to monitor their drivers [62].

4.4.3 Intellectual Property (IP)

The most important interrogation from the perspective of compliance is that who owns the collected data from the farm. This issue cannot be resolved through data privacy laws. These safeguards can be achieved by providing the copyrights, as the data cannot be safeguarded itself. IP protection clauses can be included by the farmers in their contracts that are created by them with the smart farming technology providers.

5 Attacks in AIoT Systems

Smart farming systems can eb vulnerable to cyber-attacks. This section describes some of the possible cyber-attacks. Table 2 shows some of the attacks that are possible in AIoT systems from the stances of various aspects. The table presents the causes of the possible attacks, negative impacts of these attacks, and their examples that have been seen in real life scenarios.

6 Conclusions

Owing to the security and privacy features, IoT has gained much attention in agriculture field. For future automatic systems in agriculture filed it promises to play a significant role as it is responsible for gathering, updating, and storing the significant data on servers. However, emerging AIoT applications may be prone to various cybersecurity attacks. By keeping in mind all these different aspects our study has tried to present a survey on IoT architecture and its applications in agricultural sector by providing its security challenges and privacy and security issues. At the end, this study laid out the vulnerability of the AIoT systems by

Table 2 Cause and consequences of various types of attacks

Attack	Cause	Consequences	Example/regulations (if any)
Insider data leakage	Any insider such as disgruntled employee, who can be responsible for leaking the data intentionally to sell data for money or to cause harm to the employer	The leakage of their farming-related confidential data as this data can be used by adversaries against them in commodity market	An engineer at the company Allen and Hoshall after being fired from the company sold the confidential information of the company for an estimated amount of five hundred thousand dollars
Cloud data leakage	• Distribution of various data centers on cloud • One country's data are stored on the data center of different country's data center due to distributed structure of the network; it can be more vulnerable to attacks	The government of other countries can collect or interpret the stored data within their own jurisdiction as it is stored on their country's servers	Some standards have been set for the localization of sensitive and confidential data. China has implemented a law for cybersecurity named law 24 since 2017, stating that sensitive and personal informative data must be kept only on domestic servers
False data injection attack	The invader tries to falsify or change sensitive data that is used for decision-making purposes by the organizations, with the notion that invader has the information of the configuration of the system	False information is injected at the data servers about the moisture level of soil, it might result in over-watering thereby destroying the crops	Attacker compromised sensors readings in such tricky way that concealed errors are introduced into calculation of values and state variables
Radio frequency (FR) jamming attack	Invaders may jam International Satellite Navigation (ISN) systems for malicious intentions by implementing various distributed less-powered jammers in order to disrupt ISN systems all over the areas	Destroying the ideal functioning of the smart farming equipment	Some recent examples of RF jamming include KeySniffer, MouseJack, BlueBorne, etc. These threats affected billions of devices from wireless keyboards to BLE

(continued)

Table 2 (continued)

Attack	Cause	Consequences	Example/regulations (if any)
Malware injection attack	An invader disrupts the functioning of interconnected smart devices by injecting malware into them [63, 64]	If malware is injected into a particular farm, it may reach other farms as well those are connected to the same network	Stealing of data about agricultural machinery, livestock, and vegetables, purchase information of fruits, and consumption of agricultural materials, etc.
Denial of service attack	Denial of Service (DoS) attack can be launched on large scale in smart farming systems using the IoT devices, similar case happened in 2016 with the help of Mirai botnet [65]	Disrupting the normal functionalities of not only a single farm but also on the cyber services provided by the other domains and are implemented on the same network	There was one of the biggest DoS attacks that was launched by exploiting a force of dummy CCTVs, on that occasion
Botnet	Various IoT related devices can be attached to each architectural layer of AIoT ecosystem. However, these devices might be controlled by a malicious server system and might be prone to attacks. This type of system formed is called Botnet of Things (BoT) [66, 67]	An IoT based smart farm can turn out to be the network of vulnerabilities for other networks as well	In 2018, 3ve botnet was responsible for 3 different sub-operations, each of which was capable of evading investigation after fraud and perpetrating skilfully. It infected a large number of servers and approximately 1.7 million computers
Side channel attack	Attacks that neglect the vulnerabilities existing in the implementation of the systems and have the roots on eth knowledge about the way of implementation of the system are referred to as the side channel attacks [68]	Different channels can be exploited by the invaders in such types of attacks	In timing channel attacks, adversaries exploit the patterns of memory referencing such as the time of computation, cache miss, and cache hit patterns

exploring some of the cyber-attacks that hinder the practicality of the AIoT systems. Through our survey, we hope that this study would be profitable to the design and implementation of future agriculture systems enabled with IoT for large-scale applications.

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Protocols, Solutions, and Testbeds for Cyber-Attack Prevention in Industrial SCADA Systems

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Abstract The commencement of automation with Industrie 4.0 has brought complex heterogeneous structures. These complex structures work on interconnected nodes or devices that operate on real-time data. The monitoring of industries is carried out using Supervisory Control and Data Acquisition (SCADA) system, whose backbones are the network and the data collected from numerous automated devices. Network-based attacks are prevailing huge in numbers. Therefore, it becomes vital to protect these industries and SCADA-based systems from hackers. This paper covers crucial components of the SCADA system that simplifies to understand the working and infrastructure of the SCADA system. The paper also investigates security flaws and most significant protocols that could nullify the security loopholes. Further, the most suitable security recommendations are highlighted. Finally, the pre-mortem testbeds of cyber security dedicated for SCADA system have been clubbed together, which alerts the virtually developed SCADA system about possible threats before it is actually built on the real industrial ground.

