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IoT-Enabled Agricultural System Applications, Challenges and Security Issues

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Abstract The growing demand of Internet of Things (IoT) brings many more paradigms in several areas of applications such as smart city, smart village, smart energy management, smart agriculture, smart health care, etc. It aims at integrating the virtual world along with the physical world by using the Internet as communication medium. The IoT could be practically feasible with several existing technologies such as wireless sensor network (WSN), radio frequency identification (RFID), middleware technologies, cloud computing and end-user applications. The technologies associated with the IoTs have great impact on precision agriculture or smart farming as well as global economy. This chapter aims at agricultural applications where it utilises modern technologies that benefit the farmers with decision tools and reduces manual labouring cost. The seamless integration of products, knowledge and services through IoT maximises the volume of productivity, product quality and profit of business. Even though current surveys on the IoT in agriculture focuses on the challenges, constraints, benefits and pitfalls for large scale in the agricultural food sector, all are presented in isolation to each other. So, keeping all in these in mind, a brief discussion on challenges, benefits, constraints, future trends and security issues are presented in this book chapter.

Keywords IoT · Smart farming · IoT-enabled architecture

1 Introduction

IoT is one of the promising technologies that connects billions of devices through the Internet and applications of IoT are huge in range from defence to health care,

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classroom coaching, industry, agriculture, etc. [1]. Agricultural production has a vital role in Indian's economy. The GDP of a country mostly grows proportional to the agricultural productions of a country. In India, the share of agriculture is 16% of total GDP and 10% of total exports. The overall GDP of the country has been decreased due to the share of agriculture compared with the other sectors. Countries like India and China need to increase their agriculture production due to their fast-increased population growth. Due to the increasing population in the world, the importance of agriculture is quite natural. According to the report by United Nations of Food and Agriculture Organization, it is expected that the population will be doubled by 2050. The increased production of the agriculture through modern technology using IoT will support huge economic lift to India. In agriculture, rice is the major dominating product compared to other crops and majority of the people in the world love to consume rice. Specifically, around 70% of the people in India consume rice as their major food. India's rank is the second largest producer of rice after china across the globe. The farmers face lot of difficulties in the crops due to the pests and diseases in crop, managing the soil, water, climatic change, etc. [2]. Mostly crop losses occur up to 37% due to pests and diseases every year. There are many diseases like fungi, bacteria, viruses, nematode caused by rice and it occurs frequently where ever rice is grown. Some of them are national and international importance, others occur in local areas. These crops-related problems can be resolved with the IoT-based user friendly intelligent systems. Nowadays, Internet of Things (IoTs)-based technology is going to change the structure of agriculture/industry sector and connects the stakeholders to contend with the challenges they face. The quantity and quality of the crop production can be enhanced by addressing all these issues. The advancement in wireless communication systems and VLSI design has led to the development of smart tiny sensors, handy mobile devices and ubiquitous services through Internet connectivity. It has created a new era of IoT-based agricultural applications. According to Gartner's prediction, there will be 25 billion IoT devices in the market by 2020.

According to the research report produced by Machina, the number of agricultural devices through Internet connectivity is predicted to raise from 13 million to 225 million from 2014 to 2024 [3]. The Internet Protocol (IP)is the heart of network layer that provides the route to carry the data, exchange the data and network-related information between multiple LANs called as distributed system. The connected IoT devices via Internet make the distributed system to enable the data to be accessible any place, anywhere and at any time. However, the transfer of data over a huge network through Internet services requires adequate security, privacy, data management attention as Internet Protocol (IP) is subject to theft analysis and not enough security features are inbuilt to it. The Internet with cloud computing technology has further provided a huge platform where large volume of data can be gathered, processed, analysed and accessible to the stakeholders. To manage cloud services is another challenging task [4] where many factors are involved like middleware's, APIs, services, establishing and managing the network nodes and dealing with the data in a proper computational speed. In addition, the connectivity of heterogeneous systems and devices over the Internet, communication algorithms/protocols and IoT mid-

dleware are the main building blocks for any type of application. Service-oriented architecture (SOA) is the example of middleware of IoT which consists of multilayer architecture. In extension, cloud-based IoT middleware and actor-based IoT middleware are discussed in [5, 6]. In few proposed architectures, how the data can be sensed, fetched in a connected network, how to handle middleware and application layers are discussed [5–8]. Interested researchers can refer these literatures.

1.1 IoT-Enabled Technologies Used for Smart Farming

IoT-based agriculture is about to empower farmers with automation tools, decision power and automated technologies that integrates information, service and product to maximise the product and minimise the waste. This section gives an outlook of IoT-based smart farming where modern technology can improve the farmer's life, enhance the productivity, minimise the cost and extend the supply chain as shown in Fig. 1. There are three layers active in IoT structure. These are perception layer, network layer and application layer. In perception layer, we meet sensors, RFID technologies, near-field communication (NFC), etc. In second layer (network layer) where the sensor nodes interact with the environment, communicate with the neighbour nodes or gateways, build the network by forwarding the data and send the data to the remote

