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Research Article

Grassland Ecological Protection Monitoring and Management Application Based on ZigBee Wireless Sensor Network

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Grassland plays a key role in human production and life, especially in the protection and improvement of the natural environment, which cannot be replaced by other ecosystems, such as maintaining water and soil, preventing wind and sand fixation, maintaining carbon balance, affecting climate change, and producing biological products,.. More importantly, contemporary society attaches great importance to the development of agriculture and animal husbandry. Protecting and nurturing grassland plants and animals, maintaining biodiversity, rational grazing, and maintaining the sustainable development of the grassland ecological environment have become the top priorities. In view of the current serious grassland degradation and the decline of livestock carrying capacity, this paper proposes a grassland environmental monitoring system based on the ZigBee wireless sensor network. The system consists of a grassland wireless monitoring network and a remote PC, which realizes real-time and remote monitoring of environmental information, such as air temperature and humidity, light intensity, and rainfall that affect the growth of grassland pastures. Based on the requirements of the agricultural field data monitoring system, the overall framework of the system was designed and built. The system mainly includes two parts: the ZigBee wireless sensor network subsystem and the remote management software subsystem, and data communication is realized between the two through the Ethernet system data exchange protocol. Among them, the ZigBee wireless sensor network subsystem is deployed in the grassland area and mainly realizes the functions of real-time collection, processing, and wireless transmission of grassland data. The remote management software subsystem is mainly used for data reception, storage, and display and can maintain communication with the gateway node to support real-time monitoring of grassland data by remote browsers.

1. Introduction

In recent years, people's unreasonable development and utilization of natural resources have become more and more serious in order to maximize benefits. Significant global changes in the environment and ecosystems that occur on the surface of the Earth affect the survival of mankind and the development of society all the time. However, grassland plays a key role in human production and life, especially in the protection and improvement of the natural environment, which cannot be replaced by other ecosystems, such as maintaining water and soil, preventing wind and sand, maintaining carbon balance, affecting climate change, producing organisms, products and so on. More importantly, contemporary society attaches great importance to the development of agriculture and animal husbandry. Protecting and nurturing grassland plants and animals, maintaining biodiversity, rational grazing, and maintaining the sustainable development of the grassland ecological environment have become the top priorities [1–9].

There are about 400 million hectares of grassland resources in my country, among which there are nearly 300 million hectares of grassland and more than 100 million hectares of grassy hills and grass slopes, accounting for about half of the agricultural land area. Grassland is a vital resource for human survival, especially in the vast semiarid and arid regions. Natural grassland is a very important renewable resource. It not only regulates the climate but also conserves water, purifies the air, alleviates floods, and prevents water and soil. Many effects, such as loss, provide the material basis for animal husbandry. This has become the consensus of the scientific and technological circles and the economic circles. However, from the 1960s to the present, due to the impact of global climate change, the rapid growth of our country's population and the increase in the intensity of people's business activities have led to serious degradation of our country's grasslands, severe decline in livestock carrying capacity, and various disasters repeatedly occurring. Therefore, timely understanding of grassland forage growth and grassland climate characteristics and research and analysis of the impact of grassland climate factors on the growth, development, and yield of grassland are essential for protecting the grassland ecological environment, grazing rationally, and scientifically grasping the laws of grassland climate change [10–15].

Early grassland data monitoring was mainly based on manual statistics and instrumentation monitoring. With the increase in demand for agricultural information services and with the maturity and popularization of modern information technologies such as embedded, wireless sensor networks, cloud computing, and the Internet of Things, agricultural informatization monitoring has been practically applied and widely popularized in the agricultural field. For example, in 2011, the well-known Texas Instruments semiconductor company in the United States and Qualcomm in-depth cooperation design an environmental monitoring system centered on wireless sensor networks. The system deploys a wireless sensor network for each greenhouse and collects environmental parameters such as air temperature, air humidity, air pressure, soil temperature, soil pH, light intensity, and carbon dioxide concentration through different sensor nodes in the network, so as to master the greenhouse. Environmental changes in the environment provide a scientific basis for the proper regulation of the greenhouse environment [16–20].

A wireless sensor network (WSN) is a multihop self-organizing network composed of a large number of sensor nodes with sensing capabilities and communication capabilities deployed in the monitoring area through wireless communication, and ZigBee is most suitable as the choice of the WSN wireless communication method, which has the advantages of low-power consumption, low cost, and low complexity. Therefore, in order to better monitor the dynamics of grassland climate change and promote the production of animal husbandry, this design proposes a grassland environmental monitoring program based on the ZigBee wireless sensor network to realize the impact on the climatic factors affecting the growth of grassland pastures, including air temperature, humidity, and light intensity.

