ISSN 2616-5910 Vol. 6, Issue 1: 85-91, DOI: 10.25236/AJALS.2025.060112

Research on Temperature Monitoring Technology for Smart Agricultural Greenhouses Based on Wireless Sensor Technology

Liu Yuting

School of Information and Intelligence Engineering, University of Sanya, Sanya, Hainan, 572022, China

Abstract: *The rapid development of mobile internet technology provides technical support for the automation and intelligence of agriculture. Smart agriculture based on mobile internet technology is a new direction for agricultural development in China. This paper focuses on the application of mobile internet technology in smart agriculture, introduces and analyzes the application of ZigBee wireless sensor technology in smart agricultural greenhouse temperature monitoring systems, and designs a highly applicable agricultural greenhouse temperature monitoring solution. In this solution, the entire monitoring system mainly consists of four parts: a ZigBee wireless sensor monitoring module, a ZigBee coordinator + GPRS wireless gateway communication module, a Web server, and a mobile phone monitoring client. The ZigBee wireless sensor monitoring module collects greenhouse environmental information and transmits it through the ZigBee network to the ZigBee coordinator + GPRS wireless gateway communication module. The gateway communication module uses the GPRS network to establish data links with mobile or China Unicom base stations, and then transmits the environmental information data to a remote Web server through these base stations. The Web server analyzes and stores the data, and users can use a browser on a PC or a mobile phone APP to intuitively and conveniently observe the real-time environmental data in the greenhouse and query the change curves of greenhouse information based on historical records. This solution supports real-time query and monitoring of greenhouse environmental information, and also supports users to remotely control greenhouse equipment according to the growth stage of crops and the environmental parameters of the greenhouse.*

Keywords: *Smart Agriculture; Wireless Sensor Technology; Remote Monitoring System; ZigBee*

1. Introduction

China is the world's largest agricultural country, and agricultural production is a vital component of the national economy[1,2]. However, the basic national conditions of harsh climates and a severe shortage of high-quality soil resources in most parts of China pose significant challenges to agricultural production. With economic and technological development, fewer people are engaged in agricultural labor, while the demand for high-quality agricultural products is increasing. In specific production environments, such as greenhouse cultivation, human labor cannot promptly observe and adjust the crop growth environment[3,4]. Therefore, establishing a smart agricultural greenhouse monitoring and control system is of great significance.

In recent years, the development direction of agriculture in China has been trending towards automation and intelligence. The continuous development of computer, internet, and automated control technologies has brought many emerging technologies to the agricultural production field[5]. Greenhouse control technology, as a major emerging technology in agricultural production, is favored by agricultural producers and the industry. Intelligent greenhouse control technology mainly controls the external physical conditions of crop growth to achieve optimal growing conditions. Greenhouse control technology collects environmental parameters such as temperature, humidity, and light intensity within the greenhouse and adjusts these parameters through related control equipment, enabling real-time monitoring of crop growth conditions[6]. However, it is constrained by the scarcity of related supporting technologies and equipment, high investment costs, and high requirements for operators. Therefore, China's greenhouse control technology still has many aspects that need to be improved and perfected[7,8].

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This paper focuses on the application of wireless sensor technology in smart agriculture and studies remote monitoring technology for greenhouses in response to the current development needs of smart agriculture in China. It analyzes in detail the technical requirements for temperature monitoring in smart greenhouses, introduces the key technology of ZigBee, and, based on the technical requirements for temperature monitoring in smart greenhouses, presents the overall structure and design of key functional modules of the greenhouse temperature monitoring system. The system applies sensor technology, Internet of Things technology, and wireless transmission technology in agricultural greenhouses, enabling accurate detection of crop production status, more efficient and convenient control and management of greenhouses, and improved crop production efficiency.

