Design and Implementation of LoRa-Based Wireless Sensor Network with Embedded System for Smart Agricultural Recycling Rapid Processing Factory

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SUMMARY In this paper, the effective Long Range (LoRa) based wireless sensor network is designed and implemented to provide the remote data sensing functions for the planned smart agricultural recycling rapid processing factory. The proposed wireless sensor network transmits the sensing data from various sensors, which measure the values of moisture, viscosity, pH, and electrical conductivity of agricultural organic wastes for the production and circulation of organic fertilizers. In the proposed wireless sensor network design, the LoRa transceiver module is used to provide data transmission functions at the sensor node, and the embedded platform by Raspberry Pi module is applied to support the gateway function. To design the cloud data server, the MySQL methodology is applied for the database management system with Apache software. The proposed wireless sensor network for data communication between the sensor node and the gateway supports a simple one-way data transmission scheme and three half-duplex two-way data communication schemes. By experiments, for the one-way data transmission scheme under the condition of sending one packet data every five seconds, the packet data loss rate approaches 0% when 1000 packet data is transmitted. For the proposed two-way data communication schemes, under the condition of sending one packet data every thirty seconds, the average packet data loss rates without and with the data-received confirmation at the gateway side can be 3.7% and 0%, respectively.

key words: IoT, LoRa, wireless sensor network, smart manufacture for smart agriculture, embedded system

1. Introduction

Development of agriculture is one of the most important parts for any country's economic requirement, and the Internet of Things (IoT) based network, which is composed of various sensor nodes for monitoring soil acidity, temperature, and other variables, has been broadly adopted for the smart-manufacturing based agriculture related fields. In [1], to control food quality and quantity, the IoT and sensor node based technologies were beneficial to promote smart agriculture, urban farming, agriculture robots, automation, and future food expectation, etc. In [2], the researchers developed a smart agriculture system which utilizes Arduino, IoT, and wireless sensor network to improve yield of the efficient crops. The system had a duplex communication link by a cellular-Internet interface that permit for data

inspection and irrigation scheduling. In [3], the design included smart GPS based remote controlled robot to perform many agriculture tasks, and all of the operations were connected by the sensor modules, the Wi-Fi/ZigBee modules, the actuators combined with the Micro Control Unit (MCU) and Raspberry Pi platform. In [4], the system was developed with many sensor nodes based components, which included water level, soil moisture, temperature, humidity, and rain sensors, and the LoRa based technology is used for the data transmission module. In [5], the IoT based technology supported crop management, resource management, crop monitoring and field monitoring, etc. The IoT based sensors used in proposed design were temperature sensor, soil pH sensor, soil moisture sensor, humidity sensor, water volume sensor, etc.

Besides, the smart manufacturing technologies combined with IoT and big data analysis were applied to improve the production performance of smart agriculture related domains. In [6], the researchers reviewed the IoT related technologies and systems which are the foundations of data-driven innovations for smart manufacturing, and the evolution of IoT based networks connected many manufacturing things, which included materials, sensors, equipment, people, products, and supply chain to emerge the effective cloud computing architecture. The time-sensitive properties of sensing data generated the challenges of the real-time collection, processing, and decision making. In [7], the proposed design described how the adoption of IoT in manufacturing by considering sensor based systems and mobile devices to generate industrial big data. In [8], the effective and smart factory solution was proposed to verify the real factory environment by the NB-IoT based network to get the economical implementation. For the smart agriculture related applications, in [9], the effective IoT applications with the LoRa based wireless sensor network designs were introduced, and the IoT technology was utilized to monitor the condition of air quality levels, which contains temperature, air humidity, CO, and CO₂. The system used ATmega328P-AU as a controller, and employed the LoRa module for data transmission, and applied Antares to be a cloud service for data storage. In [10], the real-time LoRa based standalone air quality monitoring system was developed to remotely measure PM 2.5, carbon monoxide, carbon dioxide, temperature, humidity, and air pressure. The data from different

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sensors were collected and transmitted by the low power and ARM based Raspberry Pi platform. In [11], the LoRa-based private networks were built for IoT applications, and the improved LoRa protocol removed the defects of the existing LoRaWAN for various applications. In [12], the design architecture used a fully functional LoRa based IoT system, and the proposed system provided services for a local application field by utilizing end devices with a LoRa transceiver, a LoRa based gateway, and a cloud server.