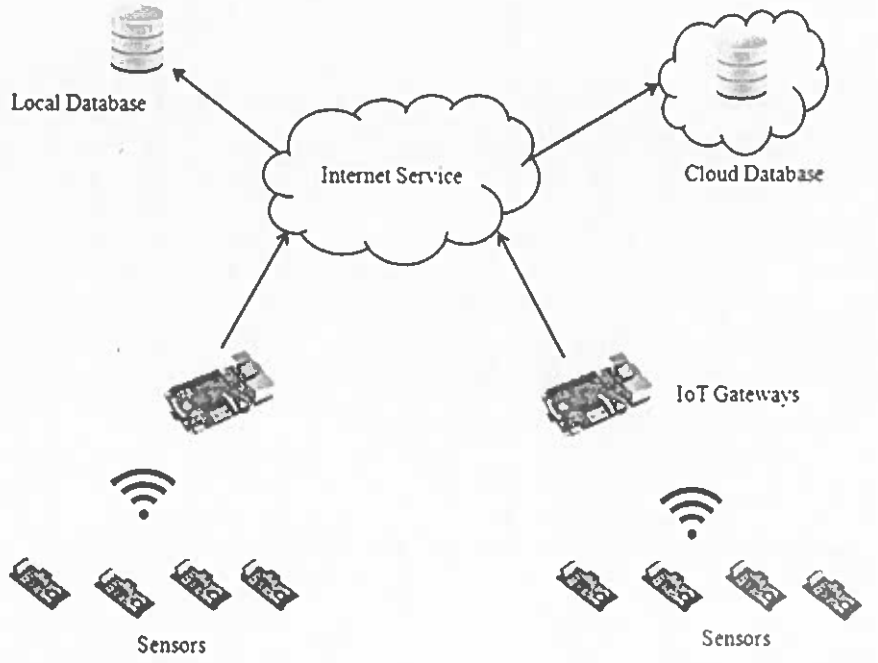

Fig. 1 Example of IoT-based farming

server for further processing. Third layer, application layer, faces many challenges and issues which has to be resolved. Application layer must provide the access to the authenticated users and modify the data. Every device should be identified with unique IP address. To provide billions of devices unique ID and address across the globe is not an easy task and each device must be empowered through Internet access and control over it. Future Internet Protocol will take care of it. In real-time scenario, sensors usually do their miracle by performing sensing activities. The major part of smart farming involves the deployment of sensors in outdoor environment which can sense the various parameters like temperature, humidity, pressure, moisture in the soil, crop's growth rate, cattle health, chicken production, etc. This large volume of sensed data are streamed via wireless link to the IoT gateway, to the local server with a replica stored in the cloud server. This big data is processed, analysed and available at the cloud so that stakeholders can access the data at any time and take care of the crop products, live stocks, etc. This reduces the production cost dramatically. Also, with livestock monitoring, you can mitigate risks of losing the yield. In addition, the waste management can be done more efficiently for many by-products. This can help in better cost management and increased revenue generation. Such process automation opens up many avenues for pest control, fertiliser recommendation with enhanced product quality and volumes.

2 Applications of IoT in Agriculture

Over the decade, we have witnessed the evolution of Internet into wireless devices providing the devices a unique address on the network. The main pillar of IoT technology is IPv6 (instead of IPv4) that provides a unique address to each object in this world. These devices are connected via Internet and have many popular applications and agricultural production is one such application. Now-a-days, IoT-based smart living, smart villages, smart city, smart machinery are high in demand. As agriculture is back bone for many countries, modern tools and technology must be utilised for proper food supplies across the world. Several environmental factors such as temperature, humidity, salinity, leaf wetness, soil moisture, dry circle, solar radiation, rainfall, pest movement and human activities can improve the agricultural productivity. If the farmers can able to monitor these factors remotely using smart technology, surely our County's economic condition can be increased. Farmers can take some preventive measures for pest control based on historical information regarding pest control, get a chance to improve the quality of farming and achieve high productivity. There are several applications of IoT-enabled agricultural system which are listed below. Figure 2 depicts the applications of IoT-enabled agriculture.

- Monitoring activities
  - Monitoring irrigation and water quality
  - Monitoring weather condition
  - Monitoring soil

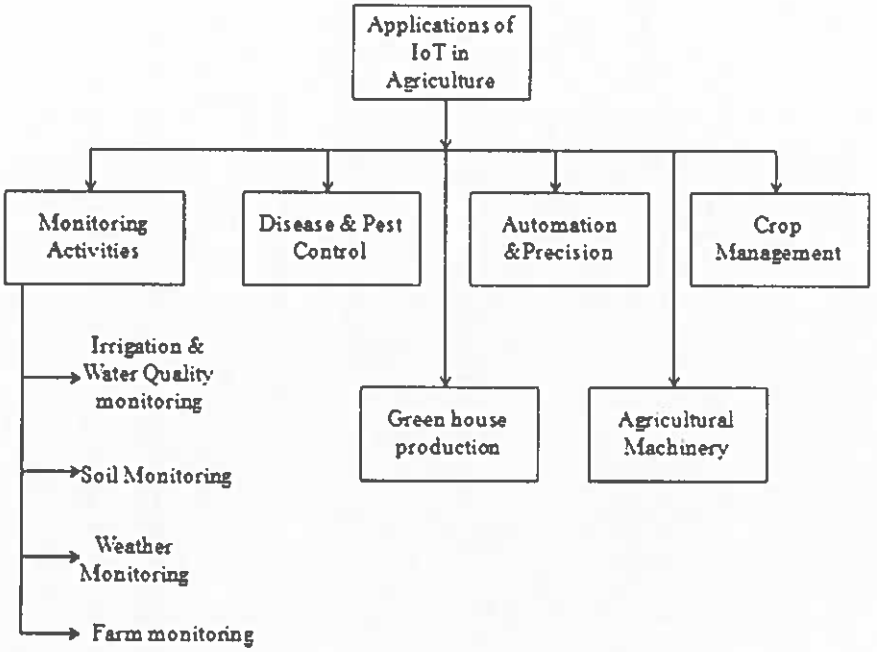

Fig. 2 Applications of IoT in agricultural sector

- Monitoring the farm

- Crop management
- Agriculture machinery
- Automation and precision
- Disease and pest control
- Greenhouse production.

2.1 *Monitoring Activities*

Today, the most critical task for farmer is to monitor, model and manage the environmental parameters which are beyond predictions by engineers and scientists. The Agricultural activities require continuous monitoring for accurate and reliable advice from agronomists. There are many parameters which need to be monitored such as environment, cropland fertility, water quality for aqua life. In this section, we present overall view about the use of IoT in monitoring system for weather, soil, water and smart farms.

2.1.1 Irrigation and Water Quality Management

Irrigation plays a major role to achieve sustainability in agriculture. Automated irrigation system [9] is the primary requirement in agriculture. So, wireless sensor nodes are deployed across the agricultural area to sense various parameters required for irrigation. The soil moisture sensor and temperature sensors collect the respective readings from the home gardening or agricultural area and push the sensed data into the cloud. The farmer can access the streamed data at any place and any time. Crop sensing for various parameters is done accurately by using IoT technology. Remote monitoring can be done to monitor and control the agricultural field using wireless senor devices. To monitor soil quality and ground water level in agricultural field, ultrasonic waves have been sed. The use of IoT-based (using Arduino) smart drip irrigation system [10] aids in optimal irrigation facility for crops. Water distribution is a major challenge even today in many developing countries especially in water scarce regions. There is a need for automatic water monitoring and distribution system to enable uniform distribution of water among the stake holders. Smart water metres need to be deployed on a large scale. The system proposed in [11] uses smart water metering in the Indus basin. There is also a need of IoT-based technology to enable demand-based water deliveries. This system has put efforts in automating the large-scale irrigation networks.

A real-time water quality monitoring at a low cost is developed for IoT environment. The use of IoT has revolutionised as the innovative technology has connected to web. Irrigation is the primary resource for agriculture. The WSNs are widely used in irrigation management applications.

