Monitoring Citrus Soil Moisture and Nutrients Using an IoT Based System

Xueyan Zhang 1, Jianwu Zhang 2, Lin Li 1, Yuzhu Zhang 1 and Guocai Yang 1,*

1 School of Computer and Information Science, Southwest University, Chongqing 400715, China; zxyssyssy@email.swu.edu.cn (X.Z.); cqkxxn@163.com (L.L.); yuzhuze@163.com (Y.Z.)
2 Dean’s Office, Tianjin Railway Technical and Vocational College, Tianjin 300240, China; zjw63@163.com
* Correspondence: paul.g.yang@gmail.com; Tel.: +86-151-7871-5875

Academic Editor: Simon X. Yang
Received: 28 November 2016; Accepted: 20 February 2017; Published: 23 February 2017

Abstract: Chongqing mountain citrus orchard is one of the main origins of Chinese citrus. Its planting terrain is complex and soil parent material is diverse. Currently, the citrus fertilization, irrigation and other management processes still have great blindness. They usually use the same pattern and the same formula rather than considering the orchard terrain features, soil differences, species characteristics and the state of tree growth. With the help of the ZigBee technology, artificial intelligence and decision support technology, this paper has developed the research on the application technology of agricultural Internet of Things for real-time monitoring of citrus soil moisture and nutrients as well as the research on the integration of fertilization and irrigation decision support system. Some achievements were obtained including single-point multi-layer citrus soil temperature and humidity detection wireless sensor nodes and citrus precision fertilization and irrigation management decision support system. They were applied in citrus base in the Three Gorges Reservoir Area. The results showed that the system could help the grower to scientifically fertilize or irrigate, improve the precision operation level of citrus production, reduce the labor cost and reduce the pollution caused by chemical fertilizer.

Keywords: Internet of Things technology; single-point multi-layer detection; fertilization and irrigation decision support

1. Introduction

Informatization is the sign and key of agricultural modernization. Agricultural information can significantly change small scale of agricultural production, great temporal and spatial variation, low scale merit and other industrial weakness. Moreover, it plays an important role in the development of agriculture and the full realization of a well-off society [1,2]. The Internet of Things (IoT) is defined as things connected to things in the Internet [3–5]. The agricultural Internet of Things is a new trend in world agricultural development, a new type of agriculture which combines the Internet of Things and agricultural production [6–8]. It will bring agriculture into the digital information age [9]. Agricultural Internet of Things is able to implement digital design, intelligent control, precise operation and scientific management for various agricultural elements. So it achieves a comprehensive perception, reliable transmission and intelligent processing, and ultimately achieves high yield, high efficiency, high quality, ecological and safety purposes [10].

Citrus is largest fruit crop in the world. Its planting area and output are the first of the fruit trees. In addition, it is the world’s third largest trade agricultural products. Citrus is produced in 135 countries and regions all over the world. Among these areas, China’s citrus planting area and production is in the first place in the world, becoming the world’s largest citrus producing country. In China, most citrus management methods are still in the relatively backward stage, monitoring
of water, nutrients, and the temperature is still in the manual monitoring phase [11]. They result in inconvenient operation, time-consuming and laborious, low precision and the lack of information. Furthermore, the data acquisition will have a certain delay. So managers cannot achieve comprehensive and clear grasp of the orchard information [12]. Based on this, the paper applies the Internet of Things technology and single-point multi-layer detection method to the soil moisture, temperature and nutrient monitoring, sets up citrus orchard fertilization irrigation expert knowledge base and makes expert decision according to the soil condition in real time to guide the actual production process of citrus. The emergence of wireless sensor, data fusion and internet technology, can achieve the remote automatic monitoring on the citrus water, nutrient and temperature of growth environment. And through the model analysis and data processing, expert decision-making system can give effective measures of citrus management. Practice has proved that single-point multi-layer detection technology can effectively expand the detection range of citrus growth environment, and it is helpful to construct a more accurate expert knowledge base. At the same time, the system can effectively guide fruit growers to scientific management of citrus orchards and significantly improve the yield of citrus.