To reveal the differences between the proposed scheme and the existing LoRa-based studies, compared with the existing LoRa-based designs in [9] and [10], the proposed system provides both one-way and two-way data transmission scheme to transmit sensing data depending on different properties and importance of data. In [11], the authors were focused on studying the protocol problems and developed a modified LoRa protocol, which could conquer the shortcomings of the existing LoRaWAN system. In [12], this design used the similar communication infrastructure as our proposed design; however, since the used gateway platform must act both of the functions for gateway and network server, the cost of the gateway side in [12] is higher in comparison with our low-cost Raspberry Pi based gateway design.

To sustain the recycling rapid processing of agricultural organic wastes for achieving smart manufacture by the IoT based technology, the contribution of this paper is that the effective LoRa based wireless sensor network is designed and constructed to support the remote data sensing functions for the state-of-the-art and smart-manufacturing based smart agricultural recycling rapid processing factory. The rest of the paper is described as follows. In Sect. 2, the background of the smart agricultural recycling rapid processing factory is briefly reviewed, and the LoRa-based wireless sensor network is introduced to develop the proposed application. In Sect. 3, the proposed sensor node design, the used measurement devices at sensor node, the proposed gateway design, and the proposed data communication schemes are described. In Sect. 4, the experimental results are revealed, and the comparisons among different related designs are discussed. Finally, a conclusion is given.

2. Background of This Work

In this section, firstly, the smart agricultural recycling rapid processing factory is briefly introduced for the application field of IoT based design. Next, the effective LoRa-based wireless sensor network will be present to engage and reveal the proposed system design.

2.1 Smart Agricultural Recycling Rapid Processing Factory [13]

Organic fertilizer, which is made from organic waste and manure, is the most important fertilizer for sustainable agriculture. Due to lots of organic wastes and the processing difficulties, the traditional composting process needs a wide

Fig. 1 Architecture of the smart agricultural recycling rapid processing factory.

zone for stacks, and it is time-consuming for several months, and then the exposure process causes public health issue, which is not suitable for direct contact with persons. Besides, the traditional process lets to the pollution of environmental problems. Until now, for the rapid process of organic wastes, the previous researches lack to focus on solving such the issue with smart and intelligent technologies. From the view point of smart agricultural circular economy, the project [13] starts to develop an innovative technology to rapidly process organic wastes to produce organic fertilizer. Figure 1 illustrates the architecture of the developing smart agricultural recycling rapid processing factory. The developed technologies in the project include: automatic detection and classification of organic wastes, wireless sensor network for smart database applications, expert system, and integration of judgment processing with intelligent hardware and software to produce high-quality organic fertilizer. The developed smart hardware and software technologies export the whole factory and promote the utilization of enzymes to enhance the agricultural productivity, and the developed technologies in [13] will effectively solve the issue troubled global human many years to process organic wastes for environment protection.

The characteristics of different organic wastes, such as pH value, conductivity value, hardness, thickness, moisture content, nutrient content, temperature, etc. are very different, and then the optimal types and proportions of the microbial enzymes used for treatment are also different. In the processing flow of the agricultural recycling rapid processing factory, the organic waste sensors are the key components developed by sensing the characteristics and properties of the specific identification of organic wastes.

In Fig. 1, after the classification process, the crushed agricultural organic wastes are fed into the storage tanks for the preparing process. For instance, the mixed material in the storage tank A is muddy type and the moisture is larger than 90%, that in the storage tank B is dry type and the moisture is less than 30%, or that in the storage tank C is wet coarse type and the moisture is ranged from 30% to 90%, etc. By the wireless sensor network combined with intelligent sensors, the measurement data of agricultural organic wastes, such as moisture, viscosity, pH, electrical

conductivity, etc. must be obtained frequently in the storage tanks. Generally, the moisture data of agricultural organic wastes is one of the important references for manufacturing organic fertilizer. To frequently measure the important properties of the mixed material in the storage tanks, the one-way data transmission scheme, which performs a high frequency of sending the sensing data and has a low data package loss rate, can be a suitable choice. In Sect. 3.3, the simple one-way data transmission scheme is designed for this data sensing and transmission condition. When the important properties of the mixed material in the storage tanks are measured by the sensor nodes and transmitted to the gateway side, the mixed material will be fed into the reaction tanks for the following process.