ZigBee technology is a short-distance wireless communication technology with unified technical standards. Its PHY layer and MAC layer protocols are formulated by IEEE802.15.4, and the network layer is formulated by the ZigBee Technology Alliance. The development and application of the application layer are developed and utilized according to the needs of users. It is specially designed for applications with large network capacities, low transmission rates, small data volumes, and low-cost requirements. ZigBee technology mainly has the characteristics of low speed, low-power consumption, low cost, short delay, and high security. (l) Low rate: the data transmission rate of ZigBee technology is only 20–25ok b/s (2.4 G H z), 40 kb/s (9l SM H z), and 20 kb/s (868 M H z). The raw data throughput rate is mainly applicable to application scenarios where data are transmitted at a low rate. (2) Low power consumption: ZigBee nodes generally use batteries for power. (3) The ZigBee protocol is free of patent fees. The hardware cost of ZigBee network nodes can generally be controlled below 100 yuan [21–26].

Compared with several other wireless communication technologies, such as Wi-Fi and Bluetooth technology, ZigBee is characterized by its simplicity of application, long battery life, networking capability, high reliability, and low cost. ZigBee technology has the characteristics of a low data rate and a small communication range, which also determines that ZigBee technology is suitable for carrying services with small data traffic. Therefore, this article applies ZigBee technology to grassland environmental information monitoring, which has important research significance and market value [27–33].

2. ZigBee Wireless Sensor Technology

What this text adopts is the network structure, making the data communication more reliable. The ZigBee protocol is divided into the PHY layer, the MAC layer, the NWK layer, and the APL layer, from bottom to top. Different manufacturers have developed their own ZigBee protocol stacks for users according to the provisions of the ZigBee protocol. These protocol stacks are both open source and semiopen source. In the grassland monitoring system, we receive data from a certain sensor through the terminal of the monitoring system, and the data are abnormal. The maintenance personnel urgently need to know the location of the sensor; that is, a reliable positioning technology needs to be provided.

The positioning principle of the TOA algorithm is to approximate the prediction by recording the time-consuming signal transmission. As shown in Figure 1, the time to send a signal to the receiver at time T_0 is T_1, and then, the party receiving the signal will reply at T_2 and respond to a signal arriving at time *Ts*, through this "handshake" transmission and signal delay. The distance can be calculated approximately during the period, and the calculation formula is shown below:

$$d = \frac{(T_3 - T_0) - (T_2 - T_1)V}{2}, \tag{1}$$

where V represents the speed of signal transmission, and the main error is the time difference $(T_2 - T_x)$ in the time it takes for the receiver to process the signal. This algorithm has better positioning accuracy, but it has higher requirements

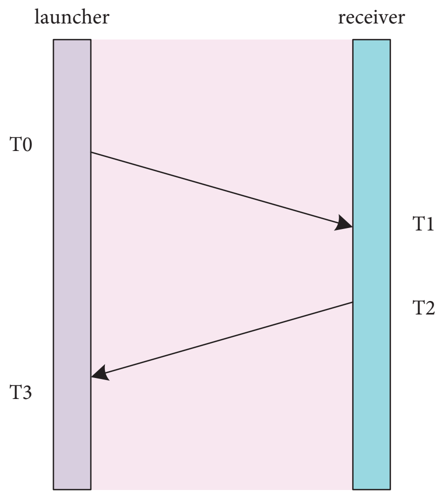

Figure 1: TOA algorithm.

for the clock of the hardware device. It is more difficult to find the distance, so it has higher requirements on the function of the sensor and the hardware.

The principle of the RSSI positioning algorithm is to know the transmitting power of the node. After the receiver receives the signal, it records the received power and then uses the formula to calculate the loss during the transmission. Finally, the propagation model is used to convert the loss into the required distance. The common shadowing model performs wireless signal transmission. The model formula is shown below:

$$p = p_0 + 10n \log_{10}\left(\frac{d}{d_0}\right) + \xi, \tag{2}$$

where P is the received signal strength, p_0 is the received signal strength when the distance is d_0, d_0 is the reference distance, n is the path loss index, which is affected by the environment and buildings, d is the true distance, and ξ is the unit of dB. The masking factor of its mean value is O, and the mean square error is a random variable of σdb(dB) i state. Since the shadowing model is a model established in an ideal state, in actual measurement, the formula below is usually used for calculation:

$$\text{RSSI} = -\left(10n \log_{10} d + A\right), \tag{3}$$

where RSSI is the measured signal strength, n is the signal transmission constant, d is the distance from the launch point, and A is the signal strength at lm from the launch point.