2. Overall Structure

2.1. System Design Objectives

The real-time monitoring system of citrus soil moisture and nutrient is designed to monitor the soil moisture and nutrient status in the citrus orchard, so that fruit farmers can grasp the condition of orchard in time, and under the guidance of decision-making support system adjust fertilization irrigation strategy. This determines the design objectives of the system.

1. Put forward the scientific distribution technology of the soil nutrient and moisture real-time monitoring system in mountain citrus orchard. It makes the layout more reasonable and the monitoring area is effectively covered.
2. Research and develop scientific detection methods to obtain more accurate citrus growth environment conditions.
3. Integrate wireless sensor network of citrus soil nutrient and moisture and remote information management system and intelligent decision support system based on ZigBee technology [13,14]. Finally, carry on scientific experimental demonstration.

2.2. System Structure

The IoT platform design idea is applied to the real-time monitoring system of citrus soil moisture and nutrient. The system is divided into four layers: perception layer, network transmission layer, information service layer and application layer. The overall system structure is shown in Figure 1.

Perception layer: Perception layer is mainly to achieve data acquisition and perception [15,16] including citrus soil moisture and temperature, air humidity and temperature, soil nutrients and sensor space coordinate. According to the experiment, we found that the temperature and humidity at different soil depths at the same location can better reflect the environmental condition. So we use single-point multi-layer detection method and the soil depth of 20 cm, 40 cm and 60 cm was selected for monitoring. Soil moisture is measured by a special soil moisture sensor which can realize on-line detection. The output voltage of the sensor varies with the change of soil water content. Air temperature and humidity are measured using SHT17 digital temperature and humidity sensors (Sensirion, Zurich, Switzerland). There is no suitable on-line soil nutrient detection sensor. Nutrient change is slow and the measurement takes a long period of time. Therefore, the portable soil nutrient detector is selected to detect soil nutrients.

Network transmission layer: It mainly includes the citrus orchard site wireless sensor network and data transmission facilities connected to the Internet. The data transmission network includes the short-distance transmission part of the citrus orchard and the data long-distance transmission part. Internet of Things Gateway is the core of wireless sensor network equipment which can achieve
which has the advantages of low power consumption, strong mobility and other advantages in
deployment and maintenance. The long-distance transmission uses GPRS [19,20] to connect to the
Internet server, which supports IPV4 and IPV6 on the transmission protocol. The concepts of rumor
and gossip routing algorithms are widely employed in sensor networks [21] and ad hoc networks [22].
So we also use this method in our system. The main function of this layer is to transmit various
agricultural information collected by the perception layer to the background network server through
the network.

Information service layer: This layer mainly includes hardware and software. The hardware part
adopts PC cluster control and the local area network. The databases include the standard data sample
database, the sensor network monitoring database, the citrus production database, the meteorological
data and the citrus production domain knowledge database. These data provide information support
services for the application layer.

Application layer: it is an integrated information platform based on business logic. The software
running on the platform include a sensor network management system, a WEB GIS-based monitoring
data query and analysis system, and a citrus precision fertilization decision support system.
Sensor network management system proposes optimal layout recommendations based on the citrus
orchard sensor network optimization distribution model. The data query and analysis system based
on WEB GIS can get the humidity, temperature and nutrient value of citrus soil. The data are obtained
from the real-time monitoring database of the sensor network in the GIS spatial database through
data fault correction. According to soil moisture and nutrient status, fruit growers use citrus growth
model and citrus precision fertilization and irrigation support model to obtain the citrus fertilization
irrigation support decision.
3. Design Scheme

