# Chapter 10
# IoT Management of Field Crops and Orchards

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**Abstract** Fields and orchards are two of the main scenarios for agricultural IoT applications. One of the common challenges in these two scenarios is posed by the large farming area in open environment, and IoT-based management of field and orchard crop productions is an effective approach to cope with this challenge. This section serves as an outline of IoT management system of crops in fields and orchards. Moreover, an introduction is laid, describing the system's basic structure and the way in which it performs environmental monitoring, soil moisture monitoring, integrated water and fertilizer application, and pest and disease monitoring. The application of IoT for field crops and orchards can effectively reduce the impact of environmental and disease and pest factors on the growth of crops and fruit trees, minimize the use of fertilizer and water, and ensure the yield and quality of crops and fruits.

**Keywords** Field crops · Orchards · IoT management system · Application of IoT system

## 10.1 Introduction

The challenges facing the adoption of IoT system for the precision management of crop growth in open fields are primarily posed by the complex environment that requires high stability, accuracy, and service life of IoT systems.

The IoT system for field crops and orchards is used for farmland resource management, agricultural situation monitoring, precision agricultural operation, and

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agricultural machinery command and dispatching. Through collecting real-time information, the IoT system for field crops and orchards promptly controls the production process and establishes a high-quality, high-yield, and efficient management model to ensure the yield and quality of products (Li 2012).

Orchard IoT means the extensive adoption of modern sensor technology, information intelligent transmission technology, computer technology, and intelligent control technology in orchards. The information on soil, environment, growth, and meteorology in the orchard can be obtained in real time through sensors, and guidance for fruit tree growth and orchard management can be given after information processing. The introduction and application of the IoT technology to orchard information management can make orchards grow more information-based and intelligent, thus facilitating the building of a high-quality, high-yield, and efficient orchard production management mode.

Fields and orchards are defined by their large planting areas, the capricious climate, the significant environmental difference in different planting areas and the different soil characteristics. Focusing on the features of wide planting range, multiple monitoring points, complex wiring, and difficulties in providing power supply, IoT system uses high-precision sensors and information transmission control technology to collect soil information (moisture content, pH, nutrients), plant growth information (including nutrients and stress), and meteorological information. Through the combination of expert system and precise spraying of water and fertilizer, crop growth can be properly regulated.

Compared with the IoT for facility agriculture, the IoT system for field crop and orchard is more advanced and more demanding in terms of system stability, sensor service life, anti-interference ability, and signal processing ability. Moreover, this system can take into consideration regional differences and adapt to local conditions.

To provide readers with a comprehensive understanding of the application of IoT system for field agriculture, this section focuses on the introduction of soil moisture meteorological monitoring system, farmland environment monitoring system, management system of soil testing and formula fertilization, early warning system of field crop disease and insect diagnosis, and agricultural machinery scheduling management system and precision operation system.

This chapter focuses on the environmental monitoring system, field monitoring system, water and fertilizer integration system, disease and pest diagnosis and early warning system, and their application in field and orchard, so as to deepen the understanding of the IoT system for field crops and orchards.

## 10.2 Architecture of IoT Management System of Field Crops and Orchards

The IoT system of field crops and orchards are consistent with the IoT system for facility agriculture. Figure 10.1 illustrates that the IoT system for field crops and the IoT system for orchards share a similar architecture. The system consists of five