Keywords Cross-site scripting · SQL injection · Intrusion detection system · Firewall · Anti-malware · Testbeds · Root privilege escalation

1 Introduction

Supervisory Control and Data Acquisition (SCADA) system has been made to monitor as well as control the field devices that are remotely situated [1, 2]. The SCADA system does this efficiently by gathering and processing data in real-time. It is beneficial for monitoring industrial processes [3, 4]. The system

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includes various components, and some crucial ones are sensors, field devices, controllers, SCADA networks, Remote Terminal Units (RTU) [5, 6]. The system is highly vulnerable to cyber-attacks because of its complex structure [7]. Since the cyber-attacks have sharply increased in the digital era, it is affecting the industrial system as well and thus targeting the weakness in the SCADA system [8]. Whenever a system lacks the capabilities of updating and upgrading itself to a newer or latest patch, it becomes a prominent target for hackers [9]. Data are the main driving force for SCADA system and thus, to collapse the whole system, hackers are more interested in capturing sensitive and private data. Moreover, if the network of SCADA system is not properly configured to avoid internal and external threats, the SCADA system again comes at a risk for cyber-attacks [10].

The installation of hardware and deployment of code on the SCADA firmware must be done according to adequate policies and rules to prevent cyber-attacks [11]. There are devices that are static in nature, such as firewalls, and these works on stagnant rules either on whitelisting or blacklisting [12]. Since, the threat that these types of devices analyze and filter depends upon the static rules and policies, it becomes immensely important to configure them properly. The threats are increasing with great speed. Cyber-attacks have now become common phenomenon among healthcare [13], defence offices [14] and smart grids [15]. The use of anti-viruses have now become a need rather than using them as option. Other defensive mechanisms such as policies and rules would lay stronger foundation for any system against cyber-attacks.

The work on SCADA system has been done before, but this paper tries to reduce the security flaws that are residing in the SCADA system by suggesting the most relevant works and technologies that have been developed. The paper tries to cover the most important testbeds for checking the SCADA security that could potentially prevent traditional and recently emerged threats. In summary, the major contribution of this work can be enumerated as below.

- This paper presents the infrastructural components of the SCADA system which lays the ground for understanding various cyber threats.
- This paper suggests and averts the most relevant protocols suitable for availability of real-time data in SCADA system.
- This paper presents state-of-art prevention techniques that will make the system sturdier to both traditional TCP/IP attacks as well as ransomware attacks.
- This paper also presents testbeds that could help to analyze and predict prominent possible attacks that might make the system a debacle.

The remainder of this paper is organized as follows. Section 2 focuses on the background, architecture, and working components of the SCADA system. Section 3 deals with the important protocols for interaction between SCADA nodes. Section 4 deeply explains Key-Management Architecture (KMA) for secure SCADA communications while data is in transit over SCADA network. Section 5 explains SCADA vulnerabilities and recommendations. Section 6 presents testbeds for SCADA system for penetration testing of SCADA system and finally, Sect. 7 summarizes the conclusion of the work.

2 SACDA System

The Industrial Control System (ICS) is built upon two components which are namely called Supervisory Control and Data Acquisition (SCADA) systems and Distributed Control Systems (DCSs) or Process Control Systems (PCSs) [16]. SCADA is mainly concern about the monitoring of various components and infrastructure of the industrial system. PCS is the interconnecting media between the sensors and actuators involved in the system. Since SCADA is more about monitoring, it becomes very important to understand the architecture in order to make this ICS more secure from threats.

2.1 Architecture

The monitoring and controlling of machines in an industry are the two most essential functionalities to keep flow of the work. In order to support the workflow smoother and efficient, the SCADA uses six major components [17] that are discussed in the latter portion. The architecture of SCADA system is given in Fig. 1. Moreover, the components of SCADA architecture and their functionalities are explained in further subsections.

2.1.1 Operator

The operator is the main coordinating unit which monitors the system, produces relevant alerts related to the address, and based upon these two activities, the operator performs required control system's operation for avoidance of an anomaly in the industrial operations. This helps the industry or organization to function well under normal circumstances.

2.1.2 Human Machine Interface

The operator needs to interact with the SCADA system and therefore, it needs an interface. So, Human Machine Interface (HMI) provides the relevant interface to the operator to communicate with the SCADA system [18]. The information to the HMI is given by Master Terminal Unit (MTU), which is further translated by HMI to appropriately translate these inputs for the control commands.

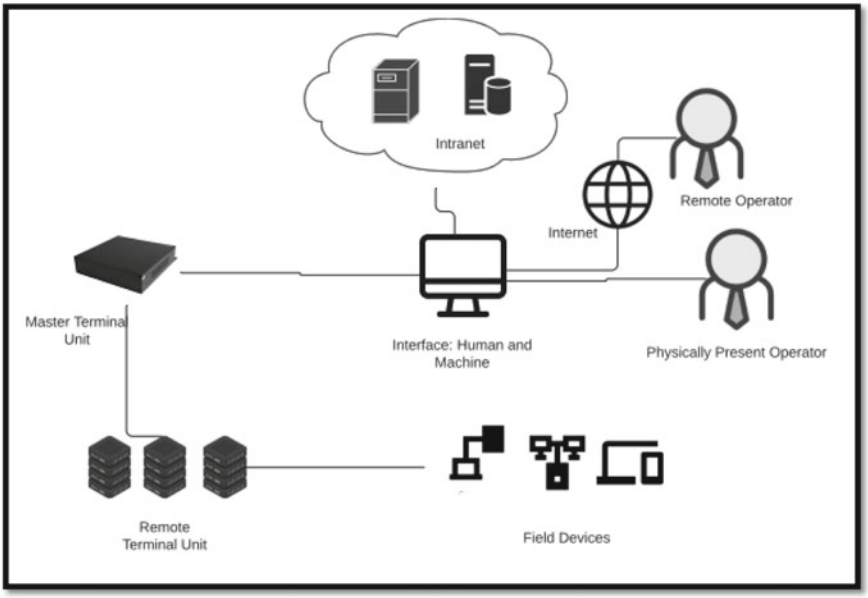

Fig. 1 SCADA architecture

2.1.3 Wide Area Network

The industry or the organization works on the Wide Area Network (WAN) or commonly known as internet. This WAN may consist of various networks, applications, and databases associated with the industry or organization for communication between them in order to perform the desired task. The communication helps to gather relevant information from the field devices that make the required industrial data analytics more optimal. Internet here acts as the backbone of the SCADA system as operator remotely connects through it.