3.1. System Hardware Design

3.1.1. Sensor Control Node

The main task of the sensor control node is to collect the citrus orchard soil temperature and humidity, air temperature and humidity and other parameters, and transfer data to the master node. We select HA2002 (Handan Dingrui Electronics Co., Ltd, Handan, China) as the soil temperature sensor, HA2001 (Handan Dingrui Electronics Co., Ltd, Handan, China) as the soil moisture sensor, and the type of air temperature and humidity sensor is FM-KWS (Hebei fly dream Electronic Technology Co., Ltd, Handan, China). These sensors have the same characteristics: fast response time, high accuracy, wide range, good stability. JN5139 module is a series of surface mount modules that enable users to realize IEEE802.15.4 or ZigBee compatible system in the shortest time and at the lowest cost. The field wireless sensor can send the parameters to the JN5139 control node through the ZigBee. The sensor node structure is shown in Figure 2.

![Figure 2. Sensor nodes structure.](image)

Terminal node part of the circuit diagram is shown in Figure 3.

![Figure 3. Part of the circuit diagram of the sensor node.](image)
3.1.2. Field Master Control Node

The system uses ARM11-based S3C6410 (YoujianhengtianTechnology Co., Ltd, Shenzhen, China) [23] as the master chip, using FORLINX’s OK6410 (Forlinx Embedded Tech. Co., Ltd, Baoding, China) control board module. The GPRS module adopts HUAWEI GTM900C (Huawei Technologies Co., Ltd., Shenzhen, China) and the GPS module uses Trimble 4600LS single frequency GPS receiver. The receiver is produced by the world’s largest GPS manufacturer Trimble Navigation Company (Sunnyvale, CA, USA), and it is the first integrated GPS receiver which has high quality, high precision, high efficiency and low price. The ARM module sent the AT commands to the GTM900C module through the serial port. Through this method, the GTM900C module achieves the corresponding function. 4600LS receives the geographical coordinates of space and transmits them to the control board through the RS232 serial port. OK6410 connects with the JN5139 GPRS module GTM900 and 4600LS through the USB serial port. The field controller node is the sink node of the sensor network which monitors the site. It is responsible for managing and maintaining the ZigBee network. The field control unit has a corresponding LCD touch screen, real-time display dynamic changes of soil temperature and humidity, air temperature and humidity in collection points. The structure of the field control node is shown in Figure 4.

![Figure 4. Spot main control node structure.](image)

3.2. System Software Design

Citrus soil, temperature and nutrient monitoring system is the core of the system. Its architecture is shown in Figure 5 below.

In this section, the permission management module can assign different permissions to different roles. In the sensor network management module, users can manage sensor network nodes and view the sensor status. The data query and analysis module based on WEB GIS can check the spatial distribution of soil moisture, temperature and nutrient. The decision-making system in the decision support module of citrus precision fertilization can make decisions according to the soil moisture and temperature. If the system decision-making model is not ideal, it will be modified or replaced to adjust the expert decision-making advice in a short time. It is the management module function of the decision model. Data management mainly includes data receiving, data storage and data processing. In order to make users more intuitive to observe the effects of temperature, humidity and nutrient and other parameters on citrus growth, providing the basis for scientific cultivation, citrus soil temperature and nutrient monitoring center drawn curves for different functions on the sensor upload data. Users can query the environmental parameters monitored by the sensor nodes at different locations and at different times.
Decision Support Module

The decision support module is one of the most important parts of the system, and other modules provide supports for it. The model management module includes the expert knowledge base of citrus fertilization and irrigation, and allows the authorized users to revise and supplement the knowledge base according to the actual situation. The data management module processes and analyzes the collected data. It ensures that these data meet the data input format of the model. We use the single-point multi-layer detection method when using sensors to obtain soil moisture, temperature and other environmental conditions. The application of this method makes the grower have a more comprehensive and accurate grasp of citrus growth environment status, while improving the accuracy of fertilizer and irrigation decisions. Take the citrus orchard soil moisture monitoring as an example, for the same fruit tree the water content at 20 cm, 40 cm and 60 cm below the surface will be monitored. The three humidity values of different surface depths are averaged as one of the input conditions of the irrigation decision system. Table 1 shows some examples of expert knowledge bases for citrus irrigation in sandy soil types. An irrigation decision-making system based on soil properties, the average water content and time stamp gives reasonable irrigation decisions. The citrus intelligent irrigation decision-making system process is shown in Figure 6.
Table 1. Knowledge base of citrus irrigation (sandy soil).

