Chapter 1
Smart Agricultural Mechanization in India—Status and Way Forward

C. R. Mehta, N. S. Chandel, and Kumkum Dubey

Introduction

In the current digital era, Information Communication Technology (ICT) is proliferating with smart/intelligent machines which can further advance the technologies in industrial and agriculture sectors. Issues concerning agriculture have been always hindering the development of the country. The only solution to this problem is smart agriculture which streamlines the traditional methods of agriculture. In order to modernize the agri-technology and precision farming (PF), there is a need of new hi-tech computing approaches like Internet of Things (IoT), Artificial intelligence (AI), big data, robotic system, unmanned ground vehicle (UGV), unmanned aerial vehicle (UAV), etc. [10]. This digital farming will lay the foundation for the "third green revolution" in India. With the introduction of smart faming technology in agriculture sector, the impact of weather conditions, use of fertilizers and water reduces, however, worker safety, efficiency, and production rate increases. It also helps growers to manage and control production threats and improve the capability to foresee process outcomes. IoT-based smart farming is a system that is built for monitoring the crop field with the help of sensors (light, humidity, temperature, soil moisture, crop health, etc.) and automating the field operations [1, 7]. IoT connects sensors, actuators, and controller with server by accessing Internet connection (Fig. 1.1). Thus, farmers can monitor the field conditions from anywhere with the help of IoT technology. They can also select between manual and automated options for taking necessary actions based on sensor data. AI-based analytical or prediction models are applied on data captured from IoT devices for monitoring crops, surveying and mapping the fields,

C. R. Mehta (✉) · N. S. Chandel · K. Dubey
ICAR-Central Institute of Agricultural Engineering, Bhopal 462038, India
e-mail: cr.mehta@icar.gov.in

N. S. Chandel
e-mail: narendra.chandel@icar.gov.in

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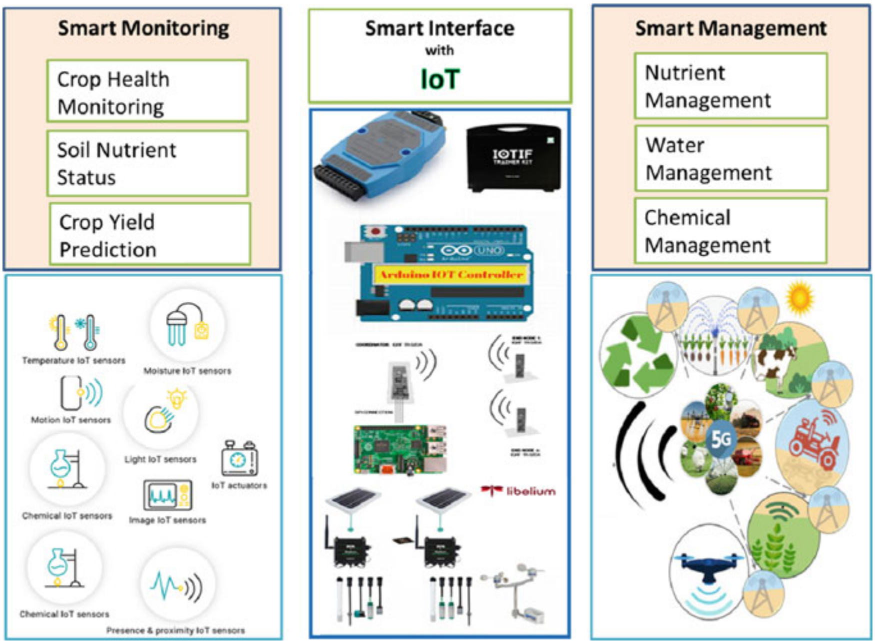

Fig. 1.1 Architecture of IoT-based smart agriculture

identify abiotic/biotic stress, predicting environmental conditions, and crop yield [4]. Such type of smart farming technologies save both time and money and also alert the farmers to take necessary action before crop damage. With the hybridization of AI and IoT approaches, autonomous robotic machines can be developed which solve major field issues like crop diseases infestations, pesticide and fertilizer control, grain storage management, irrigation control, and complex crop harvesting practices [12, 14].