2. Technical Requirements

The temperature monitoring system for smart agricultural greenhouses must achieve information collection of internal environmental parameters and remote control of greenhouse equipment, effectively transmitting data information to users and enabling user interaction. The primary task of intelligent monitoring of smart agricultural greenhouses is to collect internal environmental factor parameter data, and then transmit and aggregate environmental sensor data through a wireless network, sending the collected data information to a remote web server. The collection of internal greenhouse environmental data can be achieved through sensors, and data transmission utilizes a mobile communication network to send greenhouse data to the remote server. The remote server then configures a corresponding interface for the received environmental data to display the data in real-time, enabling user interaction. Therefore, the specific functional requirements of the intelligent greenhouse monitoring system are as follows:

(1) Environmental Data Information Collection: Complete the collection of environmental information data within the greenhouse, such as: air temperature and humidity, soil temperature and humidity, light intensity information, and CO2 concentration information.

(2) Complete the long-distance transmission of environmental data information and the reception and execution of equipment control commands (greenhouse control equipment includes: supplemental lighting, ventilation fans, irrigation facilities).

(3) The remote server should support real-time viewing of greenhouse environmental information, alarm and statistics for abnormal information, and be equipped with a database to store the received environmental information. Users can send control commands to the control equipment in the greenhouse by accessing the remote server, enabling remote control.

(4) Users can use a mobile monitoring client to remotely monitor the greenhouse and receive alarm information pushed from the remote server in real-time, facilitating real-time querying of greenhouse environmental data and management of monitoring sensor equipment.

3. Temperature Monitoring Technology

ZigBee is a highly reliable, short-range, low-power wireless sensing technology primarily suited for industrial and automation control applications. It also finds considerable use in smart homes, agriculture, and healthcare. With the continuous development of IoT technology, ZigBee, as an important technical standard for wireless sensor networks, occupies an increasingly important position in the Internet of Things. Compared to other wireless data transmission technologies (such as WIFI and Bluetooth), the ZigBee wireless communication protocol has lower power consumption and a larger network capacity. The main characteristics of ZigBee are as follows:

(1) Low Power Consumption: Transmit power is as low as 1mW, and a sleep mechanism is utilized.

(2) Low Cost: The initial price of a ZigBee module is only $1.5 to $2.5, and the ZigBee protocol is provided to users free of charge, greatly reducing the technical cost of ZigBee.

(3) Short-Range Communication: Due to low power consumption considerations, the transmit power of ZigBee devices is not very high. The effective communication distance between two ZigBee nodes is between 10 and 100 meters. By increasing the transmit power of the radio frequency module, the effective communication distance can be increased to 1 to 3 km. If multi-hop cascading is implemented through adjacent ZigBee nodes, the effective communication distance can be greatly increased. The actual effective communication distance depends on the specific application mode and

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the actual transmit power of the ZigBee radio frequency module.

(4) Reliability: A collision avoidance mechanism is used, and gaps are reserved for communication services with higher bandwidth requirements, effectively avoiding data collisions and conflicts. Each sender of data needs to wait for the receiver's acknowledgment information. If a problem occurs during data transmission, the sender can resend the data.

(5) Multiple Networking Methods: ZigBee networking is simple and flexible. By configuring the network coordinator with different software settings, various network structures such as star, tree, and mesh can be formed. Users can choose the appropriate network structure to meet their needs according to different application scenarios.

3.1 ZigBee Protocol Architecture

The ZigBee protocol stack consists of various modules at each layer of the network architecture. Communication between layers is facilitated through Service Access Points (SAPs). The physical layer and MAC layer are the bottom two layers of the ZigBee protocol stack and are defined by the IEEE 802.15.4 standard. The ZigBee Alliance, building upon the IEEE 802.15.4 standard, specifies the network layer and application layer. Each layer provides specific services to its adjacent layers.

The ZigBee protocol stack is designed with a modular structure, composed of different layers within the network architecture, with each layer containing several functional modules. These modular layers do not operate independently; they must collaborate to achieve the overall functionality of the ZigBee network. To enable effective communication and data exchange between layers, the ZigBee protocol stack employs a Service Access Point (SAP) mechanism. The SAP acts as an interface, allowing adjacent layers to transmit information and request services.