2.1.2 Monitoring the Weather

The major climatic factors affecting the agriculture are hail, frost, snowfall, flood, drought and storms. So, a weather prediction system is highly desirable, which can monitor parameters like air, temperature, humidity, barometric pressure, light intensity, rain, speed and direction of wind. So that, farmer can properly plan for sowing seeds, fertilisation of plants, sub-soiling, ploughing, irrigation, etc. activities based on the weather conditions like sunny, rainy, cloudy, snowing, etc. This helps in better utilisation of resources at a proper time. The low range (LoRa), low power consuming devices is used to check the feasibility and economy for farmers in weather monitoring. The system has been demonstrated on a wide agricultural field with several sensors deployed to collect the physical parameters. These readings are relayed to the weather station, and the data is available through a web application. This system was connected through LPWAN through LoRa-based RF transceivers. During the development of hardware prototypes, Arduino nanoboard is used as an open-source electronic prototyping platform, which consists of an Atmel microcontroller mounted on a circuit board. The farmer can view the web application for up-to-date information about the weather conditions without visiting the field. Nowadays, the weather monitoring systems exhibit many capabilities. The wireless sensor network

(WSN) is perfect choice for such monitoring applications. As the sensor nodes can deploy themselves in remote environment, they are able to reorganise themselves even after node failures. The IoT management system can protect the balance in ecology and improve the quality of environmental parameters. A case study is proposed in [12] which integrates geo-informatics, cloud computing and information systems for accurate monitoring and management of environment.

In this system, multiple sensors are used to collect data and web services to transfer that information to the server. This information system resulted in benefit of not only in data collection giving valuable big data analytics, but also the monitoring and decision-making improved a lot through the web services and cloud computing platforms.

2.1.3 Monitoring the Soil

One of the primary factors to determine plant growth is moisture in the soil. This plays a vital role in providing the essential nutrients to the growth of a plant. To determine moisture in the soil, resistive sensor can be employed. These sensors determine the change in soil resistance between two probes of the soil moisture sensor. Due to global warming, the climatic conditions have become unpredictable. The amount of rainfall is decreasing every year leading to scarcity in water and essential soil nutrients. This necessitated for automated irrigation system [9] to determine the macronutrients, i.e. nitrogen, phosphorus and potassium in the soil. This system can save time, money and power for the farmer. Many farmers are using manual methods to perform this test, which require repeated human intervention and is a tedious process. With this automated mechanism, farmer is able to receive the soil fertility and the irrigation information via e-mail directly. The IoT-enabled sensors are deployed in the agricultural land to capture the details about soil and climate.

The soil moisture sensor gives indication of water content in the soil. The growth of the plant can be determined by measuring the moisture contents in the soil. Whenever water content goes beyond the threshold, an alert message is generated to supply water in that area. These automatic intelligent devices are very much helpful in remote monitoring using IoT. In case of inadequate nutrients in soil, farmers use fertilisers to make the soil fertile. In real time, IoT monitoring system can be used to identify the requirement of soil and suggest the amount of fertiliser required. This will maintain the health of the soil to aid for plant growth. In this effect, the applications of IoT are huge in agricultural field that can be applied monitoring weather condition, environmental condition, controlling greenhouse automatically, industrial intelligent control system, tracing food safety measure, etc.

Apart from these, temperature and humidity are few major environmental parameters that affect weather change, topological change, types of soil and vegetation [13]. In this way, the temperature sensor gives measure about the coolness and heat content variation in the soil. Some of the agricultural robots also determine the dry lands while weeding the crops and suggest the irrigation requirements to the farmer.

2.1.4 Monitoring the Farm

There are many innovative applications of IoT [14–16] for connected farm management systems for agricultural industry. There are several farming activities which need attention for innovation and better management. Some of the widely found farming industries are cattle farms, bird farms, beehives, etc. The use of IoT in these farms helps the farmer in achieving higher production. Beehives are used not only for honey production, but also there is a fact that beehives greatly aid pollination of crops. The farmers have to regularly monitor the beehive status. So, a beehive monitoring system [17] gathers internal and external data of the hive. These data determine the position of the bee colony from a set of data using a classification algorithm based on decision trees. Farmers can directly take a decision for his visit to the hive, based on the sensed data available on his smart phone. Also, the study resulted in prediction of rain forecast based on the beehive status. In addition, smart beehive provides automatic honey production through its automated machinery. So, it reduces the human risk of squeezing the honey from the beehive. This beehive too can greatly help farmers in agriculture production. Some of the smart farming techniques are displayed in Fig. 3.

As the world population is increasing at a rapid rate, there is a high demand for food production. The poultry industry is in critical situation unable to cater for growing food needs. The use of efficient farming techniques and some best practices for improving the production can solve the problem. The study conducted in [18] has

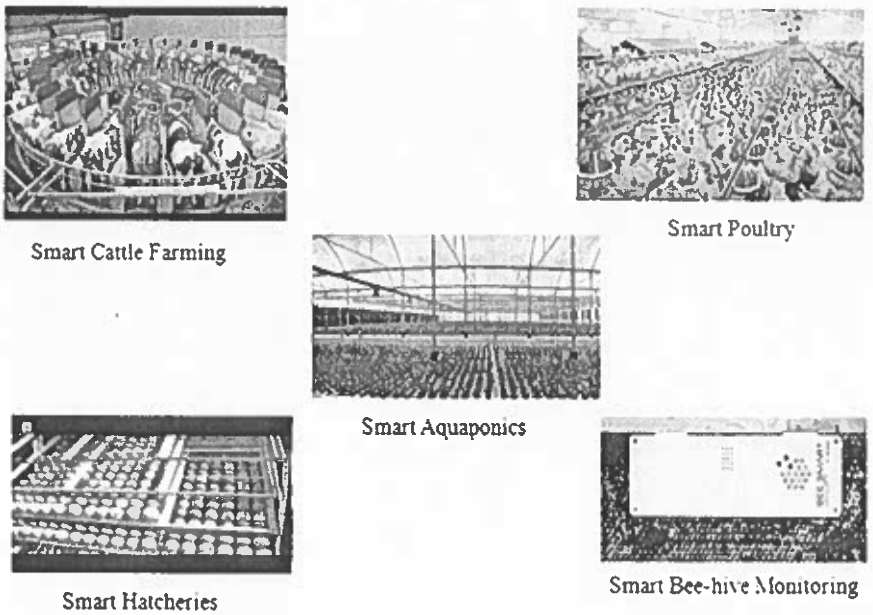

Fig. 3 Example of smart farming

pointed out the use of technology for productive management. It explores the use of smart phones to monitor chicken farm activities.