Smart farming emphasizes the concept of digital agriculture using AI, IoT, remote sensing, robotics, cloud computing, and big data analytics. Such types of smart farming practices reduce total budget and improve the value, worth, and capacity of crops. It also helps to maintain the balance between supply and demand chains of agriculture products in marketplace. Thus, smart digital farming has potential to improve the agriculture sustainability and allows real-time data collection, controlling, and decision-making under several agricultural activities [8]. The decision-making can be deployed in the embedded system using sensor data as input and results are directly transferred to the machine for performing precise management actions.

Digital agriculture shifts farming's culture from 'hands-on' and experience-based management to a data-driven approach. It is an information base agriculture framework in which digital data from agricultural production and management systems are collected, processed, and interpreted. The digital agriculture revolution relies heavily on big data and cloud computing. Cloud computing stores large amounts of data at a reasonable cost and allows instant access of data. Various firms, such as AWS, Microsoft, Amazon, Google, IBM, etc., provide three types of cloud services, i.e., software, platform and infrastructure over the Internet. Cloud service is being used in different fields, however, in current era, it plays a vital role in agriculture field. Cloud computing allows immediate gathering and storing of large amount of data and also provides numerous software applications and tools for users. Farmers may use cloud-based farm management tools to store and retrieve information of market, field data, newly developed agriculture implements, weather, and climatic information [11]. This database helps framers in taking immediate managerial decisions at right time. Cloud services assist in the resolution of farmer's queries by providing immediate solutions based on domain expertise. They can seek expert advice online via cloud-based databases.

Farm management system is a cloud-based program that provides online training for farmers to educate them about diseases and pesticides, as well as how to maintain a farm [3]. It also gives information regarding new software application of farming practices or machinery. IoT uses cloud services for storing and accessing of sensors/devices data installed in field. The cloud service also helps farmers in preventing crop damage due to climate change, as farmers receive weather reports and take appropriate action to save the crop. Big data use cloud database for predicting/forecasting different conditions of farm activities as well as environment and automate the machines according to outcomes generated from analysis tools. Big data can truly revolutionize the agricultural sector only by having a cloud-based ecosystem with the right tools and software to integrate various data sources. The opportunity for applications of big data in the present agriculture is large. The capability to track physical items, gather real-time data, and forecasting events can be a real game changer in digital farming. The big data analytics contribute and really transform the agricultural sector in feeding a growing population, using pesticides ethically, optimizing farm equipment performances, managing supply chain issues and much more to aid the farmer take decisions.

Technologies for Smart Agriculture

Artificial Intelligence (AI) in Agriculture

Artificial intelligence (AI) enables the machine to simulate like a human intelligence and provide intricate details of the problem, learns from external data, and uses those learning to provide a best-fit solution through flexible adaptation [10]. Nowadays, very complex linear/non-linear problems are being solved with this technique. AI is becoming pervasive very rapidly in agriculture sector because of its robust applicability in the complex problems of farming that cannot be solved well by humans and traditional farming approach. Different applications of AI in agriculture sector are described below.

Fig. 1.2 Device for the identification of soybean crop disease

Detection of Abiotic and Biotic Crop Stresses Using AI Models

The timely detection of water stress in crop is one of the major challenges in precision and sustainable agriculture. Hence, abiotic stress detector module has been developed at ICAR-Central Institute of Agricultural Engineering (CIAE), Bhopal, to identify water or nitrogen stress in crop. The AI-based system uses deep learning model to detect or to classify stress/non-stress crop in real-time [5]. This module helps in detecting the abiotic stress at early stages, so that farmers can take necessary actions for controlling the stress and saving the crop from further damage.

A hand-held device based on deep learning (DL) models has also been developed at ICAR-CIAE, Bhopal for identification of disease at field level in soybean crop. This device consists of a single-board microcontroller, display unit, RGB camera, DC power supply, and other accessories (Fig. 1.2). The device identifies Yellow Mosaic disease of soybean crop in less than 20 s time with 90% accuracy by using image of crop leaves. The cost of hand-held device is around Rs. 10,000/-. Deep learning model was trained by a large number of images of soybean leaves and validated, tested, and deployed in micro-controller Raspberry pi for real-time detection of crop disease. Graphical user interface was also developed in both types of modules (biotic and abiotic) so that user can easily access the software and get knowledge about the abiotic/biotic stress of crop.