For the continuous process, the server side needs to judge the optimal ratio of agricultural organic waste materials inputted from the different storage tanks, and decides the correct dosage of microbial enzymes added in the reaction tank. According to the databases, the server side provides the optimal ratio of microbial enzymes required for the rapid treatment of organic waste materials to organic fertilizer. To provide the measurement data, such as the pH value and electrical conductivity, from sensors in the reaction tanks, the two-way data communication scheme, which performs a middle frequency of sending the sensing data and has an acceptable low data package loss rate, can be a suitable selection. In Sect. 3.4, the two-way data communication scheme Ver. A2 scheme is designed for the data sensing and transmission condition.

In Fig. 1, at the final customized organic fertilizer manufacturing process, based on the national fertilizer management regulations, it is necessary to analyze the effective and important components of agricultural organic fertilizer products for each batch of products, such as: pH value, electrical conductivity value, nitrogen, phosphoric anhydride, organic matter, etc. For this application situation, the two-way data communication scheme, which provides a low frequency of sending the sensing data and has a very low data package loss rate, can be selected for the utilization. Besides, the on/off statuses of gas/power switches in the factory are monitored and transmitted by this transmission scheme. In Sect. 3.4, the two-way data communication scheme Ver. B scheme is designed to apply for this crucial data sensing and transmission condition.

By using the proposed LoRa-based one-way and two-way data transmission schemes, the rapid processing factory utilizes these sensing data to analyze the properties of agricultural recycles and find efficient processing procedure to improve the fabrication of organic fertilizers intelligently.

2.2 The LoRa-Based Wireless Sensor Network

Recently, the low-power wide-area network (LPWAN) [14] has been a well-known wireless telecommunication wide area network planned to permit the long standby time and long-range data communications at a low bit rate among many things. The LPWAN technology can be applied to

Fig. 2 System architecture of the proposed wireless sensor network.

Fig. 3 Architecture diagram of the LoRa-based node design.

Fig. 4 Architecture diagram of the LoRa-based gateway design.

establish a private wireless sensor network in the application field without spending in the gateway technique. used for building the LPWAN system. In the LPWAN based design, the LoRa-based [15]–[17] technology uses the unlicensed wireless band and can easily build the private network for the specific application field, in this work, the LoRa-based wireless sensor network is selected to support the data transmission function for the smart agricultural recycling rapid processing factory. Figure 2 shows the system architecture of the proposed wireless sensor network design. In [15], [16], the packet data in the LoRa system are divided into three parts: the preamble, the optional header, and data payload. Figure 3 depicts the architecture diagram of the LoRa-based node design in the proposed system. At the node side, the wireless LoRa transceiver module is controlled by a MCU-based processor. In general, firstly the LoRa transceiver module receives a request command from the gateway side, and the sensing data from several measurement instruments are forwarded to the MCU-based processor by the RS232 interface, and then the LoRa transceiver module sends out the sensing data to the gateway. On the other side, Fig. 4 shows the architecture diagram of the LoRa-based gateway design in the proposed system. In general, firstly the wireless LoRa transceiver module sends a request command to the sensor node, and

the sensing data will be received at the gateway after a little delay time, and then the received data is forwarded to the CPU-based embedded platform and the cloud server for further data management and analysis. The details of design and implementation of the proposed sensor node and the gateway side are described in the following section.