2.1.4 Master Terminal Unit

Master Terminal Unit (MTU) is considered the heart of the SCADA system. MTU mainly collects data remotely from the terminal. Once the data is collected, it is transmitted over to HMI [18]. The high-level logical control is done with the help of MTU.

2.1.5 Field Devices

Field devices are the main working components that accelerate the task assigned to the SCADA system. These devices are distributed in the entire SCADA system or the organization. They communicate with each other and with the application/software of the SCADA system using network. They help in monitoring and controlling the industrial process.

2.1.6 Remote Terminal Unit

Remote Terminal Unit (RTU) is very important in SCADA system for controlling the field devices and it helps these field devices to connect to the main plant of SCADA system. RTUs are based on microprocessors and these provide an interface to the physical environment. The RTU gets connected to the operator through the interface.

2.2 Traffic Properties in SCADA Network.

The traffic of SCADA network is heterogeneous as different devices work together that could be manufactured from different vendors. Hence, it becomes very important to understand the features of the traffic, which might give the clue of any cyber-attack because of variation in features of these traffics. The below subsections traverse these features in a more specified manner.

2.2.1 Traffic Features

The SCADA network is very useful as it deals with the features such as packet statistics, pattern of the packet flow, stability, life expectancy of the persistent connection, prediction of the direction flow, and various other related features [19]. Throughput is considered as one of the main features as it guarantees regular industrial operation. The steep rise or decline of throughput is one of the indicators of cyber-attack.

2.2.2 Requirements for Quality of Service

The delay in the transfer of packets from one field device to another or from one field device to the machine might occur due to intrusion in the SCADA network. Moreover, all real-time processes have their own definite time duration for transmission of data according to the working of the machine. An anomaly in the arrival time of packets or data will signal the possibility of attack. The Quality of Service (QoS) can monitor the delay in packet and data, which would indirectly help to determine the possibility of cyber-attacks on the SCADA system.

2.2.3 Update and Events' Order

The attack on SCADA or any system is possible because of the failure in updating the existing device or software to the latest patch. QoS could only detect the threat, but in order to tackle these cyber threats, the system must be updated regularly. Moreover, the event monitoring should be done by updating new data in order to guide the dynamic SCADA system to take new decisions based on the interactions with the field devices.

2.2.4 Configuration for Protocols

Every network works on the basis of specified protocols and their configurations. The anomalies in protocols suggest the intrusion of new protocols within the domain of the SCADA system of that particular industry or organization. Hence, the protocol monitoring results in the detection of malicious activities. This will guide the network administrator to configure or reconfigure the new system or existing system respectively in the most appropriate manner.

2.2.5 Addressing

The SCADA system uses traditional Internet Protocol (IP) for addressing their components for communication or interaction between the devices and the software for the functioning of an industrial system. The addressing mechanism is handled at different layers of IP. The address mapping of a socket with the Medium Access Control (MAC) is used for interaction between various devices involved in the SCADA system and hence, alterations in the MAC address suggest a change of hardware devices, thus, detection of illegal hardware installation in the SCADA system might be achieved by addressing mechanism.

2.3 Security Requirements

Security is the main concern in any system, including SCADA system. There are various parameters that should be considered to properly understand security requirements and its implementation in the SCADA system. These are elaborated further.

2.3.1 Confidentiality

Confidentiality is the first and foremost priority. The data transmitted between the field devices and data processed via machines in a SCADA system must be protected from any unauthorized access. The implementation of any proper obfuscation techniques such as encryption [20], masking or tokenization could be used to achieve confidentiality for the data in SCADA system.

2.3.2 Integrity

The integrity of data is a must in SCADA system for proper decision making by machines involved. The modification of the data might be done using an injection in the network or devices that could lead to collateral damage to the entire physical system.

2.3.3 Availability

Availability is very important to avoid damage to the employees working in the industrial system and this could only be achieved in SCADA system if the data are available persistently for decision making by machines. The discontinuity in availability of data could lead to an industrial hazard.

2.3.4 Access Control

Access Control (AC) is yet another important entity that should be tackled properly to guide the permissions to access and modify data involved in the SCADA system. The access control rights to the employees working in the system should be given judiciously for the field devices, RTU, controller, and other components involved in it [21].

2.3.5 Network Security

Securing the network to prevent intrusion by adversary is very vital. This could be achieved by separating the SCADA internal network from the internet or public network. The installation of a firewall and Intrusion Detection System (IDS) is useful in avoiding unauthorized penetration into the network by an adversary.

2.3.6 Policy

Policy for technical and non-technical functioning matters a lot from a security point of view. Physical security such as entry gates to the industrial areas must be monitored using proper policy guidelines. The password and other sensitive data and their way of using it in the system must be clearly explained in the policy without any ambiguity. The policy recovery plan, risk vector analysis, and audit procedures will ultimately safeguard the SCADA system [21].

2.4 Security: IT Versus SCADA

The securing concept for the SCADA system critically differs from that of IT (Information Technology). The IT infrastructure takes into account most of the security measures while installing and configuring the devices and allocation of software. The SCADA system, on the other hand, does not assume or take into account such security measures. Thus, SCADA system becomes more vulnerable than IT and hence, it becomes potentially exploitable. The further subsections show various issues in SCADA security in comparison to IT security.