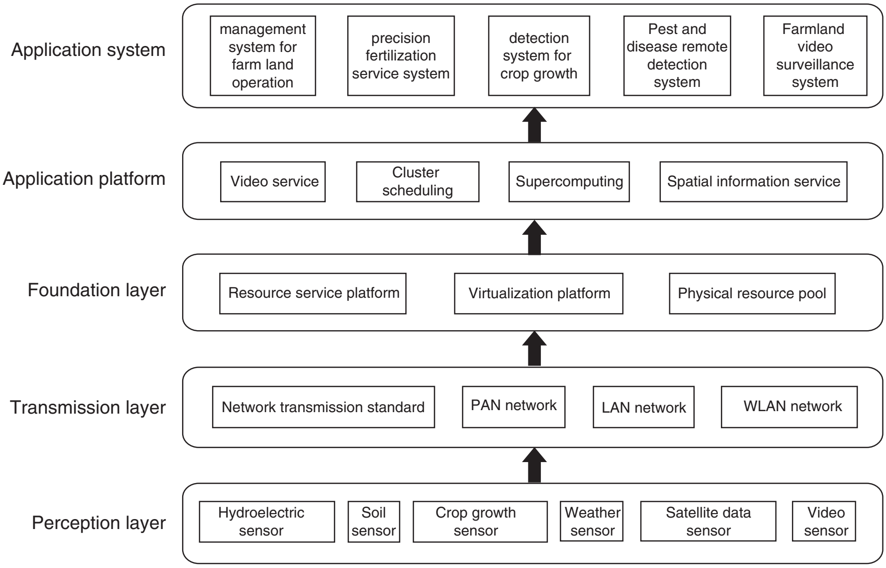


**Fig. 10.1** Architecture of the IoT system for field agriculture

layers: perception layer, transmission layer, foundation layer, application platform, and application system.

The perception layer of the IoT system for field crops and orchards mainly includes sensors for the growth environment and climate information of soil, crops, or fruit trees. These sensors enable the perception of soil status, growth status, and climate information in the planting area in a scientific manner. The perception layer collects information for transmission, while providing feedback of the corresponding information when the IoT system commences with precision management of factors such as water and fertilizer supplement.

Major components of the transmission layer include information transmission among sensor nodes, wireless sensor network nodes, and control terminals. Concerning the planting area, wireless transmission is convenient and effective. There are two main types of wireless transmission: GPRS and CDMA (3G, 4G, 5G, and other wireless networks are also included). These transmissions, relying on network suppliers, feature wireless connection, simple installation, and strong mobility. Which is why they can be applied to scenarios where wiring and network distribution are not convenient. WLAN wireless network, equivalent to wireless network in a region, has advantages in terms of bandwidth and can be combined with communication networks. The transmission layer needs to ensure the stability of transmission, meaning that the transmitted information and commands ought to be complete and accurate.

The foundation layer, the basis for the application layer, mainly includes physical networks, resource service platforms, and virtualization platforms. The layer is used to provide the basic resources and information required by the application layer.

The application layer is primarily located in the control terminal. Based on the acquired information, it stores and analyzes the information on soil, growth of crops and fruit trees, and environmental and meteorological factors acquired by the perception layer. Through the expert system, and combined with big data processing technique, the layer enables the processing and feedback of the sensing information and the regulation of crops and fruit trees growth via the intelligent management system. More specifically, the application layer includes application platform and application system.

Based on the existing knowledge and models, and combined with the information obtained by the perception layer, the application platform is responsible for data processing, evaluation of growth status that supports decision-making, and the management and functional application of field agriculture, such as precise water and fertilizer irrigation, crop pest management, etc.

The primary role of the application system is to build IoT systems applied in different aspects, including management system for field crops and orchard operation, precision fertilization service system, and detection system for crop growth. Based on these systems, the IoT system for field crops and orchard is able to provide a wide range of functions (Li 2012).

## 10.3 Application of IoT System for Field Crops and Orchards

### *10.3.1 Environment Monitoring System and Its Application*

The environment monitoring system of field crops and orchards is focused on automatic monitoring and intelligent transmission of information such as light, temperature, humidity, $CO_2$, micro-meteorology, and water quality. The monitoring system is mainly composed of various sensors distributed in different areas or various farmland environmental monitoring stations that contain different sensors, including microclimate monitoring station and hydrology and water quality monitoring station. According to the actual needs of environmental monitoring, different environmental monitoring stations carry different sensors. The information acquired by the monitoring station is transmitted to the terminal through the wireless transmission network and then processed by the application layer. Additionally, the monitoring station features low power consumption and integrated design. The station adopts solar energy as its power source and comes with outstanding tolerance for farmland environment and a certain degree of anti-theft (Wang 2018; Yao et al. 2011).