3. The Proposed LoRa-Based Wireless Sensor Network Design

3.1 Sensor Node Design with the LoRa Transceiver Module

In Fig. 5, the LoRa-based RYLR896 [18], [19] transceiver module provides long range data transmission and high interference immunity while minimizing power consumption. Table 1 lists the some specification of the applied RYLR896 LoRa transceiver module. At the sensor node, the probes are used to measure the moisture, viscosity, pH, and electrical conductivity of each sample, and all of these sensing data are forwarded to the MCU processor in the RYLR896 LoRa transceiver module via the RS-232 serial transmission by using the Arduino UNO board [20], where the Arduino UNO module provides the signal transfer interface from RS-232 to TTL level. Then the LoRa transceiver module is applied to send the sensing data to the gateway side. When the data transmission is active, the system must be designed to reduce and avoid packet data collisions. During data communication procedures, the sensor node listens for the gateway's command. When the sensor node receives the command, it starts to collect the sensing data through the probes and sends the data back to the processor via the RS-232 interface. After collecting the sensing data, the MCU

Fig. 5 Sensor node design in the proposed system.

Table 1 The specification of the applied RYLR896 LoRa transceiver module [18], [19].

Item	Min.	Typical	Max.	Unit
VDD Power Supply	2	3.3	3.6	V
RF Sensitivity	-148	N/A	N/A	dBm
Frequency Range	862	869/915	1020	MHz
Frequency Accuracy	N/A	±2	N/A	ppm
Communication Range	N/A	4.5	15	kM
Weight	N/A	7	N/A	g
Operating Temperature	-40	25	+85	Celsius

processor in RYLR896 performs the data processing to capture the key data (e.g., electrical conductivity data, including time stamps, electrical conductivity value, temperature and channel information), which reduces packet data size and further decreases transmission time for data transmission operation in the used LoRa transceiver module.

Figure 5 also depicts the sensor node design, which includes the moisture meter, viscometer, and multi-parameter analyzer used in the proposed system. Besides, all of the moisture meter, viscometer, and multi-parameter analyzer send out the sensing data to the Arduino UNO module via the RS-232 interface. The used moisture meter with the model, i.e. MS-7002 [21], provides 6 % to 40% moisture range on wood, and 0 to 100% relative moisture value for concrete and other non-wood materials. The used viscometer with the model, i.e. VM-10A-M [22], provides the measuring range from 10 to 5000 Pascal-second (Pa·s), and its measuring accuracy is ±5%. Figure 6 demonstrates the functional verification of sensor node by using the viscometer. The applied multi-parameter analyzer with the model, i.e. C3010 [23], provides the measurement data of both pH value and electrical conductivity. For pH measurement, the range is from -2 to +16pH, and the measuring resolution is ranged from 0.001pH to 0.1pH. For electrical conductivity measurement, the electrode permits to measure from 0.01 μ S/cm to 200 mS/cm in five ranges.

The AT Commands is invented by Hayes company [24] and it has become the standard command language for most modems on the market. Each command starts with "AT". Table 2 lists the utilized AT commands with the applied RYLR896 LoRa transceiver module. The process of AT Commands is that it uses the monitoring serial port to issue commands and control the modem modules or perform functions. Different AT commands are used for the analysis, judgment, and handling corresponding processes. Then the final result is returned to the monitoring software. Besides sending some specific information for actions, the AT commands can be used to adjust the parameters of modules to a state that meets some requirements. For example: To use this AT Command for sending the message from the module with Address 50 at the sending side to the receiving module with Address 1. The sender uses the AT Commands, i.e. "AT+SEND=1, 5, HELLO", and the receiver will receive the message, "+RCV=50, 5, HELLO, -99, 40". The message sent by the sender is that it sends "HELLO" data to the

Fig. 6 Functional verification of the sensor node with the viscometer.

Table 2 The utilized AT commands with the RYLR896 LoRa transceiver module [24].

Commands	Reply	Meaning of the corresponding command
AT	+OK	Test module
AT+RESET	+RESET	Reset the system
AT+MODE	+OK	Set wireless mode
AT+IPR	+OK	Set the Baud Rate of the UART interface
AT+BAND	+OK	Set the center frequency of the wireless band
AT+ADDRESS	+OK	Set the address of Lora module
AT+NETWORKID	+OK	Set Network ID
AT+SEND	+OK	Use Command Mode to send data to the specified address
+RCV	+OK	Prompt to receive the information

Table 3 The utilized AT commands to transmit sensing data.