Crop Monitoring and Yield Prediction

AI-based predictive models help in forecasting the crop yield by monitoring crop health at different stages of growth on real-time basis. AI models are trained by previous time series and then used for predicting the future outcome. It also helps in predicting the best time for sowing crop and also provides irrigation and fertilizer recommendation to farmers on the basis of weather conditions [4]. Such type of modern smart approach also helps in harvesting the crop timely without any damage due to adverse climatic condition. It alerts the farmers about the future adverse climate, so that farmers can timely harvest the crop.

Embedded System for Small Farms

Embedded system is the amalgamation of sensor, micro-controller, actuator, and software program. This system integrates electronics, computers, and computing technologies into bio-systems such as agriculture, forestry, and horticulture [14]. The potential benefits of embedded system-based agriculture devices are that they enhance application accuracy and operation safety in the precision farming sector. Robotic system is the further advancement of embedded system in electronics area. Robot is a machine that can perform specific task according to the program stored in its database using some mechanical claw, hand, or tool attached to the body [12]. There are two types of robotic systems, viz., remote-controlled robot and autonomous robot. The remote-controlled robots are semi-automatic, as they required human being for controlling their operation. However, autonomous robot is fully automatic; there is no need of human being for performing the task. Autonomous robot controls their action on the basis of information from sensors mounted on the machine. Various robotic systems are used in agriculture field like vision-based navigation system, harvesting robot, GPS-based vehicle guidance system, autonomous spraying unit, etc. Moreover, AI technology enhanced the efficiency of autonomous robotic system in farm practices.

A real-time uniform spraying system has been developed at ICAR-CIAE. It maintains uniform application rate of chemical throughout the field irrespective of forward speed of operation and reduces loss of chemicals during turning at headlands (Fig. 1.3). This system uses hall effect sensor for computing the speed of tractor and proportional flow control valve independent to pressure for varying the discharge rate. The spraying system has been evaluated in the field for application rate of 300 l/ha at 196 kPa pressure. With change in forward speed from 2.43 to 4.50 km/h, the application rates are in the range of 294–298 l/ha corresponding to the targeted application rate of 300 l/ha. The effective field capacity of the machine is 0.7 ha/h at forward speed of 3 km/h.

Automatic Object Detection Based Spraying System for Orchards

A tractor-operated ultrasonic sensor-based automatic pesticide sprayer was developed and tested at IIT, Kharagpur. This automatic spray control unit has been interfaced with arduino, ultrasonic sensors, pump, solenoid valves, nozzles, HTTP pump, pressure gauge, pressure relief valve, tank of 200 l capacity, and 12 V DC power supply (Fig. 1.4). The sonal signals of sensors instigated the micro-controller system for spraying in desired area. The ultrasonic sensor could detect a set object within a sensing range of 0–3 m. It efficiently sprays chemical only on orchard canopy and

Fig. 1.3 Sensor based real-time uniform rate spraying system in potato crop

Fig. 1.4 Ultrasonic sensor based pomegranate spraying system

cut-off spray when there is no plant canopy. The developed spraying system saves 26% pesticide especially in small pomegranate orchards.

Automatic Irrigation System for Rice Crop

There is a challenge of controlling irrigation water in rice field. Hence, an automatic irrigation system has been developed at ICAR-CIAE for alternate wetting and drying (AWD) method of irrigation to detect ponding water in rice fields (Fig. 1.5). It consists of sensors and micro-controller to detect water level and transmit signal to the controller wirelessly using radio frequency module. The controller unit has been programmed to operate the pump based on the desired water level in the field at different stages of crop growth.