Let us take the construction of monitoring system for farmland meteorology as an example (the process and function of the environment monitoring of fields and orchards are also expounded). The monitoring system for farmland meteorology mainly consists of three parts. The first part is the meteorological information collection system, which is used to collect meteorological information. The meteorological information collection system includes sensors for rain, air temperature, air humidity, wind speed and direction, soil temperature and light, etc. As for the data transmission system, the function of wireless transmission module is mainly to transmit the collected data to the connected users or terminal application layer, in order to achieve remote transmission. The executive equipment can manage and control the system. Execution equipment refers to various facilities used to adjust the field microclimate change, including irrigation equipment and lighting regulation equipment. Control equipment refers to the data acquisition module that controls the data acquisition equipment and allows the equipment to function. Its main function is to control the operation status of the data acquisition equipment through the setting of the intelligent weather station system. According to the instructions issued by the intelligent weather station system, it can control the opening/closing of the execution equipment at any time (Li 2012). Figure 10.2 offers an illustration of the service platform of agricultural IoT.

Essentially, the monitoring system for orchard environment is consistent with that for the farmland environment. The monitoring system for orchard environment is primarily responsible for the automatic acquisition and remote communication of soil temperature and humidity, air temperature and humidity, and weather and water quality information. In addition, the acquired environmental indicators are transmitted from the monitoring station to the terminal. In the monitoring system for orchard environment, sensors can be distributed separately or integrated in the environmental monitoring station. The monitoring system for orchard environment includes data acquisition system and data transmission system. The data transmission system


**Fig. 10.2** Monitoring system for farmland meteorology

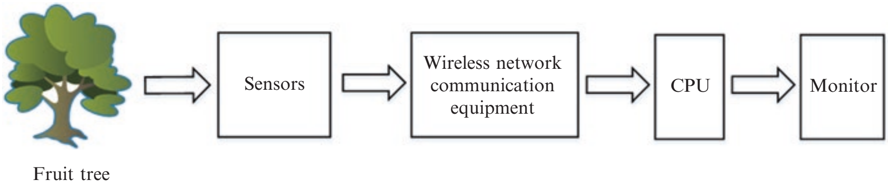


**Fig. 10.3** Schematic diagram of orchard environmental monitoring system

is composed of two modules: wireless sensor network and remote data transmission. The sensor covers the whole orchard, and the wireless sensor network collects the scattered data and transmits them to the application layer using the wireless transmission network. Figure 10.3 shows the schematic diagram of orchard environmental monitoring system.

### *10.3.2 Monitoring System for Soil Moisture*

Water is an essential resource in the growth of crops and fruit trees, while soil moisture is directly related to production capacity. Precision management of the moisture required for crops and fruit trees growth is of major significance for improving the yield and quality of crops and fruits. Against such a backdrop, IoT technology is applied to achieve the detection of soil moisture and nutrients in the field and orchard, the real-time decision-making based on soil conditions, and accurate regulation that guides the production process. The IoT monitoring system for soil moisture in field and that for soil moisture in orchard is consistent. The monitoring system for soil moisture achieves the diagnosis and early warning for soil and moisture in the following steps: first, the monitoring system obtains information (such as soil moisture content) in real time through the detection sensor. Then, it transmits the acquired information to the network node and the application layer through the wireless transmission network. To realize the diagnosis and early warning of soil and moisture, the system combines the information on meteorology, environment, and growth obtained by the sensors and taps into the diagnosis model and expert system. At last, the application layer uses intelligent control technique to remotely control the opening and closing of irrigation machine wells, canal gates, and other equipment through the service system for water management and also through the field irrigation system based on the diagnostic and early-warning information. In addition, the sensor of soil and moisture provides real-time feedback on soil moisture to control water consumption. In this way, the water consumption is controlled, the level of irrigation automation is improved, a suitable water environment is provided for the growth of field crops and fruit trees, and water resources are saved, while ensuring normal growth.

### 10.3.3 Integrated Application of Water and Fertilizer

The integrated management technology of water and fertilizer is a technology used to prepare soluble fertilizers into water mixtures according to growth and nutrient status. Apart from this, the technology could also accurately deliver the needed water and nutrients to the surrounding roots for their absorption and utilization with the help of irrigation system.

Compared with the traditional modes of irrigation and fertilization, integrated management of water and fertilizer has accomplished the transformation from channel irrigation to pipeline irrigation, from excessive fertilization to precision fertilization, and from separate irrigation and fertilization to water and fertilizer integration. It plays a major role in protecting ecological balance and achieving sustainable development of agriculture.