AT Commands sent from gateway	Received command message at nodes	Meaning
AT+SEND=50,2,H	+RCV=5,2,H	Request moisture data
AT+SEND=50,2,V	+RCV=5,2,V	Request viscosity data
AT+SEND=50,2,P	+RCV=5,2,P	Request pH value
AT+SEND=50,2,C	+RCV=5,2,C	Request conductivity data

LoRa transceiver module with Address 1, and the message length is 5 bytes. The information received by the receiving end is a “HELLO” message from the module with Address 50, and the data length is 5 bytes. The received signal strength (RSSI) is -99, and the signal-to-noise ratio (SNR) is 40. Table 3 reveals the utilized AT Commands to transmit sensing data in the proposed system design.

To enable the wireless data transmission functions, the initial and detailed transmission control schemes are listed as follows:

- Step 1: Firstly, we use AT Commands to set the Address ID of the sender and receiver. For example, the parameters used in this work are AT+ADDRESS=50 for the sender, and AT+ADDRESS=5 for the receiver.
- Step 2: Then set the network communication group ID in the chip, and the parameter used in this work is AT+NETWORKID=6.
- Step 3: Set the center frequency of the LoRa wireless terminal, and the parameter used in the work is AT+BAND=915 MHz.
- Step 4: Set the RF wireless communication parameters. When setting the RF wireless communication parameters, the receiving end and the sending end must have the same frequency to allow both sides to communicate with each other. The used AT Commands is: AT+PARAMETER=<Spreading Factor>, <Bandwidth>, <Coding

Fig. 7 The proposed gateway design with Raspberry Pi module.**Table 4** The specification of the applied Raspberry Pi 3 model b+ [25].

SoC	Broadcom BCM2387B0 chipset
CPU	1.4GHz Quad-Core ARM Cortex-A53 (64Bit)
GPU	Dual Core VideoCore IV Multimedia Co-Processor; Provides Open GL ES 2.0; Hardware-accelerated OpenVG; 1080p30 H.264 high-profile decode
Memory size	1GB LPDDR2 (shared with GPU)
USB	USB 2.0 x 4
Ethernet	Gigabit Ethernet over USB 2.0 (maximum throughput 300Mbps)
Wireless	2.4GHz and 5GHz IEEE802.11.b/g/n/ac wireless LAN
Bluetooth	Bluetooth 4.2; Bluetooth Low Energy (BLE)
Operation system	Linux

Rate>, <Programmed Preamble>. The parameters used in this work are AT+PARAMETER=10, 7, 1, 7.

- Step 5: Set the sending and receiving ends to send data, and send it to the specified Address.

3.2 Wireless Gateway Design with Raspberry Pi Embedded Platform

Figure 7 depicts the proposed gateway design with the Raspberry Pi 3 model b+ platform, and the platform is used to perform the main functions of the gateway. Table 4 lists the specification of the applied Raspberry Pi 3 model b+ platform [25]. To provide the wireless data communication function at the gateway design, the LoRa RYLR896 transceiver module is applied to receive the data from the sensor nodes, and it also sends the request command to the sensor nodes. Besides, the Cp2012 module [26] is used as the bridge interface to connect and convert between the Raspberry Pi module model b+ platform with USB signal and the RYLR896 LoRa transceiver module with Transistor-Transistor Logic (TTL) signal. Figure 7 illustrates the bi-directional data flow between the LoRa transceiver module and Raspberry Pi 3 model b+ platform via the USB-to-TTL signal conversion interface by the Cp2012 chip module.

Fig. 8 The LoRa-based one-way transmission scheme.

For the two-way communication scheme, firstly the gateway broadcasts the query commands through the LoRa transceiver module to the sensor nodes. Next, when the sensor node receives the request commands, it starts to collect sensing data, and then sends sensing data via their LoRa transceiver modules to the gateway. At the gateway side, the Python-based tool is applied to get the data from the COM port, and then the gateway checks the completeness of the received packet data. Finally, the restructured data is transferred to the MySQL [27] database through WiFi.