At the bottom of the ZigBee protocol stack, we find the physical layer and the MAC layer. These two layers form the foundation of the entire protocol stack and are defined in detail by the IEEE 802.15.4 standard. This means that the implementation of the physical layer and MAC layer functionalities in the ZigBee protocol stack adheres to the specifications of the IEEE 802.15.4 standard.

To construct a complete network protocol, the ZigBee Alliance further defines the functions and protocols of the network layer and application layer, building upon the IEEE 802.15.4 standard. This implies that, in addition to the physical layer and MAC layer, the network layer and application layer of the ZigBee protocol stack are specified by the ZigBee Alliance itself. Furthermore, each layer in the protocol stack is designed to provide specific services to its adjacent upper and lower layers. This service provision ensures the coordinated operation and functional implementation of the entire protocol stack. For example, the network layer utilizes the services provided by the MAC layer for data transmission, while also providing network management and routing services to the application layer above.

3.1.1 Physical Layer

The Physical Layer (PHY) defines the channels and frequencies for wireless signal transmission. Its main functions include: (1) Channel frequency selection; (2) Data transmission and data reception; (3) Radio frequency (RF) activation and deactivation; (4) Channel energy detection; (5) Received channel link quality indication; (6) Clear Channel Assessment (CCA). Among these, the primary task of the PHY is channel frequency selection, and the main basis for implementing this task is the Physical Layer Service Specification.

The ZigBee PHY defines three wireless operating frequency bands: 2.4 GHz, 868 MHz, and 915 MHz. A total of 27 channels are defined across these three bands: the 2.4 GHz band, a globally available band, has 16 channels with a channel spacing of 5 MHz and a transmission rate of 250 kbit/s; the 868 MHz band, used in Europe, has 1 channel with a rate of 20 kbit/s; the 915 MHz band, used in North America, has 10 channels with a channel spacing of 2 MHz and a transmission rate of 40 kbit/s. In China, ZigBee devices primarily operate in the 2.4 GHz band.

3.1.2 MAC Layer

The IEEE 802.15.4 standard specifies the following MAC layer tasks: (1) The network coordinator generates network beacon frames and is responsible for beacon frame synchronization; (2) Supports Personal Area Network (PAN) association and disassociation; (3) Supports device security; (4) Employs the Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) channel access mechanism; (5) Processes and maintains the Guaranteed Time Slot (GTS) mechanism; (6) Provides a

ISSN 2616-5910 Vol. 6, Issue 1: 85-91, DOI: 10.25236/AJALS.2025.060112

reliable transmission mechanism. The MAC sublayer service specification is the main basis for the MAC to implement its specific tasks. Similar to the PHY, the MAC layer also has a management entity, namely the MAC Layer Management Entity (MLME). The MLME needs to maintain and manage the PAN information database of the MAC sublayer. The MLME also has two interfaces: the MAC Common Part Sublayer (MCPS) service interface and the MAC Management Entity (MME) service interface. MAC data services are accessed through the MCPS service interface, while MAC management services are accessed through the MME service interface.

3.1.3 Network Layer

The ZigBee network layer resides between the IEEE 802.15.4 MAC layer and the application layer, primarily responsible for ensuring the correct operation of the MAC sublayer. The network layer is the core layer of the ZigBee protocol stack, mainly responsible for network creation, device network address allocation, support for network topology structures, and network routing management.

(1) Network Establishment and Network Address Allocation: In a ZigBee network, the coordinator has the ability to establish a new network. The coordinator establishes a new network through the ZigBee network layer. After a new network is created, the coordinator has the ability to allocate addresses to devices joining the network.

(2) Network Topology Structure: Supports three network topology structures: Star, Cluster-Tree, and Mesh.

(3) Network Routing Management: The most important core function in the ZigBee network functionality is the network routing management function, which supports multiple routing algorithms such as Cluster-Tree and AODV. When the network scale is large, ZigBee node devices also need to maintain routing tables.