The positioning process of the DV-Hop algorithm can be divided into three stages: (1) record the number of hops from an unknown node to each known node and (2) record the actual jump distance between nodes. The estimated average actual distance per hop for each known node will be calculated based on the number of hops and location information between other known nodes recorded in the previous stage. The calculation method is shown in following equation:

$$\text{Hop size} = \frac{\sum_{j\neq 1}\sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}}{\sum_{j\neq 1} h_j}, \tag{4}$$

where (x_i, y_i) and (x_j, y_j) are the coordinates of known nodes i and j, respectively; the number of hops between nodes i and j is known as h_j. Then, use the number of hops on the record to approximate the distance to the known node. The calculation method is shown in following equation:

$$D_i = \text{hops} \times \text{Hopsize}_{\text{ave}}. \tag{5}$$

Assuming that the coordinates of the three base stations Al, $A2$, and $A3$ in Figure 2 are (x_1, y_1), (x_2, y_2), and (x_3, y_3), and the mobile node M (x, y) is the three circles of intersection. The distances from the mobile node M to the base stations $A1$, $A2$, and $A3$ are d_1, d_2, and d_3, respectively. Then, the following formula can be obtained:

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = d_1^2, \\ (x - x_2)^2 + (y - y_2)^2 = d_2^2, \\ (x - x_3)^2 + (y - y_3)^2 = d_3^2. \end{cases} \tag{6}$$

Subtracting the first two formulas from the third formula in the above formula, we obtain

$$\begin{aligned} &2(x_1 - x_3)x + 2(y_1 - y_3)y = x_1^2 - x_3^2 + y_1^2 - y_3^2 + d_3^2 - d_1^2, \\ &2(x_2 - x_3)x + 2(y_2 - y_3)y = x_2^2 - x_3^2 + y_2^2 - y_3^2 + d_3^2 - d_2^2. \end{aligned} \tag{7}$$

From this, the position coordinates of the mobile node M can be obtained as shown in the following formula:

$$\begin{bmatrix} x \\ y \end{bmatrix} = \frac{1}{2}\begin{bmatrix} x_1 - x_3 y_1 - y_3 \\ x_2 - x_3 y_2 - y_3 \end{bmatrix}^{-1}\begin{bmatrix} x_1^2 - x_3^2 + y_1^2 - y_3^2 + d_3^2 - d_1^2 \\ x_2^2 - x_3^2 + y_2^2 - y_3^2 + d_3^2 - d_1^2 \end{bmatrix}. \tag{8}$$

The hyperbolic positioning method is shown in the following formula, assuming that we can use a certain measurement method to calculate the distance between the moving node M and the base stations $S1$ and $S2$, where dl is 2 = d1. d2. The mathematical equation of the hyperbola is shown in the following formula:

$$\left|\text{MF}_1 - \text{MF}_2\right| = 2a, \tag{9}$$

where M is a point on the curve and $2a$ is the distance between the two focal points F_1 and F_2 on the two curves; we can conclude from the above formula that the position of node M is at the focal point where $S1$ and $S2$ are located. The sum on the hyperbola with two focal differences of dl, 2. Suppose that the coordinates of $S1$, $S2$, and $S3$ are (0, 0), (0, $y2$), and ($X3$, $y3$), and the coordinates of the mobile node M are (X, y):

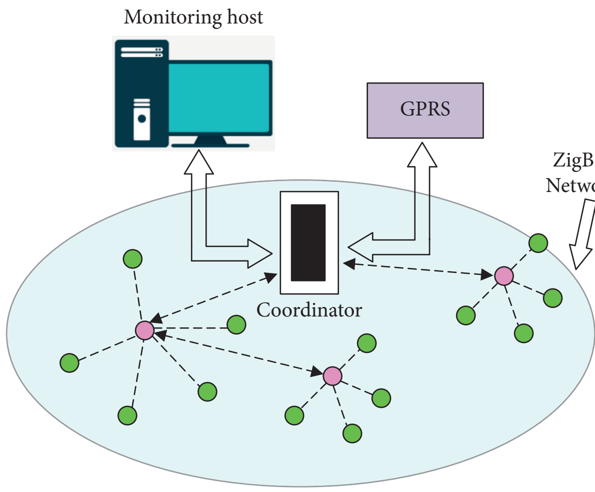

FIGURE 2: Entire environmental monitoring system.