2.4.1 Security Concept

The IT network considers information confidentiality as the primary asset. The information may consist of payment card details, customer's medical data, passwords, student details, and other sensitive and private information depending upon types of companies or organizations. Also, here availability of data and information is the next priority. Hence, in order to stop an attack in worst scenario, the individual or entire devices and servers involved in IT infrastructure could be switched off but, this is not the case with the SCADA system. The SCADA network should work whole time as the SCADA system runs continuously, and hence, there is no chance of switching it off. Thus, in case of SCADA system, availability is the highest priority, network and services must be available all the time [22]. The traditional IT security concept is useful for various IT network-based infrastructures, but it is not suitable for the industrial SCADA network. The persistent availability of SCADA network is not achievable using traditional IT network concept.

2.4.2 Managing Vulnerabilities

In the current digital era, millions of field devices are prone to malware and ransomware attacks because of fragile designed structures. Majority of the devices as well controllers used today in SCADA system were manufactured in earlier days when cyber-attacks were not considered as perquisite measures [23]. Therefore, field devices could be easily flooded with malicious codes such as viruses, malware, and ransomware. In order to prevent these kinds of attacks, the field devices and controllers must be updated to their latest software patch. It must be made as an essential daily routine checkup process in the technical policy of the SCADA system. The traditional IT systems are made secure by various automated and manually configured application software and devices such as antivirus, firewall, IDS, IPS (Intrusion Prevention System). Scanning the SCADA system for threat and vulnerability analysis is also a hard nut to crack as these systems are fragile in their designed structure. Programmable Logic Controls (PLCs) as well as Remote Terminal Units (RTUs) are so delicate that their scanning may shutdown or switch off the entire SCADA system [8]. The most relevant aver for this is the Hatch nuclear plant that got shutdown completely in year 2008 after performing update on single computer that was part of this nuclear plant [24].

2.4.3 Operational Requirements

The IT networks and devices are used in specialized enterprises such as corporates, healthcare, offices, restaurants, etc., which have controlled surroundings like server rooms, database zone, workstations, etc. In contrast, the environment of SCADA system is not very much specified. The entire unit is established and installed on the floor. Electricity in a higher power is distributed on the whole SCADA system for heavy machinery works. Hence, it requires a higher level of precision for installation of field devices and controllers inside the SCADA environment. Moreover, the lifecycle for working of devices in traditional IT systems is shorter in comparison to those field devices and controllers working in SCADA systems [25]. Hence, the blueprint for infrastructure design that includes field devices, controller, and environment must be judiciously considered in a way that it should last for a longer duration taking security as one of the vital components.

3 Protocols Involved in SCADA

The SCADA system has numerous amounts of communications involved in it. These are for smooth functioning of machines and devices, which are driving forces for the SCADA-based industrial system. Therefore, these must execute themselves on protocols that are necessary for real-time functioning. These important protocols are explained deeply in the below subsections.

3.1 Fieldbus-Based Protocols

Field Bus (FB) is a network-based protocol that is used for real-time distributed industrial systems. It is helpful for the communication between the field devices, sensors, and actuators that are interconnected over a network. FB protocol distinguishes itself from traditional topologies by their length and data size of sending and receiving capability per telegram. FB deploys a single cable for connecting all the devices or nodes. Its simple architectural implementation makes it faster to deploy in SCADA or industrial systems. This protocol is very useful for the SCADA system because it is capable of connecting devices manufactured from different vendors. Moreover, the protocol is very flexible to adhere to new technologies. Some of the protocols under this category are explained in coming subsections.

3.1.1 Bit-Bus

Bit-bus is based upon the FB protocol. It can range up to 1200 m and supports a speed of 62.5 Kbps and 1.5 Mbps which mainly depends upon distance. This uses twisted pair cable based on the specification of S485. Bit-bus uses bus topology for communication between the devices and for increasing the signal it uses a repeater that strengthens the signal up to 250 m.

3.1.2 Foundation Fields H1

Foundation fields H1 [26] is another implementation of FB which is useful for bi-directional communication. This uses either twisted pair or fiber cable for communication and has the capability to connect up to 32 nodes. The maximum distance suitable for proper signal is 1900 m [26]. It uses four repeaters for extending the signal up to 9500. Though Foundation fields H1 supports various communication methods, it still does not allow broadcasting functionalities.

3.1.3 WorldFIP

WorldFIP is also based on FB protocol which is very useful in connecting field devices and controllers. WorldFIP could be used for both types of applications that are synchronous as well as asynchronous. WorldFIP works on the specification of three layers which are application, data link as well physical. WorldFIP establishes connection to a maximum of 64 nodes for length of 1 km. It has four speeds which are 31.25 Kbps, 1 Mbps, 2.5 Mbps as well as 5 Mbps for transmitting data between the intermediate nodes.

3.1.4 Distributed Network Protocol 3

Distributed Network Protocol 3 (DNP3) [27] is used for automation-based communication. The main aim behind its development was to enable an exchange of data among various field devices and controllers. Hence, it becomes very useful in adapting SCADA system. RTU, sensors, devices, and controllers could easily get facilitated by DNP3. Though initially, it was very slower interface, it developed itself by supporting Transmission Control Protocol/Internet Protocol (TCP/IP) which made this protocol more robust and efficient.

3.2 Ethernet-Based Protocol

Ethernet-Based Protocol (EBP) is considered one of the most approved protocols suitable for a heterogeneous system such as SCADA. EBP is very viable, versatile, and ubiquitous which makes it perfect to be used in SCADA system. The low latency is one of the main requirements of any communicating network in industrial system. This protocol satisfies this by using MAC layer for communication between field devices and controllers. Moreover, these industrial ethernets are faster than the traditional Cat5 or Cat6 cable.

EtherCAT uses EBP and it is very suitable for a real-time and processing-based system such as SCADA. Though it is useful for real-time computation, it does waste high bandwidth. The protocol when work in automation with field devices, the embedding of Ethernet controller becomes an infeasible process. The master-slave architecture is used for transferring the data among the nodes or the field devices. There are four types of addressing mechanisms supported by this protocol that is logical, broadcast, physical, and multiple. Some of the protocols under this category are explained in coming subsections.