The poultry industry is in need of various monitoring services rendered by IoT. One such activity can be seen in the hatcheries of poultry industry. Traditionally, the birds give the required temperature for 21 days to hatch the eggs. But due to various reasons, some of the eggs are not hatched while some remain incomplete. In a huge poultry, it is extremely impossible to provide every bird with all the ideal characteristics. This severely hampers the profits for the poultry farmers. The IoT-based hatcheries come to farmers rescue. Such system can provide the required temperature and humidity for hatching the eggs. This improves the hatch rate, production, chicken quality and operational efficiency. Also, the monitoring service of the hatchery can help the farmer in detecting health issues in chicken. It is very difficult to identify the infected chicken for a long time until the disease spreads to other chicken and there is huge loss to the farmer. Using IoT, these birds can be monitored continuously and the respective temperature and well being of the chicken can be reported to any remote location with these IoT devices. These data can instantly be rendered on smart phone. In another instance, the chicken farmer monitors the poultry using smart lighting system [19]. The smart lighting system can be controlled by adjusting the lighting intensity to generate the required temperature inside the poultry using a smart phone. In addition, there is mechanisation of certain activities of feed and water supply to these egg laying birds at regular intervals of time aids in replacing the human intervention for accuracy and timely service.

Another important smart farming applications can be seen in cattle or animal farms. Different animals like cow, buffalo, goat, sheep etc. farm animals not only contribute to meat industry but also their byproducts like milk, wool, dung and organic manure for plants are in high demand. With the use of IoT devices, many of the traditional farming methods are replaced with artificial intelligence-enabled IoT devices and robots. Besides regular animal movement, these IoT devices can also monitor the health and fertility of the cattle. The fertile cycle for the cow is a critical 8 h window in one month of time. So, the Moo monitor can continuously monitor the cow from a distance of 1000 metres can help the farmer in detecting the exact time window to help the cow for reproduction. A neck-mounted device worn by the cattle whenever the cattle cross a defined Wi-Fi point, the information is transmitted to the mobile device of the farmer via cloud. This helps in monitoring the health of the cattle remotely to take necessary precautionary measures in case of birthing and maternity.

The cattle milking robots are in high use in many advanced countries. These robots not only replace manual milking activity, but also take care of the health of the cattle. The cattle are tracked with a unique RFID and monitored for their milking session. The robot gets the information when the animal is ready to be milked. Also, their health is monitored and fed with special grains during lactation. The giant milk industry is completely dependent on solutions provided by IoT and artificial intelligence. Thus, IoT is the main player in the smart diary industry catering to the ever-growing population.

Aquaponics

Aquaponics is one important technique of farming where plants are not grown in soil. They are grown in water using light as their source of photosynthesis and water for the essential nutrients. The continuous water quality monitoring for fish farming in tanks, along with soilless plants is termed as aquaponics [20]. The fish provides natural fertiliser for plant growth and the plants purify the water for fish cultivation. The fish wastes aid to provide the plants with essential nutrients. For monitoring the water quality and various other parameters such as sunlight, salinity and pH level, IoT devices are widely used. Hence, automation is highly desired in such applications, where there is less human intervention and monitoring can be done remotely.

Forestry

Forestry has great impact to produce carbon cycle. An early detection and alert system can protect against many activities such as forest fire by nursing the soil, monitoring the air, temperature, humidity and different types of gases such as carbon monoxide, carbon dioxide, oxygen, hydrogen, methane, toluene, isobutane, ammonia, ethanol, hydrogen sulphide and nitrogen dioxide.

2.2 Crop Management

Agricultural process does not follow only sowing, watering, adding fertiliser, spraying pesticides and collecting harvest from the field but also requires a lot of analytics in every phase of life. For instance, soil moisture, and damp weather condition is required for germination of seeds. So, weather prediction system is desired during germination phase. Similarly, to grow a healthy plant, fertiliser is required. The amount of fertiliser required or pesticide required requires an in-depth analysis for better management of crop. Farmers can take the decisions by maintaining some historical data or with the help of IoT-based management technique. In real time, the information can be accessed or monitored remotely through mobile phones, URLs, etc.

The distributed systems across the greenhouses can also be managed in an efficient way. It provides the users of the applications with various authentication levels. The real-time information can be delivered through e-mail alerts or through SMS in the smart farming technology. SmartFarm Net [21] is a data acquisition, analysis and visualisation platform for IoT-based smart farming applications. It is the largest in the world to provide crop performance analysis and recommendations. This platform can virtually support any type of IoT device and provide data visualisation with zero programming effort. It provides tools for fast and scalable data access from millions of sensor nodes for monitoring crops. The advantages of IoT-based technology promises better infield monitoring of cropland. Finally, smart agriculture is the new weapon

against the increasing climate change and global warming. It also increases the crop productivity by efficiently using IoT along with cloud service for an economically feasible solution for farmers.

2.3 *Agricultural Machinery*

The use of IoT in agricultural machinery, the crop productivity can be greatly improved. Some of the machinery such as unmanned aerial vehicles and robots operated in autopilot mode are the direct applications of IoT in agricultural machinery. The agricultural equipment manufacturer CLAAS [22] has implemented IoT in their equipment. The Precision hawk's UAV sensors can provide information such as wind speed and air pressure. There is a mechanism called sub-soiling which can enhance permeability of soil, improve soil physio-chemical properties, grow crop root system environments without disturbing soil layer structure and facilitate increases in crop yield. This requires the use of agricultural machinery for ploughing and seeding. The government has to monitor the geographical region to identify number of such agricultural machinery being used. An IoT-based sub-soiling system for agricultural machinery monitoring was developed in [23]. This scheme uses convolution neural network-based automatic image recognition system to identify the agricultural machinery spread over a geographical region. There was a study conducted in which examines the productivity of swine farms on usage of IoT-based electronic sow feeder.

In the era of IoT, most of the ancient farming methods are going to be replaced by IoT-based modern technology. The advancement of wireless technology, sensor network along with cloud computing and fog computing has brought a new era in agriculture. It all starts with sensing and monitoring with the help of the IoT-enabled sensors from the remote locations and then transferred directly to the cloud for direct access across the globe. In monitoring the crop growth and crop diseases, IoT-enabled agricultural drones are playing a major role. The drones are unmanned aerial vehicles operated with a remote control for better crop management. Drones can be used for soil analysis which can help in monitoring the nitrogen content (main requirement for germination) in the soil. Also, these drones can be used in sowing of seeds and spraying of fertilisers and pesticides with uniform coverage of the geography. This greatly reduces the cost and aids in better crop management. Drones are fitted with hyper-spectral, multi-spectral and thermal sensors. This helps us the farmers to calculate the crop index and proper planning of crop. Overall, drones replace the human intervention in continuous crop monitoring activities. Example of smart agricultural machinery is shown in Fig. 4.