$$\begin{cases} d_{1,2} = d_2 - d_1 = \sqrt{x^2 + (y - y_2)^2} - \sqrt{x^2 + y^2}, \\ d_{1,3} = d_3 - d_1 = \sqrt{(x - x_3)^2 + (y - y_3)^2} - \sqrt{x^2 + y^2}, \\ d_{2,3} = d_3 - d_2 = \sqrt{(x - x_3)^2 + (y - y_3)^2} - \sqrt{x^2 + (y - y_2)^2}. \end{cases} \tag{10}$$

After simplifying the above formula, we can obtain

$$\left[4d_{1,2}^2\left(b^2 + 1\right) - 4y_2^2\right]y^2 + \left[8\,\mathrm{abd}_{1,2}^2 + 4\left(y_2^2 - d_{1,2}^2 y_2\right)\right]y + \left[4a^2 d_{1,2}^2 - \left(y_2^2 - d_{1,2}\right)^2\right] = 0. \tag{11}$$

The nodes in the ZigBee network can be divided into two types according to their communication capabilities: full-featured devices (fun-function devices, FFDs) and reduced-function devices (reduced-function devices, RFDs).

(1) Full-featured device (FFD): a full-featured device has all the functions and characteristics specified in the ZigBee protocol, has sufficient computing power and storage capacity, can act as a coordinator and router in the network, and of course, can also be a terminal node work.

(2) Reduced-function equipment (RFE): reduced-function equipment has limited functions and can only work as a terminal node. Reduced-function equipment reduces the complexity and cost of nodes.

Both FFD devices and RFD devices can communicate together. RFD devices cannot communicate directly; they can only communicate with FFD devices and forward data through an FFD device. The full-function devices (FFD) and reduced-function devices (Xing D) mentioned above are divided according to the communication capabilities of the nodes. In fact, from the point of view of node functions, the ZigBee standard specifies three types of network nodes: coordinator (Coordinator), router (Router), and terminal node (End Device). The definitions of these three node types are as follows.

2.1. Coordinator (Coordinator). The coordinator is a full-function device (FFD). Regardless of the topology of the ZigBee network, there must be one and only one coordinator node in the network. The coordinator is the core of the entire network. The task of the coordinator at the network layer is to select the frequency channel used by the network, establish the network and allow other nodes to join the network, and provide information routing, security management, and other services. After the network is established and the initialization of the entire network is completed, the network can still work normally even if the coordinator node is closed.

2.2. Router (Router). The router is also a full-featured device (FFD). If the ZigBee network adopts a tree or star topology structure, you need to use a router of this type of node. The router node is responsible for data routing and forwarding functions. A ZigBee network can have multiple routers, and router nodes are the key components of the long-distance extension of the ZigBee network. The main functions of the router node are to send and receive the node's own information, forward data between nodes, and allow child nodes to join the network through it.

2.3. Terminal Equipment (End Device). The terminal device may be a reduced-function device (RFD). The main task of the terminal device node is to send and receive information. Usually, a terminal device node is powered by a battery, and when it is not in the data transceiver state, it is usually in a dormant state to save power. It should be noted that terminal nodes can neither forward information nor allow other nodes to join the network. The ZigBee standard stipulates that a single network can accommodate up to 6 5 53 5 nodes. All nodes of the ZigBee network belong to one of the three types of nodes. In fact, the three types of nodes represent the concept of the network layer. They determine the topology of the network.

The ZigBee protocol was formulated by the ZigBee Alliance and is based on IEEE802.15.4. Three types of devices are specified in the ZigBee protocol: a coordinator used to start and configure the network, a router that forwards messages to other devices, and a terminal node that can perform other functions and communicate with other nodes. The ZigBee network can realize the following three topological structures: star topology, tree topology, and mesh topology, as shown in Figure 3. The star topology is the simplest one; it includes a coordinator node and a series of terminal nodes. Each terminal node can only transmit data to the coordinator node. If it is necessary to communicate between two terminal nodes, the information must be forwarded through the coordinator node. The disadvantage of this topology is that there is only a single path for data routing between nodes, and the coordinator may become the bottleneck of the entire network, but its structure is simple. The tree topology includes a coordinator and a series of routers and terminal nodes. The coordinator connects a series of routers and terminal nodes, and the routers of its child nodes can also connect a series of routers and terminal