Fig. 1.5 Automatic irrigation system for rice field

Automatic Grain Health Monitoring System

An automatic grain storage monitoring system was developed at ICAR-CIAE to monitor the micro-environment, to control insect activity and restrict spoilage of stored grain in storage system (Fig. 1.6). A sensor rod was mounted with DHT22 sensors for monitoring temperature, relative humidity, and carbon-dioxide levels at three different locations inside a storage system. In the developed embedded system, sensors, LED indicators, and LCD with a data logger are interlinked with micro-controller arduino. The developed program generates an alert message when any of the physical parameters like temperature, relative humidity, and carbon-dioxide deviate from their threshold values. The sensor rods have been tested in a flexible PVC-coated fabric bag to monitor wheat grain health for a period of 8 months. It has been observed that insect infestation activity increases the CO_2 level. It was also observed that CO_2 sensors are more suitable in detecting the grain health as compared to conventional temperature and relative humidity level of the interstitial environment of a bagged grain storage system. The detection sensitivity of CO_2 sensor used in the system is 406–5764 ppm.

Automated Packing Line for Spherical Horticultural Produces

An automated packing line for spherical horticultural produces has been developed at ICAR-CIAE for real-time sorting of produces on the basis of three weight categories and color (Fig. 1.7). Color and weight-based sorting algorithms are individually programmable to accommodate variety of spherical fruits like oranges, sweet limes, apples, etc. The packing line is attached with a water jet washer and perforated cylindrical LDPE heat sealing packing unit. The overall capacity of the machine is about 200 kg/h. The efficiencies of color and weight-based real-time sorting machine are 92 and 88%, respectively.

Fig. 1.6 Alert system for automatic grain health monitoring

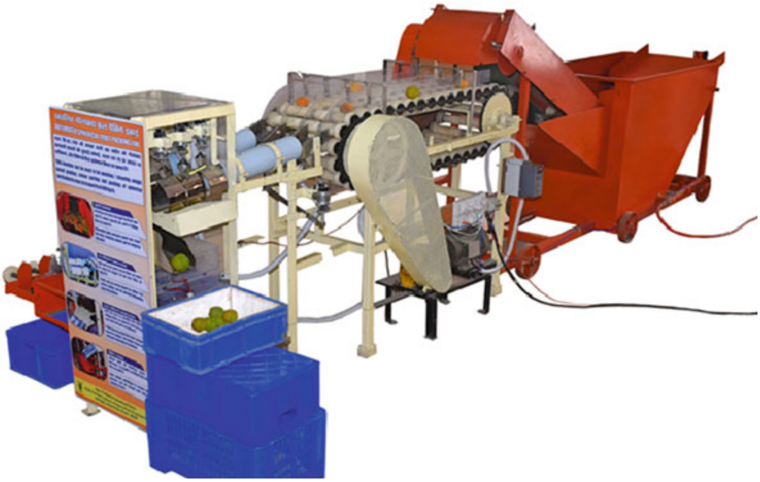

Fig. 1.7 Automated packing line for spherical horticultural produces

Unmanned Aerial Vehicle (UAV)

UAV is the amelioration of remote sensing technology for precision agriculture (PA) and smart farming. Remote sensing is commonly used for monitoring cultivated fields and vegetation parameters at specific growth stages through images of different wavelengths. In early decades, remote sensing was often based on satellite images, however, satellite images have low spatial resolution and sometime environmental conditions hinder the image-capturing process. There is a period between acquisition and reception of satellite images. The development of UAV-based remote sensing systems has enhanced remote sensing for farm practices. The application of UAVs to monitor crops offers great possibilities to acquire field data in an easy, fast, and cost-effective way compared to traditional remote sensing methods [13]. Moreover, UAV can provide ultra-high spatial resolution of crop images at low altitude by covering a large field in a short time more efficiently than the ground systems. Equipped with sensors of different types, UAVs can identify different problems of fields and inform the farmers about their field condition, so that they can take necessary action on time for saving the crop from damage. UAV can be used in different agriculture applications such as crop health and growth monitoring, yield prediction, weed management and detection, abiotic, and biotic stresses detection. UAV provides an imagery database for training AI models or IOT-based system by mounting camera of visible or IR range on drones. UAV system can also be used for spraying in small fields on the basis of GPS and imagery data.

In current scenario, UAV technology is not only used for capturing images at different altitude but also used for spraying in small or marginal farmlands. Marut Drone Tech start-up has developed an intelligent and autonomous drone for spraying application in agriculture. The drone collects data, analyzes them and generates disease map of a particular field with the help of RGB (red, green, blue), hyper, multi-spectral cameras, and powerful sensors. Drone takes the payload with it and sprays the targeted areas using a predefined route. The start-up is presently working with input manufacturers and Farmer Producer Organizations (FPOs) to provide services [8]. It has already covered about 2000 ha of crops by targeted spraying of pesticides in Telangana and Andhra Pradesh states.