On the other hand, there are many other options for such video geography monitoring with driverless tractor and robotic vehicles. The manual methods of sowing the seeds is very labourious and cumbersome and often inaccurate. Often the seeds fall out of the guided line for germination. So, driverless tractor used for ploughing and seeding can save farmers time and effort. With the precision seeding devices,

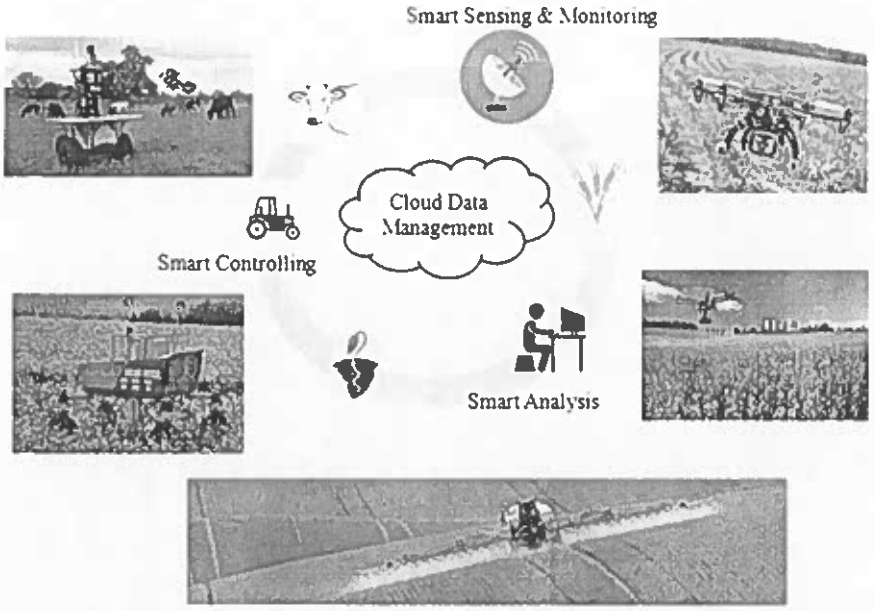

Fig. 4 Example of smart machinery in IoT-based agriculture

sowing and spacing of plants can be done with accuracy without any wastage. This facilitates optimal plant growth. In general, robots can replace human activities, and the precision agriculture can be greatly benefitted by Bonirob robot. It is useful in the weeding of crop. The robot was developed as a prototype in UC Davis smart farm initiative. The robot was developed by integrating artificial intelligence and machine learning. The size of the robot is like a car. It is well trained and can autonomously move around the field and look for weed plants to eliminate. Also, these robots are used in apple plucking kind of tedious human work. It can move around the fields between the plant spacing without damaging the crop.

2.4 *Precision Agriculture*

Precision agriculture deals with the evolution of traditional technology for miniaturisation of the electronics industry. The precision agriculture is the management of information specific to agriculture to improve the crop production. These include metrological factors (temperature, humidity, sunshine, wind and water), smart irrigation details, etc. which are crucial for farmer in planning his activities and make it profitable. Hence, use of IoT cloud platform [24] offers users massive information collected at a low cost using cloud service. The IoT system implements a decision support system to estimate the water needed for the soil conditions. Also, the farmers

can get alert message notified by SMS when the crop needs irrigation facility. Precision agriculture came into existence to optimise the crop production, to improve the crop quality and efficient use of resources like water, power, soil fertility, etc. But, due to the high cost, operation and maintenance of equipment, these networks are not being widely used. The evolution of IoT and embedded systems have allowed the development of economically feasible systems which are easy to install and easy to maintain with minimal power.

2.5 *Disease and Pest Control*

Since several years farmers have been facing difficulties in crop monitoring and disease prediction. Today with the evolution of IoT, farmers are able to achieve good crop production. This section gives details about the usage of IoT in crop monitoring and disease prediction. Disease and pest control is one of the major challenges in agriculture. Every year farmers are losing an average of 37% loss in their crop production due to diseases and pest. With the use of IoT, early disease detection is possible which can facilitate in taking some preventive measures. The continuous crop monitoring activity can be assigned to an IP camera and the recorded video of the crop can be rendered daily to a smart phone. This data could be shared to expert advices to choose a proper pesticide. Also, the farmers need not visit and invite agronomists to the rural areas for their advice on pesticides. Obviously, this kind of monitoring activity could minimise the human intervention, save time and effort. By using deep learning application for disease detection, farmers can classify the disease and also get recommendation of proper pesticide in the smart phone. As smart phones have become affordable, it can change farmer life tremendously with ever-growing IoT technology. For crop disease detection, image processing and for pest control, deep learning algorithms can be used. But deep learning and image processing technologies are limited due to their computational intensity to run on a smart phone. However, very few researches have been carried out in this direction with some limited disease detection for rice crop. The authors in [16] have used inception V3 transfer learning to train on a deep convolutional neural network to classify three types of diseases and two types of pest for cassava leaves. This can be rendered to a smart phone for taking necessary action.

Potato late blight is a dangerous disease for potato crop. There has been a steep decrease in the potato crop quality and productivity due to this dreadful disease. An IoT-based system has been developed to predict the disease based on weather data like temperature, humidity, pressure, etc. and notifies the farmers by SMS to take appropriate measures. The system uses a cloud server to store the weather data like temperature, humidity, pressure, etc. and these data greatly help to the farmers. The wheat disease classification by using smart phone was presented in [25]. The algorithm was limited to identify (rust, septoria and tan spot) on wheat images. They have used smart phone to capture the images and identify the affected region of the plant. Further, the images are processed with a high-level classifier. The disease

detection using smart phone is made feasible by reducing the training data size to 100 photos in [26]. This presented a windows phone application for plant disease recognition. This technique uses image processing to analyse the spot colour features on the plant parts. It achieves 90 per cent accuracy when tested on grape diseases. One interesting study was done in [27], which can monitor water level, soil, temperature, humidity, etc. remotely monitored through smart phone or PC. These data are used to study the environment for rice cultivation. The system proposed in [28] has developed a framework to detect plant disease and provide diagnosis in consultation with the agricultural advisory call centre. The plant images are captured by a camera in the field and transfers it an IoT web repository. The system processes the images and provides diagnosis and recommendation for the disease.

2.6 Green House Production

Many farmers use wireless sensor network (WSN) [29–31] for rose gardens to maintain the temperature inside the greenhouse. The WSN is employed to detect the environmental conditions and transmit the data to web or a mobile application to perform data mining and obtain a prediction model with good accuracy. This gives the farmers some relief from monitoring activity in the green house. He can get the status and prediction directly to the mobile application accurately.