3.2.1 Foundation High-Speed Ethernet (HSE)

Foundation High-Speed Ethernet (HSE) comprises of Foundation fieldbus H1 protocol that uses Ethernet protocol as well [28]. These two protocols are combinable by Linking Device (LD) within the SACADA system. The LD makes a bridge connection between devices of HSE and Foundation fieldbus H1. The MAC address is used for identity of devices incorporated in the SCADA system. FD acts as an interface for communication between user layer and devices.

3.2.2 International Electrotechnical Commission (IEC)

International Electrotechnical Commission (IEC) 61,850 specifies stack of service as well required functions for enabling exchange of data and information among SCADA HMI and devices [28]. Similar to HSE, MAC address is used for addressing the field devices involved within the SCADA network. IEC consists of critical messages which are directly mapped with the Ethernet. The Manufacturing Messaging Specification (MMS) uses TCP/IP for transmitting messages among the field devices and controller while it uses User Datagram Protocol (UDP) for timely synchronized (TimeSync) message transmission.

3.2.3 Sercos III

Sen et al. [28] proposed protocol termed as Sercos III that acts as an interface among three entities such as controller, device, and ethernet node. It transmits the data among various nodes in a cyclic manner by using the concept of master and slave nodes. SERCOS III performs data exchange with two telegrams. The first one is termed a Master Data Telegram (MDT) that consists of all information transmitted by master node. Second one is the Acknowledge Telegram (AT), which is also initiated by master node, but here the response by slave node is inserted inside AT.

3.3 Serial-Based Protocols

There are various standards that are very useful for controlling and monitoring the industrial system remotely. Serial-Based Protocol (SBP) is one of those kinds which is essential for SCADA system. The most popular SBP is IEC60870, whose data rate is 9600 bits/second [29]. There are two important protocols based on SBP IEC60870, which are explained in further subsections.

3.3.1 Modbus

Modbus is a widely adopted protocol for communication among devices and controllers involved in the industrial system [29]. The ease of deployment, viable maintenance, and simple specifications has made this protocol more popular among industrial system such as SCADA. Moreover, Modbus is also capable of establishing connections among devices residing on different networks. Modbus frames are capable of making address for the frame to be transferred and it also does error check for the received frame.

3.3.2 Unitronics PCOM

Unitronics PCOM or simply known as PCOM is another protocol under this category that is very useful for communication among PLC devices. The exchange of data and information is based upon traditional request-response mechanism. Moreover, PCOM is substantially capable of providing inter-PLC communication. This communication incorporates master-slave architecture. The messaging in PCOM is done either using ASCII or using Binary mode. Here ASCII uses one operand but, Binary mode uses multiple operands. This protocol also performs an error checksum for data authenticity.

3.4 Common Industrial Protocol

Common Industrial Protocol (CIP) is a peer-to-peer protocol that is used for data transmission between devices and controllers in an industrial application [30, 31]. This protocol increases the interoperability as well as consistency among all heterogeneous devices within the industrial network, such as SCADA network. The interface of this protocol provides a set of data and commands that are useful for communication between the field devices. Also, the routing layer guides message exchange between different networks. Many CIP protocol implementations could be seen in further subsections.

3.4.1 Highway Addressable Remote Transducer (HART)

Highway Addressable Remote Transducer (HART), which is also commonly known as HART, is the most vital protocol as it could be used for both analogs as well as digital data transition over SCADA network or any other industrial network. The digital transition is done either using 1.2 kHz frequency or 2.2 kHz frequency depending upon the number of bits. Like previous protocols, it drives on master-slave concept. Moreover, the Point-to-Point, as well as Multi-drop communication topologies, are supported. Though this protocol seems very useful, it is not capable of broadcasting messages.

3.4.2 Device Net

Device Net (DN) is considered as the first and foremost CIP implementation. This implementation was done on Controller Area Network (CAN) [32]. The node of industrial system or the SCADA system which uses this concept is connected via trunk-line topology. For the addressing of field devices, the DN uses 11-bit number. The broadcasting of messages is not backed by the DN.

3.4.3 EthernetNet/IP

EthernetNet/IP is another practical implementation of CIP that uses ethernet as standard. This protocol works on the data link layer of Open System Interconnect (OSI) model. EthernetNet/IP embeds CIP message inside ethernet frame and uses MAC address for identity management of field devices in a SCADA or industrial network. It also incorporates traditional TCP/IP for flow control of packets, fragmentation of large packets, and acknowledgment of requested messages. Moreover, in order to tackle timely fashioned packet transmission, the protocol uses UDP.

3.4.4 DC-Bus

DC-BUS is another vital protocol whose signals are analog-based, which makes it well suited for message transmission on both that is Direct Current (DC) as well Alternating Current (AC). The physical nature of this protocol makes it suitable for transmission over physical layer of OSI model. The protocol is very useful as it performs data transmission despite huge noise present in the signal. This protocol is made effective using sleep mode to reduce the consumption of power while data exchange process over the power line.

4 Key-Management Architecture for Secure SCADA Communications

The SCADA system has real-time data transmission over RTU, controller, and field devices. Therefore, it is important to safeguard these data from adversary. The obfuscation of data could be done more efficiently using cryptographic techniques. The important cryptographic key management techniques for SCADA system are enumerated in the below subsections.