| Soil Properties | Humidity (%) | Season | Diagnostic Conclusion | Expert Advice |
|-----------------|--------------|--------|-----------------------|---------------|
| sandy soil      | <17          | spring |                       | Immediately carried out winter irrigation. first build the hillock in the crown to form a water plate, Dug irrigation water hole 2–4 in the drip line around the crown, Irrigate 10 kg per square meter of canopy projected area. |
|                 | <15          | autumn winter | lack of water | Immediately carried out winter irrigation. first build the hillock in the crown to form a water plate, Irrigate 10 kg per square meter of canopy projected area. Dug irrigation water hole 2–4 in the drip line around the crown, Irrigate 7 kg per square meter of canopy projected area. |
|                 | <18          | summer |                       | First loose soil and cover tree plate with grass. Irrigate 30 kg per square meter of canopy projected area. Dug irrigation water hole 2–4 in the drip line around the crown, Irrigate 15 kg per square meter of canopy projected area. |
|                 | 16–20        | spring |                       | First loose soil and cover tree plate with grass. Irrigate 15 kg per square meter of canopy projected area. Dug irrigation water hole 2–4 in the drip line around the crown, Irrigate 10 kg per square meter of canopy projected area. |
|                 | 15–20        | autumn winter | low level | Immediately carried out winter irrigation. first build the hillock in the crown to form a water plate, Dug irrigation water hole 2–4 in the drip line around the crown, Irrigate 15 kg per square meter of canopy projected area. enough water is given to the tree tray before the frost. |
|                 | 17–21        | summer |                       | First loose soil and cover tree plate with grass. Irrigate 15 kg per square meter of canopy projected area. Dug irrigation water hole 2–4 in the drip line around the crown, Irrigate 10 kg per square meter of canopy projected area. |
|                 | 21–80        | anniversary | suitable | Without irrigation, soil cover and weed moisture under the canopy. |
|                 | >80          | anniversary | excess | Timely excavate ditches and discharge orchard water. If there is an unbroken spell of wet weather, plastic film can be used for ground cover. |

Figure 6. Decision system procedures.
4. System Testing

The server receives soil temperature and humidity, air temperature and humidity every minute. Soil temperature and humidity, air temperature and humidity sensors transmit data to the network through the RS232 serial port. The interface of remote server receiving data is shown in Figure 7.

![Remote server monitoring interface.](image1)

Figure 7. Remote server monitoring interface.

The data collected by citrus soil temperature, humidity and air temperature, humidity sensor will be transmitted to the background. They need to be compared with the standard sample database and modified using data tolerance and data correction model to get the desired data format. The citrus precision fertilization and irrigation support model and citrus soil moisture, temperature and nutrient monitoring model give real-time expert decision-making advice according to the citrus growth knowledge database. The soil nutrients will not change significantly in a certain period of time and there is no suitable wireless sensor. So the system uses artificial data collection. The real time monitoring part mainly monitors the temperature and humidity of soil and air and gives irrigation decisions in real time based on air temperature and humidity. Figure 8 is the interface of the irrigation decision support system. The corresponding season is spring, when the average soil moisture is more than 20%. The system suggests that the orchard does not need to be irrigated, and the experts reached the same conclusion as the system after their field visit. After a year of use we found that the soluble solid content of fruit was increased by 1%–2%, orchard per mu yield increased 500 kg or more and save water and fertilizer resources 20%. It proves that the system can guide the management of the citrus orchard in the Three Gorges reservoir area scientifically.