An automatic temperature control inside the green house [32] can be achieved using a WSN. The WSN prototype has employed MicaZ nodes to measure temperature, light, pressure and humidity and to share with greenhouse farmers. Greenhouse monitoring using IoT has been very much useful to monitor the light intensity on the plants in green house. This improves the crops production and further maximised the photosynthesis activity. There are many studies for remote monitoring of green houses for their water requirement, soil nutrients, etc. can be done in an effective way.

3 Challenges and Issues in IoT-Enabled Agriculture

This section describes most of the challenges and issues involved in IoT-enabled agriculture. Figure 5 represents the graphical model of challenges and issues involved in IoT-enabled agriculture.

3.1 IoT Hardware and Software Issues

When smart agriculture comes to picture, IoT and some electronic devices immediately come to our mind. Which types of devices can be used for smart agriculture?

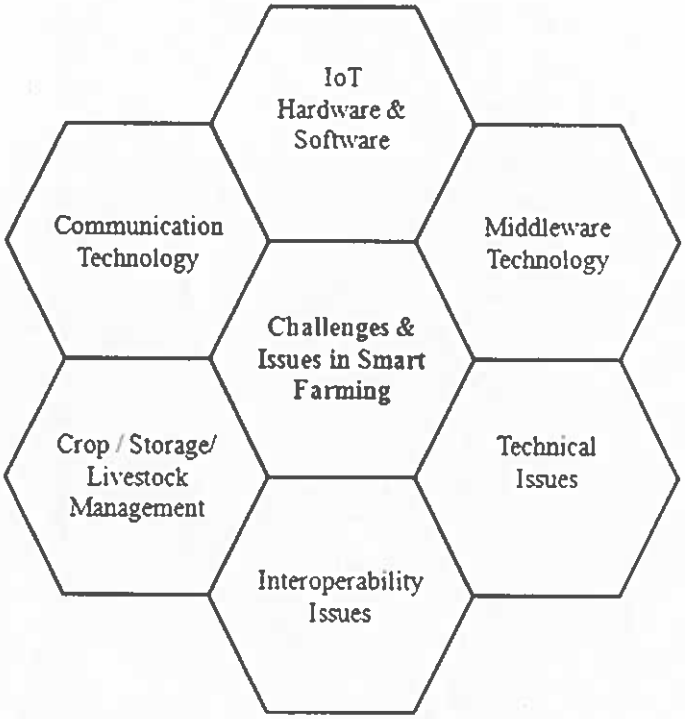

Fig. 5 Challenges and issues in smart farming

These devices must be robust enough to protect them from solar radiation, temperature fluctuation, heavy winds, high rain falls, humidity, all types of environmental changes and other danger activities that destroy the electronic devices. These devices must be battery powered and should actively work for long period of time with limited battery sources. Power harvesting modules like solar panels and turbines can be helpful to some extent for implementing IoT. The devices must be connected to each other through Internet facility which produce large amount of data. This large amount of data (big data) must be handled by small-scale infrastructure of server and the programming tools must be low-power capabilities to be compatible with hardware devices. Further, the IoT devices are required to be deployed in outdoor environment that will expose the devices to frequent changing environmental conditions which may affect the performance of deployed sensors and cause link failures. Basic issues involved in hardware/software are depicted in Fig. 6.

- **Reliability Issue**: There is a big question of physical safety of the deployed IoT sensors and interconnectivity of the networked systems so that data must be reached to the destination. Physical protection must be provided to secure the costly equipment from different climatic changes as well as natural calamities.
- **Scalability Issue**: As billions of IoT devices are required to be deployed in IoT agricultural platform, existing gateways and protocols may not support huge num-

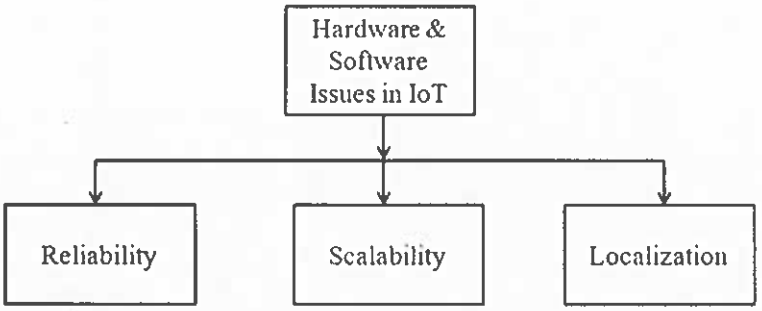

Fig. 6 Hardware/Software issues in IoT-based agriculture

ber of IoT devices/nodes. For instance, Sigfox gateway can support 106 nodes, Ingenu gateway can support 104 nodes, and LoRa supports up to 104 nodes respectively [33]. It requires intelligent/robust IoT management system for each node with a unique address and identification number.

- **Localisation:** When the IoT devices are deployed, several factors are required to be considered. The position of the device must be considered so that it can communicate with other IoT devices and gateways. Its best position, coverage area so that it can provide reliable communicate with other devices without causing any minimal interference.

3.2 Interoperability Issues

Interoperability is a key concept in implementing IoT technology. As millions of devices need to communicate with each other, interoperability is the main crucial and defining element in IoT. There are many ongoing works on protocols and standards needed for billions of devices to interoperate with each other. There are different types of interoperability issues need to be handled in IoT such as technical interoperability, syntactical operability and organisational interoperability. These operability issues are depicted in Fig. 7.

- **Technical interoperability** [21]: Technical interoperability defines the integration of hardware devices with software programming. The programming tools must be lenient enough to be compatible with robust hardware devices.
- **Syntactical interoperability** [34]: Syntactical interoperability is associated with data formats. The syntax of the message must be defined in order to exchange the data from one device to other device (D2D) communication in the form of bit tables or high-level languages like HTML, XML, Java Script Object Notation (JSON), comma separated variables (CSV), electronic data interchange (EDI) as data standard syntax to share the information. Semantic interoperability should well match with users for interchange of information exchange between end-users.

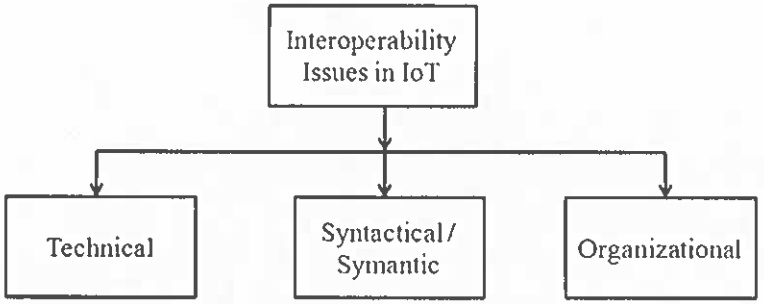

Fig. 7 Interoperability issues in IoT

- **Organisational interoperability** [35]: The effective communication and transfer of meaningful data over highly fluctuating systems and over various geographical regions can lead to a successful distributed system and global-IoT infrastructures.