3.1.4 Application Layer

The ZigBee application layer is located above the network layer and mainly includes three parts: APS, AF, and ZDO, namely the Application Support Sublayer, the Application Framework, and the ZigBee Device Object. The main function of the application support sublayer is binding and binding maintenance. The application framework provides a corresponding working environment for ZigBee objects. The ZigBee device object is mainly responsible for the role assignment of network nodes and network service management.

(1) APS provides service interfaces for the network layer and the application layer. This interface is a common service used by ZigBee device objects. This service is implemented through the APS Data Entity (APSDE) and the APS Management Entity (APSME). The APSDE and APSME provide corresponding data services and management services for the application support sublayer through the APSDE Service Access Point and the APSME Service Access Point.

(2) AF provides a working environment for ZigBee device objects. The ZigBee standard provides the option of using Application Profiles when developing applications. Profiles are a collection of descriptions of logical devices and their interfaces, and are conventions and guidelines for a specific application category.

(3) ZDO is located between the application framework and the application support sublayer, responsible for initializing the application support sublayer, network layer, and security specifications, specifying the role of devices in the network, device discovery, service discovery, binding management, etc.

3.2 ZigBee Network Device Types

Table 1 Functional description of ZigBee devices

Type	Topology	Function
FFD	Star Topology Mesh Topology Tree Topology	FFD node has abundant storage space to store routing information, has the function of data forwarding and routing, and has relatively strong control and processing ability. FFD can be used as a coordinator, router, or terminal device.
RFD	Star Topology	RFD has small memory space and low power consumption, and only undertakes data sending and receiving tasks in the network, without forwarding and routing functions. The RFD is used only as a terminal device.

The ZigBee standard employs a comprehensive set of technologies to achieve scalable, self-organizing, and self-healing wireless networks, capable of managing various data transmission modes.

ISSN 2616-5910 Vol. 6, Issue 1: 85-91, DOI: 10.25236/AJALS.2025.060112

To reduce system costs, the network, according to the IEEE 802.15.4 standard, defines two types of physical devices: Full-Function Device (FFD) and Reduced-Function Device (RFD). Table 1 provides a detailed description of the functions of these two physical devices.

Based on the IEEE 802.15.4 standard, the ZigBee network logically divides these two physical devices into three types of devices: the Coordinator, the Router, and the End Device.

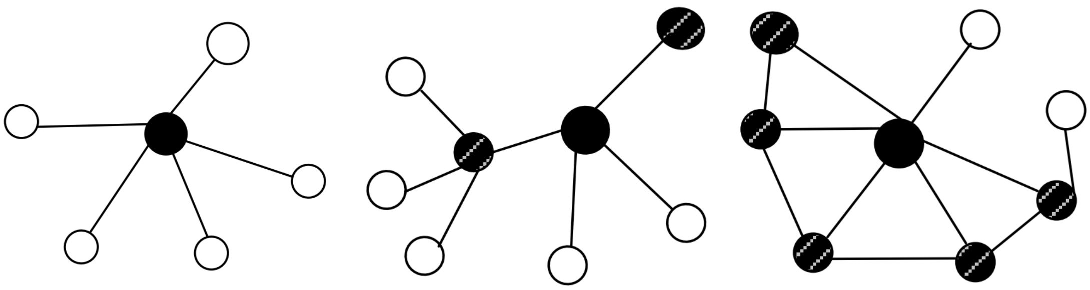
(1) ZigBee Coordinator: Responsible for establishing and maintaining the network. Due to the significant tasks and high resource requirements of the Coordinator, it can only be implemented by an FFD node, and there is only one Coordinator device in a network.

(2) ZigBee Router: Searches for and joins a network, and can also configure node addresses within the network. It also has the functions of initiating routing, network data routing, and repairing data packet routing paths. Multiple Routers are allowed in a ZigBee network. Because it needs to undertake data forwarding and routing functions, the ZigBee Router must also be a Full-Function Device.