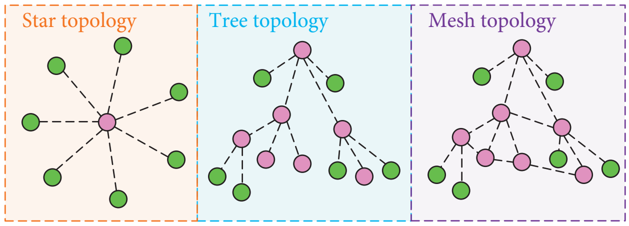

Figure 3: Three topological structures.

nodes so that multiple levels can be repeated. The structure of the tree topology is shown in Figure 3. Any two nodes can transmit data to each other, and the data can be transmitted directly or forwarded through multilevel routing during transmission. In the routing process, the network will automatically select a better routing path as the data transmission channel according to the ZigBee protocol algorithm to make the network more stable. Within the coverage of ZigBee wireless signals, the fewer the routing stages, the smaller the data transmission delay. The mesh topology is shown in Figure 3. The ZigBee protocol stack defines three network topologies: star, cluster tree, and mesh.

3. Structural Design of Grassland Monitoring System

There are about 400 million hectares of grassland resources in my country, among which there are nearly 300 million hectares of grassland and more than 100 million hectares of grassy hills and grass slopes, accounting for about half of the agricultural land area. Grassland is a vital resource for human survival, especially in the vast semiarid and arid regions. Natural grassland is a very important renewable resource. It not only regulates the climate but also conserves water, purifies the air, alleviates floods, and prevents water and soil. Many effects, such as loss, provide the material basis for animal husbandry. This has become the consensus of the scientific and technological circles and economic circles. However, from the 1960s to the present, due to the impact of global climate change, the rapid growth of our country's population and the increase in the intensity of people's business activities have led to the serious degradation of our country's grasslands, a severe decline in livestock carrying capacity, and various disasters repeatedly occurring. Therefore, timely understanding of grassland forage growth and grassland climate characteristics, research and analysis of the impact of grassland climate factors on the growth, development, and yield of grassland are essential for protecting the grassland ecological environment, grazing rationally, and scientifically grasping the laws of grassland climate change.

One of the most important factors that induce grassland degradation is climatic factors. Under severe weather conditions (such as drought and strong winds), grassland degradation can occur. The regional climate environment has caused a certain impact, which further deteriorates the meteorological conditions. Climatic conditions have a great influence on the growth and development of natural forage grasses. For example, air temperature and humidity are closely related to the growth and development of natural forage grasses, and they can only grow and develop at a suitable temperature; light intensity directly affects the photosynthetic capacity of natural forage grasses. Within the range of light intensity, the photosynthetic capacity increases with the increase of light intensity, but when the light intensity exceeds the saturation point, it will cause photoinhibition and cause physiological obstacles to the forage; precipitation has a great influence on the level of forage yield. If the rainfall is sufficient, the forage yield will be high, and vice versa, the forage yield will be low, and the rainfall will affect the height of the forage growth. The predicted value is shown in Figure 4.

The entire environmental monitoring system is composed of a monitoring host and a ZigBee network, as shown in Figure 2. This is a hierarchical network structure, with sensor terminal devices at the bottom, and routers, coordinators, and monitoring hosts in the ascending order. The monitoring host is a computer used to display environmental monitoring data and send commands to the network. The ZigBee network is responsible for the collection of environmental data. It consists of a ZigBee coordinator, a ZigBee router, and ZigBee terminal equipment. The ZigBee coordinator is responsible for initiating the network and managing and maintaining it, including allocating network addresses for newly added devices, joining and leaving nodes, distributing and updating of network security keys, and uploading the collected data to the monitoring host or sending the command to the monitoring host on the network. The prediction is shown in Figure 5.

There are two ways to connect the ZigBee network and the monitoring host. Normally, the coordinator and the monitoring host can be directly connected through the serial port for data communication. When it is not convenient for the monitoring host to be used on site for a long time, you can connect the coordinator to GPRS and send data to the monitoring host connected to the GPRS receiving device through GPRS.

The monitoring host needs to monitor the working status and health of the sensor node, display the source address of all data, the data collected by the sensor, and the changing trend of the data and adjust the task of the node accordingly. The health status of the node includes the remaining energy, the working status of the sensors, and the communication components. By monitoring the sensor status, the working cycle of sensor nodes can be adjusted in time and tasks can be redistributed, thereby avoiding premature failure of nodes and extending the lifetime of the entire network. At present, the remaining energy information of the node is mainly judged by the operating voltage of the node. If the voltage value is too low, the reliability of the sensor data read by the node is also greatly reduced. There is a voltage alarm in the monitoring center. Once the voltage of a node is too low, it will prompt to replace the battery. The amplitude vs. distance is shown in Figure 6.