4.1 SCADA Key Establishment Protocol

SCADA Key Establishment (SKE) is a very efficient protocol. The cryptographic technique is based upon the symmetric key concept. The main function of SKE in SCADA system is to secure the transmission of data for Controller-to-Subordinate (C2S). Maximum Transmission Unit (MTU)-RTU communicates with its subsection via SKE mechanism. The key management process in SCADA system is initiated by the controller. The controller and it's subordinate initially share the Long Term Key (LTK). The key is distributed in manual manner. Then a random number of 128 bit is chosen by the General Key (GK) with the hashing mechanism performed on the General Seed Key (GSK). The controller designates GK to its subordinate. The encryption of GK is done with the help of LTK of the subordinates. Finally, the session key is derived before starting actual communication with C2S. The communications among MTUs are done using public key via exchange of keys in SKE. The public, as well as private key, are designated by Key Distribution Center (KDC). Prior to actual communication between MTU and its subordinate, the MTU has to gain common key, which is usually done through a key exchange algorithm.

4.2 SCADA Key-Management Architecture Protocol

Giraldo et al. [32] proposed a protocol for managing key exchange in a SCADA system which is termed as SCADA Key-Management Architecture (SKMA). This key uses only symmetric key cryptographic techniques rather than using both that is asymmetric and symmetric, which is there in the case of SKE. The downside of this cryptographic mechanism for key exchange in SCADA network is that it is not capable of broadcasting data or messages in a secure way. The various nodes such as the RTU, MTU, and its subordinates use this technique for exchange of three keys. Firstly, the key termed as Long Term KDC (LTKDC) is shared among nodes which are distributed in a manual fashion. Secondly, the key known as Long Term Node-to-Node (LTNN) is shared among nodes that are willing to carry on communication among themselves. Finally, the last key, which is known as the Session Key (SK), is utilized for encryption of the data or messages over the SCADA network for key exchange. Thus, SKMA protocol works with KDC for key establishment and it is based on ISO 11770-2 technique [32]. Once the establishment of key among various nodes as per node's requirement is achieved, SKMA creates SK that has a definite time duration for its use.

4.3 The Logical Key Hierarchy Protocol

Buchanan [33] purposed Logical Key Hierarchy (LKH) protocol works upon the logical tree concept. LKH uses symmetric key cryptography. Moreover, every member knows the key which is associated with the leaf of the logical tree. When a new member joins the existing logical tree, the LKH protocol then updates the whole symmetric key starting from the leaf to the root of the tree. The members in SCADA system could be controllers, field devices, RTUs, Master Station Units (MTUs), etc. Once the new nodes (controller, field devices, RTU, MTU) are added to the SCADA network, the KDC updates the key for all these newly added nodes. In case any node or member leaves the logical tree, the KDC again updates the key. The modified version of LKH that is LKH++ is more efficient when the node or member leaves the logical tree [33].

4.4 Iolus Framework

The SACDA system is heterogeneous system that has devices from multiple vendors and these devices need to multicast or broadcast their messages according to the application involved in the SCADA system. Therefore, the Iolus framework is very useful in industrial systems such as SCADA, because it has the capability to multicast as well as broadcast the communication required between the field devices, RTUs, and other SCADA related nodes. Also, this framework is very useful for managing communication between the Master Station Unit (MSU) and the RTU of the SCADA or other industrial systems. The framework is also similar to LKH in the sense of logical tree concept but, here all the subgroups or sub-members are secure. The encryption of data is done again at the subgroup level apart from main group. This is usually done using Group Security Intermediary (GSI). GSI also relays all the traffic of the network which falls between subgroups.

4.5 Advanced Key-Management Protocol

Donghyun et al. [34] proposed a new protocol for the SCADA system termed as Advanced Key-Management Protocol (AKMP). The SCADA system does require broadcasting of messages for data transmission among the field devices, RTU, MSU, MTU, controller, sensor, actuator, and other related components. Also, this data exchange occurs in real-time and the processing in SCADA system goes on, it never ends. Therefore, it is essential to secure these data in transit over the SCADA network. AKMP becomes very essential in such a case as it aims at securing the data from external access attempted by adversary or hacker. This protocol consists of one sub-protocol, which aims to provide security to the backward process. The newly introduced key in the RTU does not depend upon the previous key to avoid any similarity. Moreover, the key for the new RTU gets replaced by the KDC. KDC uses the hash function for updating the key. AKMP also discusses another sub-protocol that works for the secrecy of newly formed key. When a member leaves the group, the leaving member can try to predict the new key that might be formed in the future. The protocol is termed as Leave Protocol (LP). In this case, when nodes leave the group those nodes are made incapable of computing the new key by KDC. KDC deletes all the leaving nodes and updates the remainder of the keys on the paths that were traversed by these leaving the nodes. Since the leaving nodes do not know the updated key after it has left, it becomes impossible for it to predict the new key. Thus, security of data over the network increases.

The protocol also provides encryption of data with the help of an SK and it needs to be used within certain predefined duration. The SK, which exists for a longer duration gives a clue that there could be possibility of session hijacking or key compromise. In such a case, the key is not used for further process. The protocol also shares the data load over the entire traffic within the SCADA network in a distributed manner, which ultimately avoids any bottleneck for data transition between the nodes (field device, RTU, MSU, etc.). Further, it also reduces load on the low powered field devices, sensors, etc.

5 SCADA Vulnerabilities and Recommendations

Industries are very useful as it manufactures daily needs such as foods, utensils, medicines and other elements for humans. This points that SCADA system contains huge amount of sensitive and personal data for processing machines. Also, the SCADA system is heterogeneous. These two features fascinate the hackers to disrupt the secure functioning of SCADA system. Therefore, various forums and organizations are dealing with the analysis for predicting the threats in SCADA system to discover and implement most optimal tools and techniques for the same. Department of Homeland Security-National Cyber Security Division's Control System Security Program (DHS-CSSP) and Indus-Trial Control System Computer Emergency Readiness Team (ITCSCERT) of the Unites State has performed various vulnerability assessments for cyber-attacks in industrial systems such as SCADA system [35]. Various SCADA systems are now using robots and other automated machines for their work. Therefore, an organization of the United Kingdom known as Centre for the Protection of National Infrastructure (CPNI) is dealing with the threats that may occur in these automation-based SCADA systems [36]. The vulnerabilities and their probable recommendations in SCADA system are segregated. These are covered in upcoming subsections.