Relying on the monitoring system for soil and moisture, effective water management can be carried. The creation of a fertilizer requires the measurement of soil fertility. More specifically, the core of formula fertilization is to adjust and resolve the contradiction between the fertilizer requirements and soil supply. To improve fertilizer utilization rate, reduce the use amount, increase crop yield, optimize the quality of agricultural products, save labor and costs, and bring greater economic benefits, the elements required are supplemented in a targeted manner to achieve a balanced supply of various nutrients and to meet the needs of crops at the same time. The regulation of the proportions of various components in fertilizers is based on data derived from soil tests and fertilizer field tests. On the basis of reasonable application of organic fertilizer, the quantity, application period, and application method of nitrogen, phosphorus, potassium, medium and trace elements, and other fertilizers are determined according to the law of crop fertilizer demand and the performance and the effects of soil fertilizer.

Relying on the management system of soil testing and formula fertilization, the formulation of fertilization formula can be derived. This system, a software service system with strong functions, generates reasonable fertilization plans based on the key points of soil testing and formula fertilization. The system fully enables the management and application of soil measuring. It is divided into two large subsystems, a management system of soil data, and an application system of soil data. The management system, mainly used by specialists on agricultural technology at fertilizer station, is a maintenance management system for soil measurement data and basic information. It mainly includes functions of expert management, soil data management, fertilizer formula management, fertilizer management, fertilizer formula analysis, knowledge about fertilizer formula management, agricultural supply station management, and questionnaire management. The application system of soil data, mainly used to serve community-level agricultural production, is a platform for soil data application, fertilization formula application, and fertilization formula evaluation. It is also a platform for basic learning of fertilization formula. Its primary functions include query for soil data, fertilization formula, material supply, soil testing and formula fertilization technology, video face-to-face, and feedback on fertilization formula recommendation (Hu et al. 2015).

At the present stage, the integrated management technology of water and fertilizer based on IoT is combined with sensor technology, wireless transmission, intelligent systems, and other technologies. Sensors are used to quickly obtain information of crop, soil, meteorology, etc. Data transmission and management are then realized by IoT technology and an expert system or artificial intelligence, establishing an evaluation model of the demand for water and fertilizer to achieve a fully automated integrated management system of water and fertilizer. The integration of water and fertilizer can improve the utilization of water resources and fertilizers, increase the utilization of farmland, improve work efficiency, save resources, protect the environment, and ramp up yield.

### *10.3.4 Diagnosis and Early Warning System of Diseases and Pests*

As common threats in the growth of field crops and fruit trees, diseases and pests have a great impact on the yield of crops and fruit trees. If not controlled, diseases and pests will occur and spread on a large scale. Severe diseases and pests will lead to large reductions in yields. Therefore, scientific monitoring, prediction, and prevention of diseases and pests are essential to the normal growth of crops and fruit trees.

There are many ways to diagnose and prevent diseases, but they often have little effect because of their unscientific and unsystematic nature. Therefore, it is of great significance to establish the IoT system for disease diagnosis and early warning, which includes five levels: perception layer, transmission layer, basic layer, application platform, and application system. Among them, the sensing layer is the key to obtaining information on diseases of crops or fruit trees. It integrates data acquisition, image acquisition, and information processing functions, and connects multiple disease detection and reporting sensors in series to monitor the environment and disease status in real time. In addition, when the IoT system starts with the precision management or other operations, the perception layer can be used to provide the corresponding feedback information and assist users to adopt the correct methods to prevent and control diseases. Generally speaking, disease detection and prediction instruments mainly refer to sensors used for crop information perception in the field, including RGB imaging, spectrometer, infrared thermal imaging, hyperspectral imaging (Cen et al. 2017; Zhao et al. 2016), and chlorophyll fluorescence imaging (Weng et al. 2018). These instruments can achieve high-throughput, full-automatic, and digital detection for different organs of crops and fruit trees. According to the corresponding measurement standards of the disease, the abnormal IoT monitoring signals obtained are analyzed through a series of data or image processing. The relevant information, such as the type and severity of the disease, are transmitted back through the transmission layer and the base layer, so that the IoT system can start the response mechanism for diseases. Aiming at improving the disease response mechanism, control measures are taken in the application platform and application system to realize the IoT diagnosis and early warning of crops and fruit trees diseases. At the same time, the expert system, featuring online remote video consultation and Q&A, can provide full technical guidance and services for production entities. The expert system, connected with smart agricultural clients, provides disease management knowledge to customers through smartphones or smart terminals. Furthermore, the disease diagnosis and early warning system can be used for remote diagnosis and consultation of common diseases and pests of crops and fruit trees, offering corresponding management measures.