Modern Horticulture Farming Techniques

In order to enhance the innovations in agriculture sector, smart farming techniques are bringing forth new approaches that help the farmers to increase productivity and quality of the products with less use of natural resources. Nowadays, soil-less farming techniques like hydroponics and aeroponics are in vogue, as they save natural resources up to a great extent. Hydroponics means growing plants in a water and nutrient solution, without soil or any other solid media. The nutrients are provided to plants by water solution and EC, pH, and TDS of solution are maintained timely for proper growth of crop. There are various types of hydroponic systems according to their design and functioning, i.e., nutrient film technique (NFT), ebb and flow system (continuous flow culture), water culture, drip system, wick system, and aquaponic system. Similarly, aeroponics is also a soil-less method for plant production. Among all the currently available technologies that allow us to grow plants in a soil-less environment, aeroponics is the newest and most advanced. It is an advance version of hydroponics in which the plants are placed on a culture panel and the roots hang in air. Further, the nutrient solution is sprayed on the hanged roots with electronically controlled nutrient supply system.

ICAR-Central Potato Research Institute (CPRI), Shimla developed a state of the art aeroponic technology at Jalandhar with the use of IoT. It has huge potential to increase production in terms of number of mini-tubers per plant (40–70 mini-tubers per plant) from three to four times as compared to conventional method [2]. It facilitates congenial climatic conditions to produce targeted number of potato mini-tubers. The aeroponic unit consists of a grow box, solution tank, crop lifting system, and sensors and electronic controls. In this system, a series of nozzles are installed with the nutrient supply lines inside the grow box to supply the nutrients to the roots. A solution tank is provided with aeroponic unit to supply and store the nutrient solution for the plants. The aeroponic unit is provisioned with a PLC-based automatic nutrient supply system, which supplies prescribed amount of nutrients to the plant roots. An automatic EC and pH monitoring and dosing system are also integrated with the nutrient supply lines to maintain crop-specific pH and concentration of nutrient solution. Capacity of the solution tank depends upon the solution consumed by the plants per day.

Automatic controlled IoT-based greenhouse/polyhouse is also one of the advanced horticulture farming techniques. IoT played an important role in controlling the hardware unit remotely and automatically and also provided data to remote location. Some sensors (soil moisture, light, temperature, and humidity) and actuators are mounted inside the greenhouse and their data are sent by Wi-Fi module to the server. When the physical parameters reach their threshold value, micro-controller automatically actuates the motor, solenoid valve, exhaust fan and fogger to control the soil moisture or environment of greenhouse. Also, users access the data from Internet server and process them on different data analytical tools to estimate threshold value or predict the future values of physical parameters. Such type of system helps in controlling the biotic and abiotic stresses in greenhouse/polyhouse at an early stage.

Operational Issues and Challenges

During the past few years, various issues have emerged with the development of digital agriculture, which are related to proper maintenance, management, safety, and performance of smart devices implemented in agricultural practices [10].

Compatibility

Digital farming combines different technologies in a single platform; hence, it uses various protocols or standards for performing different tasks. Thus, computability issues arise when connecting different devices which worked on different firmware and operating systems. Sometimes compatibility problem arises when deploying software to hardware, like some controller boards are not capable for handling AI models.

Network Connectivity and Scalability

Connecting a large number of devices is one of the big challenges in digital world. The future of digital agriculture depends on the decentralization of networks. This issue has a greater impact on IoT devices, since IoT is completely based on internet connectivity. The proper availability of network is the basic requirement of IoT devices [6]. Network issues also occur when using Zigbees, LoRaWAN, Wi-Fi, and RFID technologies for communicating among different devices. Number of physical devices will be connected to the Internet in near future. So, the management of various devices over a variety of networks will be a threat. System scalability is another challenging and tedious work to achieve with collective consensus. This was more challenging when additional devices are added to the existing framework of software and hardware using different protocols.