![Irrigation decision support interface.](image2)

Figure 8. Irrigation decision support interface.
decisions in real time based on air temperature and humidity. Figure 8 is the interface of the irrigation decision support system. The corresponding season is spring, when the average soil moisture is more than 20%. The system suggests that the orchard does not need to be irrigated, and the experts reached the same conclusion as the system after their field visit. After a year of use we found that the soluble solid content of fruit was increased by 1%–2%, orchard per mu yield increased 500 kg or more and save water and fertilizer resources 20%. It proves that the system can guide the management of the citrus orchard in the Three Gorges reservoir area scientifically.

5. Conclusions

In this study, the project of the citrus moisture, temperature and nutrient monitoring based on the Internet of Things platform was proposed. The project regards early warning and decision-making as the basic objectives, and provide a reference solution for citrus large-scale cultivation. As a result of the hierarchical thinking of the Internet of Things, the decision support system is divided into the perception layer, network transport layer, information service layer, application layer. This idea reduces the coupling between various services and improves the reliability of the system. The single-point multi-layer detection method to obtain temperature, humidity and nutrients is an innovative point of the system. This will not only expand the detection range, but also improve the accuracy of the model. According to the characteristics of geographical environment and citrus management experience of many years, the expert knowledge base suitable for the Three Gorges reservoir area was established, which provided a model for citrus fertilization and irrigation decision support. Practice has proved that the system can make scientific management decisions according to citrus growth conditions. The system has many shortcomings, such as “silo” solutions [24] and high cost problems. In the future we will optimize it in these areas.

Acknowledgments: This work was supported by the Chongqing 151 Major Science and Technology Projects (cstc2013jcsf-jfzhX0002), Chongqing, China.