To handle all types of interoperability issue, open connectivity [36] must be promoted. Further, the usage of adapter services such as If This Then That (IFTTT) [37] allows users to create powerful connections through simple conditional statements are currently being used.

3.3 Middleware Technology

Middleware lies on the top of the network and down of application layers that aim to facilitate interoperability. It takes care for both data processing and communication interface between these two layers. It is basically a connecting software that provides a mechanism for process to interact with other processes running on multiple networked devices.

3.4 Communication Technology

The communication technology has great impact on successful deployment of IoT applications. Wireless communication is the most vital part in IoT applications as the wireless link gets affected very often by the climatic changes, weather conditions, etc. The environmental characteristics not only bring challenges on the hardware devices, but also on the network layer. Basically, wireless communication can be categorised in three ways: based on spectrum, standard and applications. Further, it can be divided into short-range communication or long-range communication. Radio spectrum is again divided into two parts such as licensed and unlicensed frequency spectrum. The unlicensed spectrum utilises 2.4 GHz industrial, scientific and medical band (ISM band). The major drawbacks of using unlicensed frequency band is less

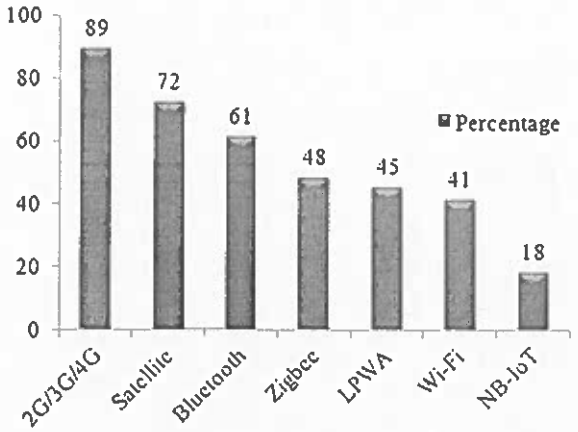

Fig. 8 Communication technologies used in IoT [Ref. from HUAWAI report]

secure, more interference and unreasonable deployment cost. On the other hand, the licensed frequency which is used by cellular communication (GSM network) has less interference, good traffic management, good congestion control management, more reliable, more secure and more quality of service. Despite huge positive impacts, there is a trade-off between cost and power consumption of IoT devices. The wireless technologies used in IoT domain are Groupe Special Module (GSM) authorised by license frequency, wireless personal area network (WPAN), wireless regional area networks (WRAN), mesh network, point-to-point (P2P) and low-power wide-area network (LPWAN). The communication technology for IoT device also depends on type of applications and types of topology to be used. According to HUAWAI marketing report, the usage percentage of all wireless technologies is shown in Fig. 8. Simple network management protocol (SNMP) plays a vital role to manage all the objects, devices and to support communication between them.

3.5 Issues in Crop Management

In crop farming, several factors that affect the farm product includes amount of rain fall, leaf wetness, temperature, humidity, soil moisture, climate, salinity, solar radiation, dry circle, pest movements, human activities, etc. [38]. Those data like type of soil, crop type to be planted and the appropriate pesticide and fertiliser can be structured as a data set. In future, the type of pesticide to be sprayed across the field based on the crop can be identified in advance to save the plants.

3.6 Livestock Management

In livestock management, which factor must be monitored depends upon the types of animals. For example, by experimenting the milk from the buffaloes and cows, health condition of animals can be predicted. According to USDA, farmers in the USA lose nearly $2.4 billion per year due to the sickness of animals and their death. IoT solutions can help farmers to closely monitor the health condition of their livestock, which is an effective way to prevent death rate. Generally, IoT solutions involve sensors attached with the wearables that can be connected to a gateway through low cost, low bandwidth to stream the data to the cloud. The sensors fitted with the wearable of animals can monitor blood pressure, body temperature, digestion, heart rate, respiratory rate and other vital parameters that gives an alarm to the farmer to predict the health condition of animals so that the farmer can take care of the feed issue and illness without waiting for a strong veterinary care. These sensors continuously measure each animal's health, behaviour and send message to farmer, so that farmer can take corrective measure without spending money for the illness. For instance, a cow's temperature rise triggers an alert well before the farmer notices a change in behaviour.

Even to prevent livestock theft, animals are attached with radio frequency identifiers (RFIDs) that can track the animal's movement [39]. The movement of the animal can be visualised on a map in a centralised control system through wireless connectivity. Mostly in rural areas where animals go for communal grazing, usually, animals get lost. RFID chips fitted with wearable really can help farmers to identify their livestock and RFID readers are placed at various monitoring spots to transmit information to an agricultural extension services centre.

3.7 Storage Management

Storage management is an essential activity to maintain food quality and maximise business profit. A large quantity of agricultural product usually gets lost due to lack of proper storage management. The use of IoT can help storage management in an effective way. The contamination of food products is greatly affected by temperature, moisture and humidity, whereas quality of product is affected by insects, rodents, microorganism, etc. Sensors can be deployed to monitor the environmental conditions as well as storage facilities and send to the gateway node. A self-organised automated feedback system must be deployed which can take the decision by analysing the data and adjust the environmental parameters [40, 41]. It can send a warning message to farmers if any deviation occurs in the environment or any pest is reported in the storage facility. In India, many reports show that almost 40% of the fresh product gets spoiled due to pest or spoilage. In [42], a cold storage management based on IoT is designed where the temperature is controlled automatically. Although IoT can

manage crop storage efficiently, security is major concern. It can be embedded with storage management system.