Advantages of the IoT system for disease diagnosis and early warning of crops and fruit trees can be presented as follows:

Firstly, the system is equipped with an efficient and outstanding disease monitoring and identification system, which can automatically identify the type and degree of disease.

Secondly, wireless transmission technique can be used to establish collection points of disease information according to different crops in the monitoring range, so as to facilitate the automatic collection of monitoring data and the remote transmission of wireless network. The real-time reappearance can monitor the trend of disease occurrence in the field at any time when it is not in the field, effectively improving the promptness and accuracy of prediction.

Thirdly, multiple release methods can be adopted to send notification to farmers and guide them to carry out scientific and effective prevention and control.

Fourth, follow-up monitoring is undertaken on diseased objects, recording the disease occurrence dynamics, prevention and control situation, degree of loss, etc. The relevant records are then sent back to the decision-making side in a timely manner.

Pests constitute one of the major contributing factors for reductions in yield. Throughout their life cycle, pests often turn into large-scale and severe biological infestations, depriving large areas of crops of their normal physiological functions. In this context, scientific monitoring and prediction of pests and prior prevention and control are essential to reducing the impact of pests on the yield and quality of crops and fruits. Though manual monitoring and application of chemical pesticides is the most important method of pest control, it brings such problems as insufficient recognition of pests, pesticide residues, and environmental pollution. Thanks to IoT technology, field monitoring can be replaced with real-time monitoring of IoT devices, hence ensuring effective and real-time monitoring and reducing labor intensity.

Pests are unavoidable hazards to crops during their growth. The real-time monitoring of pests can be divided into three parts: the monitoring and sensing layer, the transmission network layer, and the application management layer. The monitoring and sensing layer, the bottom layer of the system, is mainly responsible for monitoring the pest status and real-time collection of relevant information. The transmission network layer transmits the acquired information to the application management layer through a specific protocol and then processes, stores, and makes the final decision (Heamin et al. 2017; Potamitis et al. 2017).

For field crops, remote photo-type pest monitoring light, wireless remote automatic weather monitoring station, and remote video monitoring system can be used as the collection terminal of the monitoring and sensing layer, obtaining the pest information, field epidemic situation, and environmental data in real time. Machine vision technique is a technique used to obtain the information of pests, and the IoT pest monitoring system based on machine vision technique is also a focus in related research (Han 2014). The collection status of pest images holds the key to subsequent monitoring and analysis. Therefore, the design of image collection system and image acquisition is critical. Industrial cameras generally use CCD or CMOS image sensors (depending on the actual needs). Based on the camera to collect the image of pests, an effective image segmentation algorithm is applied to segment the target and background of pests. According to the characteristics of the target area, the identification model of pests is established to engage in the environmental monitoring of farmland and the species identification of pests. Image segmentation and feature extraction are relied on to understand and analyze the acquired target image for better application. Commonly used segmentation algorithms include edge detection image segmentation algorithm and region-based segmentation algorithm, whereas feature extraction includes color, texture, geometry, etc. When there is a large number of identified species and pests, there will be interspecific similarity, intraspecific diversity, or attitude change among pest populations, which will further complicate data. In machine learning, an effective method to deal with large numbers of data, convolutional neural network can have direct access to data, thus constructing the layer-by-layer expression relationship between "image pixels – underlying features – high-level abstraction – final category," accurately detecting the information related to perception and improving the classification capacity of visual patterns (Liu 2017). The pest monitoring system based on IoT can improve the real-time monitoring and identification ability of field pests and provide accurate information for pest control.