The node hardware design adopts a modular design idea. The sensor node and coordinator node are designed with TI's CC2530 chip as the core. The node structure mainly

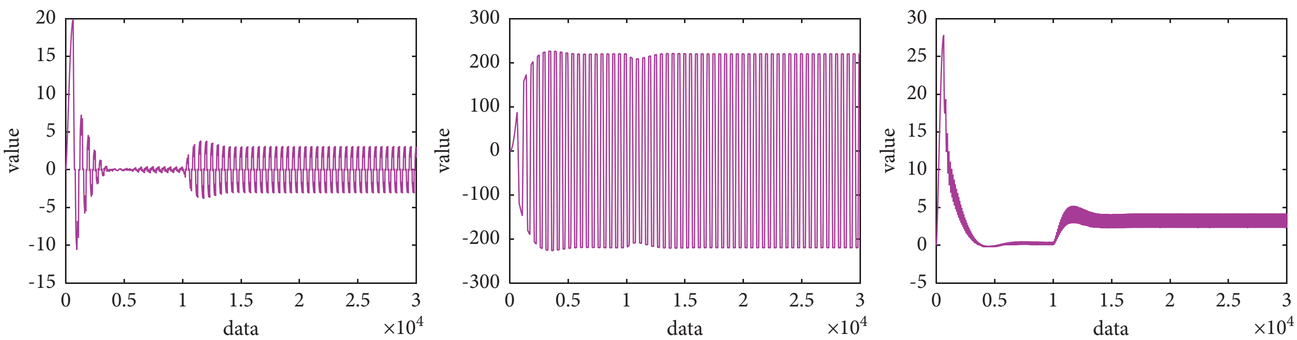

Figure 4: Predicted value.

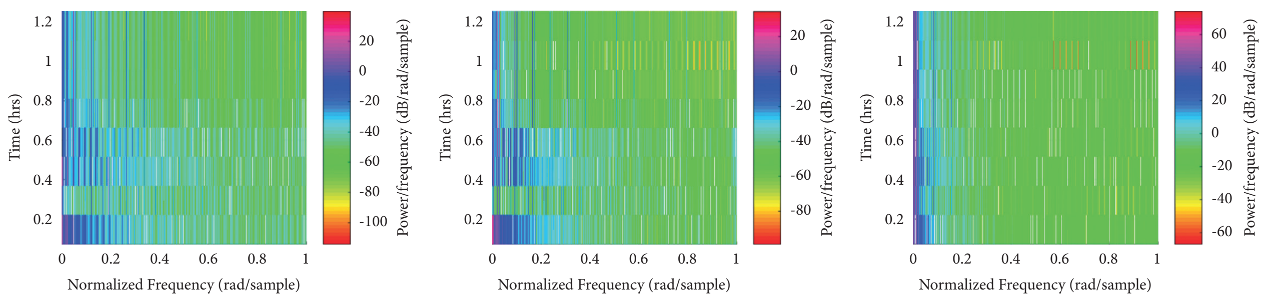

Figure 5: Prediction.