Author Contributions: Jianwu Zhang and Guocai Yang conceived and designed the experiments; Lin Li and Xueyan Zhang performed the experiments; Yuzhu Zhang analyzed the data; Xueyan Zhang and Guocai Yang wrote the paper.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Wang, Z. Study on the Model of Agricultural Information Propulsion in Different Regions. Ph.D. Thesis, Chinese Academy of Agricultural Sciences, Beijing, China, 2011. (In Chinese)
2. Gebbers, R.; Adamchuk, V.I. Precision Agriculture and Food Security. Science 2010, 327, 828–831. [CrossRef] [PubMed]
3. Atzori, L.; Iera, A.; Morabito, G. The Internet of Things: A Survey. Comput. Netw. 2010, 54, 2787–2805. [CrossRef]
4. Tan, L.; Wang, N. Future Internet: The Internet of Things. In Proceedings of the IEEE 3rd International Conference on Advanced Computer Theory and Engineering (ICACTE), Chengdu, China, 20–22 August 2010; Volume 5.
5. Zhang, C.; Sheng, W. Application of Internet of Things in Agriculture. Dongbei Nongye Daxue Xuebao 2011, 42, 1–5. (In Chinese)
6. Baggio, A. Wireless Sensor Networks in Precision Agriculture. In Proceedings of the ACM Workshop on Real-World Wireless Sensor Networks (REALWSN 2005), Stockholm, Sweden, 20–21 June 2005.
7. Ferrández-Pastor, F.J.; García-Chamizo, J.M.; Nieto-Hidalgo, M.; Mora-Pascual, J.; Mora-Martínez, J. Developing Ubiquitous Sensor Network Platform Using Internet of Things: Application in Precision Agriculture. Sensors 2016, 16, 1141. [CrossRef] [PubMed]
8. Kopetz, H. Internet of Things. In Real-Time Systems; Springer: New York, NY, USA, 2011; pp. 307–323.
9. Fei, Y.J.; Xu, Z.J.; Feng, L. The Research of Internet of Things in Agricultural Production and Management. 
In Proceedings of the Fifteenth Session of the Annual Meeting of the Association of China, the Tenth Venue: 
Conference on Information Technology and Agricultural Modernization, Guiyang, China, 25–27 May 2013. 
(In Chinese)
10. Li, D.L. Internet of Things and Wisdom of Agriculture. 
Agric. Eng. 2012, 2, S126.
11. Lin, Y.H. Introduction to Internet of Things; 
Science Press: Beijing, China, 2011; pp. 60–63.
12. Zhang, W. Research on Key Technologies of Wireless Sensor Networks for Precision Agriculture. Ph.D. Thesis, 
Zhejiang University, Hangzhou, China, 2013. (In Chinese)
13. Kinney, P. Zigbee Technology: Wireless Control That Simply Works. In Proceedings of the Communications 
Design Conference, San Jose, CA, USA, 29 September–2 October 2003; pp. 1–7.
14. Zhou, Y.; Ling, Z.; Wu, Q. ZigBee Wireless Communication Technology and Investigation on Its Application. 
Process Autom. Instrum. 2005, 6, 002.
15. Dan, L.; Xin, C.; Huang, C.; Ji, L. Intelligent Agriculture Greenhouse Environment Monitoring System Based 
on IoT Technology. In Proceedings of the 2015 IEEE International Conference on Intelligent Transportation, 
Big Data and Smart City (ICITBS), Halong Bay, Vietnam, 19–20 December 2015; pp. 487–490.
16. Lee, M.; Hwang, J.; Yoe, H. Agricultural Production System Based on IoT. In Proceedings of the 2013 
IEEE 16th International Conference on Computational Science and Engineering (CSE), Sydney, Australia, 
3–5 December 2013; pp. 833–837.
17. Broch, J.; Maltz, D.A.; Johnson, D.B.; Hu, Y.-C.; Jetcheva, J. A Performance Comparison of Multi-Hop Wireless 
Ad Hoc Network Routing Protocols. In Proceedings of the 4th Annual ACM/IEEE International Conference 
on Mobile Computing and Networking (ACM), Dallas, TX, USA, 25–30 October 1998; pp. 85–97.
18. Johnson, D.B.; Maltz, D.A. Dynamic Source Routing in Ad Hoc Wireless Networks. In Mobile Computing; 
Springer: New York, NY, USA, 1996; pp. 153–181.
19. Zhang, J.; Hu, S.; Long, Z.; Kou, Q. The Wireless Data Transmission System Based on GPRS and its Discussion 
for Application. J. Electr. Meas. Instrum. 2009, 23, S1.
20. Wang, N.; Zhang, N.; Wang, M. Wireless Sensors in Agriculture and Food Industry—Recent Development 
and Future Perspective. Comput. Electr. Agric. 2006, 50, 1–14. [CrossRef]
21. Braginsky, D.; Estrin, D. Rumor Routing Algorithm for Sensor Networks. In Proceedings of the First ACM 
International Workshop on Wireless Sensor Networks & Applications, Atlanta, GA, USA, 28 September 2002; 
pp. 22–31.
22. Luo, J.; Eugster, P.T.; Hubaux, J.P. Route Driven Gossip: Probabilistic Reliable Multicast in Ad Hoc Networks. 
In Proceedings of the Joint Conference of the CiteSeer IEEE Computer and Communications, San Francisco, 
CA, USA, 30 March–3 April 2003; Volume 3, pp. 2229–2239.
23. Tian, B.; Zhao, X.L.; Yao, Q.M.; Zha, L. Design and Implementation of a Wireless Video Sensor Network. 
In Proceedings of the 2012 9th IEEE Conference on Networking, Sensing and Control (ICNSC), 
Beijing, China, 11–14 April 2012; pp. 411–416.
24. Zhao, S.; Yu, L.; Cheng, B. A Real-Time Web of Things Framework with Customizable Openness Considering 
Legacy Devices. Sensors 2016, 16, 1596. [CrossRef] [PubMed]
© 2017 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access 
article distributed under the terms and conditions of the Creative Commons Attribution 
(CC BY) license (http://creativecommons.org/licenses/by/4.0/).