(3) ZigBee End Device: Can only join an existing network and does not have the functions of data forwarding and routing; that is, it can only perform wireless data transmission and reception. The ZigBee End Device has relatively simple functions and undertakes fewer tasks in the ZigBee network. Its resource requirements are not very high, so the ZigBee End Device can be implemented by either an FFD node or an RFD node.

3.3 ZigBee Network Topology

The ZigBee network topology is defined by the network layer and primarily consists of three network types: star, tree, and mesh. Different network topologies correspond to different application areas, as illustrated in Figure 1.



(a) Star Topology (b) Tree Topology (c) Mesh Topology

Figure 1 ZigBee network topology structure diagram

(1) Star Topology

The star network topology is relatively simple, mainly composed of a coordinator and end devices, as shown in the left diagram of Figure 1. All device communication must be relayed through the coordinator; end nodes cannot communicate directly with each other. If an end device needs to send a data packet to another end device in the network, it must first send the packet to the coordinator, which then forwards the packet to the destination device.

(2) Tree Topology

The tree topology adds router devices to the network compared to the star topology. In this case, when a device needs to send data information to another device, the data will be transmitted upwards along the tree structure to the nearest router node. The router node is then responsible for forwarding the data information until it is sent to the destination node's parent node or the destination node itself. A diagram of the tree topology is shown in the middle of Figure 1. The main drawback of the tree structure is that nodes cannot communicate directly with each other and need to be forwarded through layers of parent nodes, preventing the optimization of communication routing paths.

(3) Mesh Topology

The mesh topology is very similar to the tree topology, but compared to the tree topology, the routing of the mesh topology is more flexible, and router nodes can communicate directly with each other without the need to forward information through parent nodes or coordinator nodes. Therefore, this network topology can more effectively complete information communication between nodes. Even if a routing path fails, information can still be communicated along other routing paths, providing self-

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organization and self-recovery capabilities. A diagram of the mesh topology is shown on the right in Figure 1. The mesh topology can also form very complex networks through "multi-hop" methods. If the coordinator in the network fails and cannot work normally, the routers in the network can compete to acquire the coordinator role and continue the network maintenance function. The intelligent monitoring system designed in this paper is for greenhouses. Considering the maintainability, reliability, and scalability of the system, the ZigBee network topology of this system adopts a tree topology.

4. Temperature Monitoring System Design

The greenhouse temperature monitoring system designed in this paper mainly consists of four parts: a ZigBee wireless sensor monitoring module, a ZigBee coordinator + GPRS wireless gateway communication module, a Web server, and a mobile phone monitoring client. The ZigBee wireless sensor monitoring module is primarily responsible for collecting and transmitting environmental data, and transmits the data to the ZigBee coordinator + GPRS wireless gateway communication module through the ZigBee wireless sensor network. The wireless gateway communication module is responsible for aggregating the data from the entire wireless sensor network and transmitting the data to a remote Web server. The Web server processes and stores the received data separately and supports real-time user queries. The specific functions of each part are as follows:

(1) ZigBee Wireless Sensor Monitoring Module: In the architecture of the intelligent greenhouse monitoring system designed in this paper, the ZigBee wireless sensor monitoring module is equivalent to the information perception layer in the Internet of Things (IoT). This module is mainly responsible for environmental data monitoring and equipment control tasks. The ZigBee wireless sensor monitoring module mainly completes the collection of internal environmental data information of the greenhouse through sensors (temperature sensor, humidity sensor, CO2 concentration sensor, light intensity sensor) arranged throughout the greenhouse, and uses the ZigBee wireless sensor network to realize wireless data uploading and control command receiving functions. To complete control tasks such as turning on and off equipment like supplementary lighting, ventilation fans, and sprinkler irrigation facilities, this module also needs to be able to accurately control the greenhouse equipment according to the control instructions sent by the gateway communication module.