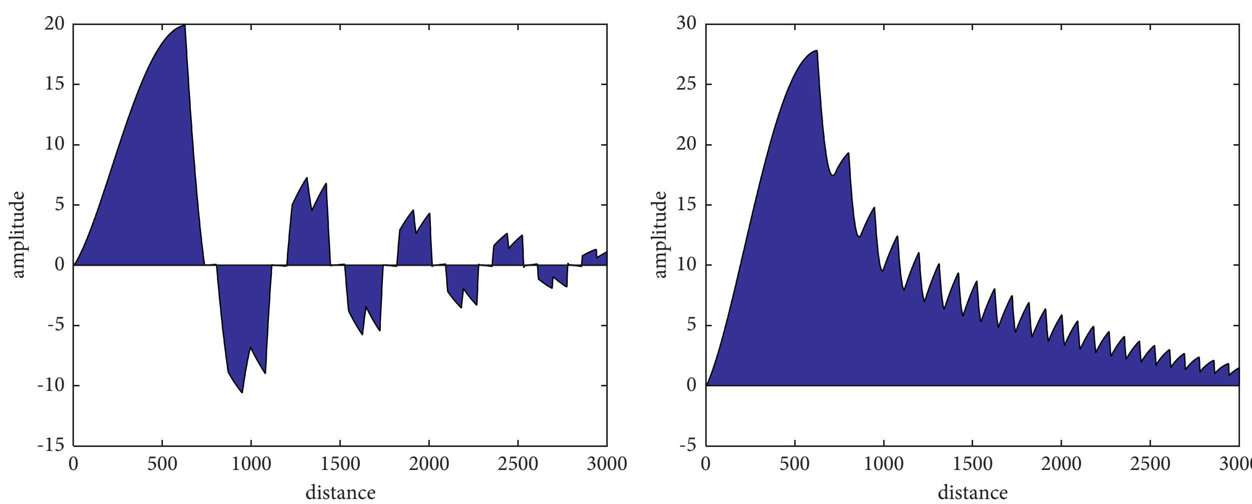

Figure 6: Amplitude vs. distance.

includes a processor and wireless communication module, a sensor module (sensor node only), a solar power module, and a GPRS module (coordinator node only). In response to the design requirements of the grassland environmental monitoring system, based on the ZigBee wireless sensor network technology, a grassland environmental monitoring system was constructed, which is composed of a ZigBee monitoring network and a remote monitoring PC. This design uses a star network topology, as shown in Figure 3. The ZigBee monitoring network includes sensor nodes and coordinator nodes. The sensor node completes the parameters such as air temperature, humidity, illuminance, and rainfall of the natural grassland growth environment and periodically sends the collected information to the coordinator node through the ZigBee monitoring network; the coordinator node realizes the establishment of a ZigBee network, assigns network addresses, sends the network response and other functions, and completes the communication with the monitoring PC at the same time; the monitoring PC is used to display and store the grassland environmental information so that the manager can analyze the climatic factors that affect the growth and development of the grassland natural pasture and is used to regulate and manage the natural pasture.

This module uses the CC2530 chip introduced by TI. It is a new generation system-on-chip solution. It integrates a

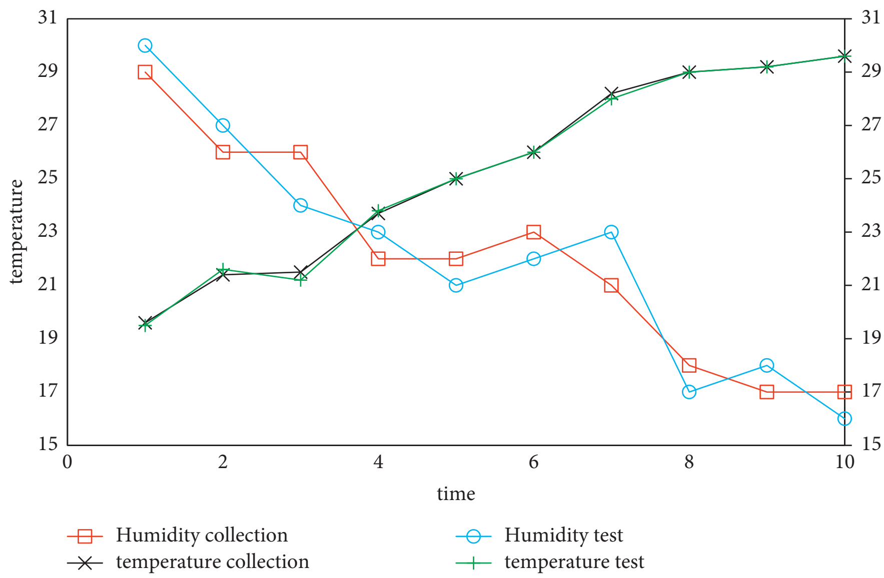

Figure 7: Comparison of air temperature and humidity results.