5.1 SCADA Software and Hardware

The software is the interface for the operators that enables the operator to access the functionality of the system. Therefore, the foremost step should be to develop secure software. The Stuxnet was able to attack the SCADA database because of misconfigured deployed code [36]. The software as well as the system combines to work together to ensure the entry of authentic and authorized persons into the SCADA system. The cyber-attacks such as Cross-Site Scripting (CSS), SQL injection are commonly found in SCADA systems. These attacks are possible because of vulnerable authentication process provided by SACDA software interface.

Buffer Overflow (BO) is one of the most commonly occurring attacks where the amount of data provided in buffer is more than the available memory size. The only way to stop BO is by developing the code in proper manner and also deploying it on the SCADA system with proper configurations. The attacks on SCADA system were reported 30% due to code injection, 6% because of directory traversal attack, and 15% due to CSS attack [37]. In order to prevent such attacks in SCADA system, proper authentication must be practiced. The new authentication practice, such as 2-Factor authentication must be adopted in SCADA authentication mechanism to avoid authentication bypass. Moreover, the adversary also sends malicious packets to the SCADA network. The misconfiguration of rules and policies in the defending network devices are the main reasons that provide path for malicious packets to be inserted by the hacker. Therefore, proper configuration and adequate implementation of rules and policies in networking devices are the two major steps for tackling malicious packet injection attacks on SCADA systems. Another deadly and commonly occurring cyber-attack that is Denial of Service (DoS) could also be avoided by performing integrity check of the data and assets involved in the SCADA system. This is very important because the DoS attack has the potential to demolish the whole SCADA network, which will consequently become debacle for the entire SCADA system.

SQL injection and CSS dominates where databases are involved. In case of SCADA system, SQL injection's main intention is to bypass the authentication and authorization phase to access unauthorized data that could be the id and password of the employees working there or plan of the new product that company has preserved. The real-life example could be that of nuclear power plant situated at Oak Harbor where DoS attack was executed with the help of SQL injection [38]. The SCADA systems are vulnerable to Operating System (OS) based command injection that can corrupt the main server of the SCADA system on which controller and other applications are operating. The preventive step for such an attack in SCADA system could be importing internal library calls rather than relying or exporting external processes by the control operators. Similarly, the CSS is done using fake website having injected malicious scripts that penetrate the web server of the original one. This usually happens because the legal clients accidentlly enter their credentials on this fake website. To avoid such attacks, the employees or clients should be trained or guided to identify the original website of the company. Also, the website should be remotely tested before it is made available for the users.

There are situations where the code is insecure, which might not refer to any vulnerabilities but rather the complexity and difficulty in the code makes it vulnerable to cyber-attacks. Numerous hard coded devices are involved in SCADA system and therefore, it is important to make optimal code and the code should go through rigorous testing before deploying in the SCADA system. Inadequate logical structure and calling of unsecured functions in the SCADA system such as OPC dynamic linking library functions make the system vulnerable to cyber-attacks. The only solution to such vulnerability in the code is to train the developer according to the specification of the node and machinery involved in the SCADA system and following secure lifecycle code development method for the same.

Apart from software vulnerabilities, hardware could also add vulnerabilities to the SCADA system. It has been noticed that the old components of SCADA system make the system vulnerable in two ways, either they do not have the feature of upgrading their software or if they have this feature, they are not timely upgraded and updated to their latest patch. The most commonly found old components are outdated web servers, weaker database versions used, weak Secure Sockets Layer (SSL), etc. Therefore, patch updates and replacement of old version nodes are two essential recommendations that must be followed to prevent cyber-attacks due to unpatched nodes.

5.2 Vulnerability Due to Archaic Defensive Components

The vulnerabilities are exploited because of weak infrastructure that includes both physical access to resources and access to resources through software applications. The Access Right (AR) that is read, write and execute (rwx) plays crucial role to defend root privilege escalation attack that is one of the deadliest cyber-attacks as it could give root or administrative ownership of the targeted system to hacker. Therefore, the access right to the webserver, database server, controller, RTU, and other related SCADA system's resources should be adequately given according to proper rules and policies of the companies. The AR guarantees the triad of cyber security for any system that is confidentiality, integrity, and availability, which are very crucial for system such as SCADA, which works 24 × 7 a day.

The traditional defensive device such as firewalls is not intelligent enough to prevent SCADA system from newly malicious crafted codes. Therefore, similar to corporate sectors, even SCADA system needs to adopt intelligent defensive devices and concepts. Web Application Firewall (WAF), Intrusion Detection System (IDS), Intrusion Prevention System (IPS), log management server, anti-malware software are advanced and intelligent components that must be adopted by SCADA system to tackle intelligently crafted attacks such as malware and ransomware attacks. Also, the intelligent routers and manageable switches should be replaced with the traditional ones for anomaly detection. Now, some of the SCADA systems are using cloud technology and cloud network are more secure when used with proper standards and protocols [39].

Data are the most important asset in any real-time system such as SCADA system. Also, protecting these data in SCADA system is more challenging than the corporate system because the corporate system might turn off their system for a while in case of cyber-attacks but, this is not possible with SCADA system as they work continuously. Therefore, data in the SCADA system could be protected using obfuscation techniques such as encryption, masking, or tokenization. Any of these techniques could be used in SCADA system depending upon the sensitivity and probability of data exposer. Moreover, the wireless sensor which is working in SCADA system is very much used and these are also useful in intelligent computational transmission [40–43]. There are various preventive measures adopted for wireless sensors which can provide security to any system [44, 45]. Therefore, they must be configured with proper encryption standards. Also, new technologies such as Machine Learning (ML) and Deep Learning (DL) are used in various sectors [46–49]. These technologies could be used to detect and analyze vulnerability in the SCADA system and consequently guarding it. SCADA works similar to Internet of Things (IoT) and hence the steps adopted for securing IoT [50, 51] could be used in SCADA system also.