(2) ZigBee Coordinator + GPRS Wireless Gateway Communication Module: The ZigBee coordinator + GPRS wireless gateway communication module is similar to the information transmission layer in the IoT. The ZigBee coordinator is the data aggregation center of the ZigBee wireless sensor network. The ZigBee coordinator uses the GPRS module to connect to the mobile internet and send the aggregated data to a remote Web server. Data communication between the ZigBee coordinator and the GPRS module is implemented through a serial port. The wireless gateway communication module mainly combines wireless communication technology and internet communication technology to realize the collection and long-distance transmission of agricultural greenhouse environmental data information.

(3) Web Server and Mobile Phone Monitoring Client: The Web server and mobile phone monitoring client are like the information application layer in the IoT, and are composed of a mobile APP and a PC. GPRS sends all environmental information data collected from the ZigBee sensor network to the Web server through the mobile network. The Web server's program parses and processes the information to facilitate user queries and use. Users can query the real-time environmental information inside the greenhouse by accessing the Web server or using the mobile phone monitoring client, and query the greenhouse environmental data change curve based on the historical environmental data stored on the server. In addition, when the user finds that the current environmental data information does not meet the optimal growth conditions for crops, control instructions can be sent to the corresponding ZigBee wireless sensor monitoring module through the Web server and mobile phone monitoring client to drive the corresponding control equipment to adjust environmental parameters. For example, when the user finds that the current light intensity in the greenhouse is low, which is not conducive to crop growth, they can send a command to the ZigBee wireless sensor monitoring module to turn on the supplementary lighting equipment through the mobile phone monitoring client or by accessing the Web server to ensure that the internal environment of the greenhouse is maintained in a state conducive to crop growth.

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5. Conclusion

This paper, with the background of wireless data acquisition and remote control in greenhouses, introduces the wireless sensing technology of the greenhouse monitoring system, mainly including two parts: key system technologies and the overall system design scheme. The key system technologies mainly introduce ZigBee wireless communication technology, which is the key technology of this system. The main content includes the ZigBee protocol architecture and the typical topology of the ZigBee network. The overall system design scheme starts with proposing system requirements and provides the overall design framework of the system based on the requirements analysis. The system is mainly composed of four parts: ZigBee wireless sensor monitoring module, ZigBee+GPRS wireless gateway communication module, Web server, and mobile phone monitoring client. They respectively complete the collection, transmission, and storage of greenhouse environmental data information, and support users to query online in real-time.

References

[1] He Jianqiang, Zhang Ying, Xu Xing. Research on intelligent agriculture monitoring and management System based on Internet of Things [J]. Hubei Agricultural Sciences, 2024,63(08):176-181+187.

[2] Zhang Chunmei, Quan Zhaofeng, Wu Shutian, et al. Design of intelligent agricultural environment monitoring system based on Internet of Things [J]. Electronic Production, 2024,32(15):37-40.

[3] Wang Dan, Yao Jingfa, Cui Xiuyan, et al. Design and implementation of smart agriculture monitoring System based on STM32 [J]. Electronic Products World, 2023,30(08):18-21+29.

[4] Huang Fuda, Chen Songqi, Tao Zhilin, et al. Design of intelligent agricultural monitoring linkage system based on Internet of Things [J]. Electronic Production, 2023,31(08):56-59.

[5] Ma K. Design of intelligent agriculture network monitoring system based on ZigBee [J]. Jiangsu Communications, 2021,37(05):85-88.

[6] Zhou B. Design of monitoring and control system for smart agricultural greenhouses based on Internet of Things [D]. Xidian University, 2023.

[7] HE Mian. Application of ZigBee technology in environmental monitoring system of smart agricultural greenhouse [J]. Rural Economy and Science and Technology, 2024,35(22):62-64.

[8] Song Junkang, Zang Xiang. Design of intelligent agricultural monitoring data transmission network based on ZigBee bearing ModBus-RTU [J]. Intelligent Computers and Applications, 2020, 10(07):247-249.