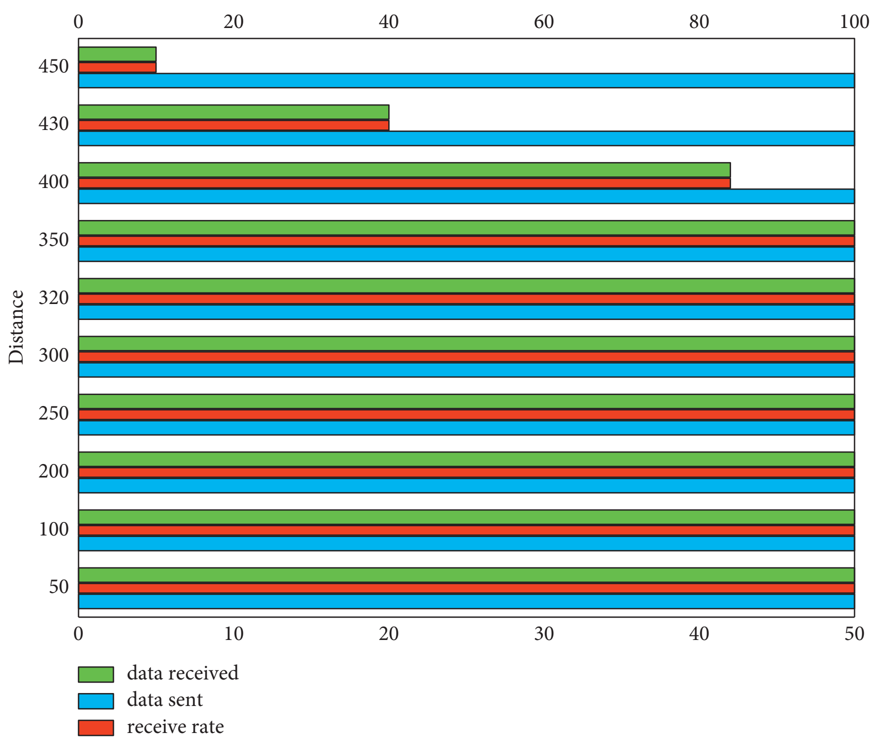

Figure 8: Effect of distance.

low-power 8051 microprocessor and a high-performance RF transceiver. The working frequency band is 2.4 GHz ISM (Industrial Scientific Medical). It supports wide voltage power supply range of 2 V ~3.6 V, and the working environment temperature is −40°C~125°C. It supports five working modes: receiving, sending, sleep, etc., and the conversion time is short. In sending and receiving modes, the current consumption is 29 mA and 24 mA, respectively. The current in the mode is only 0.4 μA, which meets the design requirements of ultralow-power consumption. Because CC2530 has low-power consumption, small package, simple hardware design, and internal integration of some commonly used functional modules, it has been widely used in WSN (wireless sensor network). The comparison of air temperature and humidity results is shown in Figure 7.

The GPRS module uses Siemens' MC39i module. This module has high stability and high cost performance. It works on EGSM900 and GSM1800 dual frequency. It provides digital, short message, voice, and fax. It supports GPRS multislot Class10 and AT command programming.

ZIF is used by users to provide interfaces such as RS-232, SIM card, and voice, which have the advantages of low-power consumption and a simple interface. The MC39i module is connected to the coordinator node through the serial port, so as to realize the long-distance transmission of data in the ZigBee monitoring network.

The system software includes three parts: the coordinator node, sensor node, and monitoring center. The coordinator node is the core of the entire ZigBee network. It is mainly responsible for establishing the network, allowing nodes to join the network, and assigning short addresses. Power on the coordinator first, and then, initialize it, including system initialization and task initialization. Then, scan and configure an appropriate channel to establish a ZigBee network. When a node requests to join the network, the coordinator assigns a short address to it and automatically enters the binding permission mode to respond to the binding request of the node. After the binding is successful, the coordinator node receives the data transmitted from the routing node and the sensor node and transmits it to the remote monitoring PC through the GPRS network.

The sensor node is mainly responsible for collecting grassland environmental information and sending it to the routing node or the coordinator node. After the node is powered on, it first initializes, scans the channel, and requests to join the existing ZigBee network. Then, after joining the network successfully, request binding is carried out. If the binding is successful, start collecting data and send the data to the routing node or coordinator node. Then, switch to low-power consumption mode and timing; if the time is up, continue to collect data.

The monitoring center uses Kingview from Beijing Yakong company 6.55. The software has a wealth of function controls and galleries, which can quickly complete the user interface. The monitoring software mainly includes real-time data curve display, alarm setting, and historical data queries. Among them, the real-time display of air temperature, humidity, light intensity, and rainfall is realized on the Kingview interface, and the Kingview is connected with a SQL server to realize data queries. The effect of distance is shown in Figure 8.

4. Conclusion

In this design, three types of sensors, digital, analog, and switch, are integrated into the ZigBee network, including the soil environment measurement part and the small space weather station part, which are, respectively, assigned to soil temperature sensors, soil moisture sensors, air temperature and humidity sensors, and rainfall sensors, wind speed sensors, wind direction sensors, and illuminance sensors. Experiments show that these sensors are suitable for application in grassland environmental monitoring and can ensure high accuracy.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

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