Reliability

The system's reliability is the main goal of enhancing the success rate of the smart farming technologies. The system failure or virus threat is always a major challenge in hardware or software architecture of digital agriculture. Failure of network or smart devices can lead to loss of information, economic loss, and damage to crops. It is a very critical issue in autonomous robotic system because it is totally dependent on software and hardware system.

Data Confidentiality and Security

Possible cyber-attacks in digital services can lead to serious security issues like data integrity, data loss, data theft through smart applications, stealing of information in supply chain from stakeholders affecting agri-business, and unethical access of foreign sensors, drones, or robots in field. This data confidentiality and safety issues are arisen in the agriculture sector due to the internet connection of devices used in field. Therefore, there is a need to pay more attention to secure and complete data transmission in smart farming systems.

Intelligent Analysis and Actions

Analyzing field data and drawing good conclusions from the collected information is a major concern in AI-based robotic systems. The findings derived from data analysis tools help the autonomous system to take intelligent decisions. Hence, proper analysis of data is essential to get the right decision and accurate and precise action.

Lack of Skilled Workforce

For proper operation of smart devices requires skilled/experienced workers. Hence, training is required to end users for operating the software application or hardware systems with proper safety in field. A skilled workforce is not only required to handle software and hardware set up but also handling the issues related to agriculture practices like sowing or harvesting at right time, maintenance of electrical components or farm implements, etc.

Future Strategies for Smart Agricultural Mechanization

Present Indian agriculture is highly labor-intensive whereas smart agriculture is all about machines and technologies. The research institutes of the Indian Council of Agricultural Research (ICAR), SAUs, IITs, NITs, and other private organizations in India are involved in development of technologies based on precision agriculture, digital farming and AI through different projects such as the National Agricultural Innovation Project (NAIP), Consortia Research Platform on Farm Mechanization and Precision Farming (CRP on FMPF), AICRP on Farm Implements and Machinery, etc. These institutes are applying modern tools and techniques for application of sensors and robotics in planting, rice transplanting, spraying, weeding, drone-based spraying with the help of AI, etc. It is vital that these centers should focus on the stakeholders' interests to ensure that research concepts (farming methods and machinery) should not remain at the prototype stage [9]. The themes of PA, DF, and AI in agriculture can be applied across disciplines and may bring a paradigm shift in how we see farming today. The following strategies will not only enable farmers to do more with less but also help to improve quality and ensure faster go-to-market for crops.

1. Promotion of digital farming and precision agriculture technologies in addressing issues related to sustainable farming through research and development and financial assistance.
2. Lowering the cost of hardware/technology so that it is available and affordable for small and marginal farmers. The hardware/technology must be portable, plug-and-play type, and has better chance of success in India.

3. Establishment of an interactive digital platform to allow farmers full access to information and technology databases, expert systems, and DSS for web-based agro-advisory, skill development, machinery management, and financial assistance.
4. Need for increased application of smart agriculture and digital farming with involvement of private sector for farm mechanization.
5. The application of ground-based sensors and remote sensing data at high spatial and temporal scales can be integrated for forecasting and allocation of irrigation water.
6. Promotion of an app-based farmer-to-farmer aggregation platform, which bridges the demand and supply gap of machinery or equipment by connecting owners of tractors and farming equipment with those who require their services.
7. The drudgery prone and repetitive farm operations such as weeding, spraying, and harvesting of costly fruits and vegetables can be enabled with AI, leading to improved accuracy and productivity.

Conclusions

The smart digital technologies modernize the agriculture sector using IoT protocols, AI models, autonomous robotic system, UGV, and UAV. Smart agriculture utilizes the pipeline of ICT for sharing the information with experienced domain expertise to engender better solution of the problems related with farm practices. The smart farming techniques reduce environmental impact, hazards, and error; save time and cost; optimize inputs (water, fertilizer, and pesticides) usage, and increase crop yield and product quality. Digital agriculture is the hybridization of smart farming and precision agriculture. Digital agriculture collects, stores, processes the data, and develops actionable intelligent smart farming devices. Smart framing is applicable not only for large farms, but also for small and marginal lands. With the help of smart farming, farmers can plan and take decision through software-managed and sensor-enhanced system.

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