3.8 *Technical Issues*

- **Interference**
  The biggest challenge in the wireless technology is the interference that causes among the IoT devices operating in the same frequency band (For instance, Bluetooth, ZigBee and Wi-Fi) or in neighbouring bands. For IoT application, wireless communication is the key medium that focuses on range of communication, distance, data rate, battery life, mobility, latency, security, resilience, and the cost of gateways and modems. Among the communication technology, the LPWA is attracting so much interest [43] especially with the emergence of narrow band IoT (NB-IoT). The NB-IoT promises interesting features which include low device power consumption, ultra-low device cost, simpler to implement, support of a massive number of low throughput devices, long distance coverage and can support upload and download of data [44].
- **Security and Privacy**
  There are several security issues that need to be addressed during implementation of IoT-based farming. The lack of adequate security may lead to data loss, access of raw information, destruction of sensor nodes and many more on-field information. It is very difficult to incorporate sophisticated encrypted algorithm in IoT devices due to limited memory, limited processing capability with by consuming less energy. In [45], it is discussed that security is the major obstacles in smart farming. The location-based service which is a mandatory requirement for smart farming is vulnerable to device captured attacks. In device captured attack, the hacker captures the device, analyses the cryptographic algorithm, gets unlimited access to the device storage and collects the information. On the other hand, communication layer is exposed to denial service attack (DoS), jamming attack and man in the middle attack. Further, cloud server is prone to unauthorised services, data tampering, session hijacking and database issues that can hamper cloud service infrastructure. In IoT, there are three mandatory requirements such as authentication, confidentiality and access control. IoT must ensure the aggregation of data in the network layer, authorised access in the application layer and protection of data and devices at perception layer. RFID security issues are usually related to leakage of information, which can reveal the location and other sensitive data. APIs, middleware integration and machine-to-machine communication are some of the terms which are creating the complexity and new risks of security in higher level. Therefore, suitable encryption/decryption algorithms, key distribution mechanisms, intrusion detection systems and secure routing policies must be deployed, considering the limitations of smart hardware devices. IoT connects huge number of smart devices that provide multiple distributed controlling points. These decentralised points are prone to malware which creates a negative impact

on the smart agriculture and becoming the main challenge in IoT-based agricultural sector. Further, less expensive devices are more prone to tampering attack. As IoT devices are distributed by nature and deployed in diverse environments, current security protocols are not enough to provide adequate security. So more encryption and decryption private key algorithms must be designed to provide support to IoT-based real-time applications.

4 Benefits and Pitfalls of IoT-Enabled Agricultural Systems

The agriculture is getting automated day by day on IoT platform. This is reducing the work of farmers and expecting the optimised crop production. Basically, it is very useful for community farming in rural areas [46]. IoT-based agriculture performs well by gathering the information from soil, humid level, and temperature. Monitoring can be done in a regular basis through technological advancement which is helpful in predicting the ecological factors. IoT together with cloud can improve the efficiency of country's agricultural production. From various researches, it is observed that the IoT-enabled agricultural system can be further extended in many ways. Few parameters such as reliability, scalability can be improved. The open-source programming languages like R and Python could be used as a programming language. The development of smart irrigation system could be implemented in other plantations and the data set can be still increased to improve the accuracy of the system. In authentication scheme, the complexities can be reduced further without compromising the security features. The entire work can even be merged with cloud computing environment. From the previous work, some of the new decisions can be made in crops. The data set is maintained for every smart work in agriculture and can be used for further reference.

The country lacks in good agriculture and it could be made still smarter. Using drone with all the weather and temperature information, the type of crop which has to be planted in agriculture can be found. Which crop suits to which environment, that historical information can be found and send to agricultural experts. With those data, the farmer can plant new crops. If the field has the capability to grow by spreading the seeds, it can also be automated. A new device may be invented and made to spread the seeds across the fields based on soil type information. If the climate changes, it can also be intimated through intelligent systems so that some different seeds can be spread. Big data plays a great role in maintaining the data set for weather information, soil type characteristics, etc. Based on the collected data, the seeds can be thrown by agricultural experts or by drone like device to spray the seeds. Another important challenge is that the research has shown that the type of fertiliser can be identified for a typical soil. Despite the huge benefits of IoT-based agriculture, there are lack of awareness among the farmers about the IoT technology. Mostly, farmers are uneducated in rural areas. Young generation is not interested in farming. Our education system does not support in curriculum the intelligence of farming.

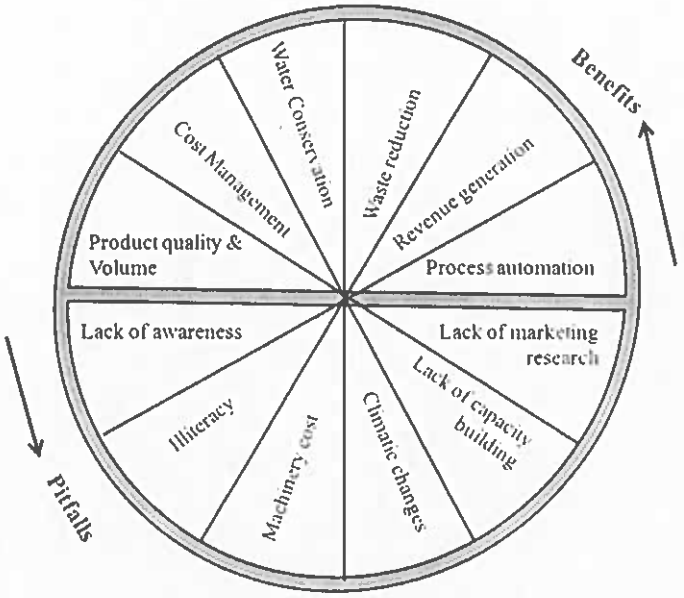

Fig. 9 Benefits and pitfalls of IoT-enabled architecture

Sometimes high-cost machinery may not be affordable by farmers. There is a lack of sale distribution information, lack of marketing research, drastic changes in climatic conditions, more manual work and less knowledge about the weather forecasting may not maximise the productivity (Fig. 9).

5 Conclusion

The interconnected farm called as 'smart farming' is the future of IoT-based agricultural farming. The concept is widespread and creating significant attention in agricultural sector. It seems IoT is changing in agricultural practices in daily basis. Farmers can work their land anywhere taking the real-time data related to any assets from crops, machinery and markets. All can be monitored without the presence of the farmer. The technology today can view data on crops and soils, predict and prevent diseases. Even, the crop can be fed and watered without human presence. Vital data can be stored in the cloud and can be fetched from the cloud at the convenience of the farmers. The sensors are becoming smaller, smarter and cheaper day by day. Network is becoming more secure and intelligent. The future of farming lies in connecting, collecting and analysing the big data to maximise the productivity and efficiency. It is expected that licensed low-power wireless access (LPWA) is the game changer for smart farming due to two reasons. First, due to its well geographical coverage and second is economical. Although unlicensed spectrum is freely available and there-

fore appealing as a solution, there are significant drawbacks to its use in practice, as its ability to deliver a guaranteed quality of service is compromised by issues of interference and congestion. The regulatory restrictions—which might vary from market to market—will make it difficult for unlicensed spectrum solutions to generate economies of scale. Consequently, narrow band IoT (NB-IoT) has strong industry support as an effective global standard for LPWA connectivity. It has the potential to deliver a step change in smart agriculture by changing the industry's perceptions of what the Internet can provide efficiency connectivity from a wide range of sensors with long battery life over reliable, low-cost, secure, licensed spectrum.

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