6 Testbeds for SCADA System

The security is one of the main concerns in SCADA system, also maintaining security in it is difficult as the SCADA network communicates with the devices and components 24 × 7. Therefore, it is important to test the system for security with different testbeds. The important testbeds for SCADA system have been traversed in further subsections. Table 1 explains various types of testbeds that are practically used to test possible threats in SCADA system before its actual implementation.

6.1 Physical Testbed

The Physical Testbed (PT) relates to the relocation of the existing SCADA system. It is also used for other industrial systems. It becomes very useful for demonstrating reliability in existing industrial or physical systems. The SCADA system has huge collection of hardware both in working and stock conditions. So, it becomes very vital to compute the economy involved it. The fixed and variable cost incurred in the SCADA system needs to be calculated for viability of the business. PT could be of great scaling mechanism for such cases. Further, the PT is subdivided into two categories which are termed Small-scale and Full-scale physical models. The Australian ICS Security framework is developed for Small-scale model [52]. The Industrial Control System Security Testbed (ICSST) is another implementation of Small-scale physical model which is mainly mechanized for generation of electrical power [52]. This system constitutes generation unit, interface for human and machine, controller as well as logic unit. The United States' department of energy has developed Full-sale physical model, the model is useful for SCADA system communication's safeguard and named as National SCADA Testbed (NSTB) [53]. The NSTB serves by monitoring heavy charged power line which is stretched to larger distance and this helps to secure hardware and software involved in the SCADA system. The NSTB also uses some of the traditional TCP/IP devices such as a firewall as well as Virtual Private Network (VPN) to support network security.

Table 1 Various types of testbeds in SCADA systems

Testbed types	Testbeds	Technology adopted
Small-Scale Physical Mode	Australian ICS Security framework [52]	Programmable Logic Controller, Network devices, and VMware Server
Full-scale physical mode	National SCADA Testbed [53]	Power grid System
Virtual	TASSCS [54]	Automatic Software Protection System and Opnet
Hybrid	SCADA_SST [55]	C++, Smart Grid, and Water Control System

Moreover, the testing of system must be performed prior to implementation phase by penetration testing to find potential vulnerabilities that could arise after real implementation.

6.2 Virtual Testbed

The Virtual Testbed (VT) has been developed to eradicate the shortcoming of both that is software and PT. This is achieved by segregating physical nodes from the external components during activities that are carried out at test phase. The summary for the software layer as well as hardware layer is well achieved using VT. Hence, the configuration of SCADA system becomes easier and the controlled environment is achieved using VT. Testbed for Analyzing Security of SCADA Control Systems (TASSCS) is an implementation of VT which was made by NSF Center for Autonomic Computing (CAC) [54]. Modbus and TASSCS are based on Opnet which checks the behavior of the operations [54]. This is mainly used to predict and prevent cyber-attacks. Another crucial testbed is the VSSCADA or Virtual SCADA which is used for power systems [56]. This testbed is having the flexibility to reconfigure to test the attack according to the system. This is supported for various versions of windows such as Window 7 and Window 8 [54, 56]. Also, it is useful for checking possible attacks on controller and HMI. Another framework known as SCADASim was developed by Australian which is useful for various testing SCADA nodes such as RTU, MTU, PLC, and field devices [57]. SCADASim checks the Modbus and TCP communication in an industrial system for threat assessment. The few important attacks that might be checked in SCADA system are Man-in-the-Middle (MITM), Denial of Service (DoS), eavesdropping, and spoofing attacks. Idaho CPS SCADA Cybersecurity (ISAAC) testbed was developed under VT for SCDA system [58]. ISAAC is very useful in SCADA system as testbed because it supports cross-platform which is one of the possible features in the SCADA heterogeneous environment, also it could be reconfigured for dynamic tests for cyber-attacks.

6.3 Virtual Physical Testbeds

The testbed is very easy to use as it is capable the testbed to convert entire physical system into a suitable computer model. Virtual Physical Testbeds (VPT) is also known as Hardware-In-the-Loop (HIL) [59]. VPT mainly focuses on the communicating network of the field devices for data transmission. Moreover, VPT is economically viable and more practical in nature. The latency, pattern of communication is so realistic that it could be embedded easily with the real SCADA control system. Vulnerability analysis is optimally supported by VPT. VPT developed by smart grid lab successfully checked cyber-attacks on power grid [59].

6.4 Hybrid Testbed

Hybrid Testbed (HT) is implemented using the replication of SCADA system through virtualized simulation. This is very useful for checking cyber-attacks. Boockmeyer et al. [55] has explained various cyber-attacks that could be tested under HT. This is based on two-layer architecture. Hybrid Cyber (HC) and Virtual Physical (VP) are the two layers of HT. SCADA_SST is another useful implementation of HT. SCADA-SST is very versatile and could be used for different SCADA system test-cases. Moreover, it can also detect any malicious node existing inside the SCADA network. The programming language which it uses is C++ and it is also used for network traffic analysis. SCADA-SST is very useful in water tank management.

7 Conclusion

The paper optimally explains various components that are involved in the SCADA system. It clusters together important protocols that are very relevant for SCADA system and then it explains various key management strategies that enhance the security of the SCADA system. Also, it explains various attacks that are possible because of traditional security approach adopted in SCADA system. The famous attacks such as SQL, CSS, DoS have been covered and their prevention has also been suggested in this paper. It then recommends certain mechanisms that could make SCADA system a hard nut to crack by the hackers. Finally, the testbeds are covered, which is very essential to test the possibility of attacks in industrial systems and especially in SCADA systems before deploying it over the industrial system.

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