IoT of pest diagnosis and early warning for fruit trees is similar to that for field crops. The pest monitoring system of orchard IoT monitors the growth and pest of fruit trees with the help of images and multi-channel videos. Once problems are identified, measures will be taken right after. The layout of insect collecting nodes plays an important role in the efficient operation of the system. This requires pre-assessment of the characteristics of the pests that occur, and the nodes are then distributed accordingly. For example, the information collection node may have a distant view node and a near view node. The former uses a rotatable and zoomable camera device to observe the growth of fruit trees in a wide range, whereas the latter uses a high-macro camera device to observe the specific situation of pests in the fruit trees. This solves, to a certain extent, the problems of low accuracy, poor timeliness, and high labor intensity of manual monitoring. Based on the analysis of the acquired information on insects, the trend of orchard insects can be predicted and forecasted, and the information on the changes of orchard insect conditions can be grasped at regular intervals as needed (Heamin et al. 2017; Potamitis et al. 2017).

The information of pests is transmitted wirelessly to the system model and then combined with cloud computing analysis to determine pest management decisions and behaviors.

The application of the IoT system has enabled disease and pest monitoring in fields and orchards. It proves to be laborsaving, real time, efficient, and accurate, addressing the problems of low accuracy, poor timeliness, low utilization rate, large collective labor intensity, and unintuitive performance with manual monitoring in the past. IoT systems provide major technical guarantee for the production and development of fields and orchards.

## 10.4 Examples of Application Systems

The Wangbuliao Citrus Specialized Cooperative in Yongquan Town, Linhai, Taizhou, Zhejiang Province, and Zhejiang University have jointly built the first intelligent IoT precision monitoring system applied in citrus orchard in China. The cooperative has established a demonstration base for citrus information management in the park and constructed a real-time monitoring and intelligent control system for the ecological information of citrus base, physiological development of tree fruits, and orchard video information, so as to master the main information of the orchard in a timely manner and to facilitate remote management and monitoring. Remarkable achievements have been made in the construction of the demonstration base, which has been well-received by the general public. Citrus growth environment data are collected through sensors, and the data are then forwarded, received, stored, and fused through wireless sensor nodes in IoT. In addition, the environmental parameters in the orchard are acquired in real time by means of the Internet, mobile APP platform, and SMS.

Accurate real-time monitoring revolutionized Wangbuliao citrus professional cooperatives. When the data exceeds the warning value, the system automatically alarms and undertakes reasonable control, such as automatic heating, irrigation, and so on. Figure 10.4 shows the IoT application case of citrus professional cooperatives in Yongquan Town, Linhai, Taizhou.

Zhejiang University and Ningbo City, Zhejiang Province, have jointly developed the digital precision cultivation technique of southern pear and the IoT system for the collection and processing of orchard environmental information. Through the establishment of a system database, the intelligent management information system, the disease and pest diagnosis expert system, and the wireless sensor network monitoring system of soil and environmental information for southern pear cultivation are developed to allow digital and precise cultivation management and intelligent information acquisition and monitoring in the growing process. The intelligent management of southern pear cultivation, the online diagnosis of southern pear diseases and pests in orchards, and the real-time monitoring and transmission of information are achieved, thanks to the interactive interface. As a result, the digital

**Fig. 10.4** Application cases of Wangbuliao citrus professional cooperatives in Yongquan Town, Linhai, Taizhou, Zhejiang


**Fig. 10.5** Intelligent management platform for digital precision cultivation of pear

management of southern pear precise cultivation and the collection and processing of environmental information in orchards are made possible. Figure 10.5 is an illustration of the digital management platform for precision cultivation of pears and the IoT system for the collection and processing of environment information orchards.

## 10.5 Summary

Fields and orchards are the main application scenarios of agricultural IoT. Compared with facility agriculture, the environment of field and orchard is more complex and accompanied with more uncontrollable factors. The application of the agricultural IoT in fields and orchards is based on the basic structure of IoT. Considering the special application scenarios of the fields and orchards, appropriate sensors and networking methods can be selected. At the application layer, through the use of diagnostic models or expert systems or real-time online diagnosis, the precision management of growth enabled by IoT is achieved.

IoT in fields and orchards, monitoring and controlling the growth of crops and fruit trees in an open environment, is subject to changes in the climate and environment. Which is why it is difficult to adopt IoT in fields and orchards. In open environments, the stability and durability of sensors, the stability of information transmission, and the reliability of decision making are all issues that demand further research.

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