3.3 The Applied One-Way Data Transmission Scheme

Figure 8 depicts the simple one-way transmission scheme used in the proposed system. In the one-way transmission mode, the gateway side does not need to send the command of data request to the sensor node. At the sensor node shown in Fig. 5, through experiments, when the Arduino UNO module is the transmitter, it takes about 4 seconds to receive the data message for the Raspberry Pi based gateway. Because it takes about 4 seconds to send data from the sensor node to the gateway end, if a data package is sent every 2 seconds, because the time interval of transmitting the data package is not long enough, it will cause the packet collision. Thus, the sensor node initiative sends the packet data to the gateway every a suitable time interval, which can be ranged from 5 to 8 seconds. Then the gateway will receive the data with the same time interval when the sensing messages are required in the factory.

3.4 The Proposed Half-Duplex Two-Way Data Communication Schemes

Three half-duplex two-way communication schemes are developed in this work, where the Ver. A1 and Ver. A2 schemes do not use the function of data-received confirmation at the gateway, and only the Ver. B scheme adds the data-received confirmation function for transmitting the vital sensing data to the gateway side. In Fig. 9, the diagram depicts the LoRa-based half-duplex two-way protocol actions between the gateway and a node during bidirectional transmission. The sequences of the protocol flow used in

Fig. 9 The proposed LoRa-based two-way communication scheme.

Fig. 10 The two-way communication flow with the proposed Ver. A1 scheme at the gateway side.

the Ver. A1 and Ver. A2 schemes are briefly described as follows:

- Step 1: The gateway side sends the command to the sensor node for data request.
- Step 2: Compare the content of command at the sensor node.
- Step 3: Collect the sensing data at the node side according to the command content, and then the node sends back the data to the gateway side.

Figure 10 illustrates the two-way communication flow with the proposed Ver. A1 scheme at the gateway side. For the proposed Ver. A1 scheme, when the gateway sends the command of requesting moisture to the sensor node, after a moderate delay, the data sent back by the node is received. To estimate the required time for the proposed two-way data communication architecture, we try to send a command from the gateway side (i.e. Raspberry Pi) to the MCU at the node side (i.e. Arduino), and the node side sends back the required data to the gateway side. By our experiments, the required time from gateway request to receiving data is about 6 seconds. To effectively reduce the data collision situation at the two-way data communication scheme in the application field, the time of these delays can be set to be larger than 10 seconds. The AT commands, which are mentioned in Sect. 3.1, are used for control of the RYLR896 LoRa transceiver module. At the gateway side, if the sensing data is received at the same time as the request command is sent, not only the sensing data will not be received because of the time to wait for the response, but also the “+OK” string

Fig. 11 The two-way communication flow with the proposed Ver. A2 scheme at the gateway side.

returned by the AT commands will be received. Thus, the situation will cause packet data loss errors when the gateway side is receiving the data. In other words, when the gateway is sending the request command and receiving the sensing data from the sensor node simultaneously, the gateway may receive the response “+OK” from the module itself, and it causes a waste of memory access.

Figure 11 shows the two-way communication flow with the proposed Ver. A2 scheme at the gateway side. By experiments, the system takes about 4 seconds to send data from the sensor node to the gateway side. To reduce the probability of package collision further, the proposed Ver. A2 architecture inserts an extra 5 second interval between sending a request command and receiving sensing data each time at the gateway side. When the sensor node side is working to compare the strings of AT commands, the actual working time for strings comparison is different at each processing time. For the Ver. A2 scheme, a 5 second interval is inserted in the communication protocol to effectively reduce the possibility of packet data collision between the command packet sent from the gateway to the node and the data packet sent back from the node to the gateway with each other. Compared with the Ver. A1 scheme, the possibility of packet data collisions by the Ver. A2 scheme can be decreased efficiently. In Fig. 11, the gateway waits for 5 seconds before transmitting the first moisture command. After the waiting is over, the command of requesting moisture will be sent to the sensor node, and then an appropriate time delay, e.g. 25 seconds, will be passed before receiving the data sent back from the node side. Based on the same communication scheme, the gateway continuously sends different commands in the order of viscosity, pH value, and electrical conductivity.

For the proposed Ver. A1 and A2 schemes, Fig. 12 reveals the two-way communication flow at the sensor node side. In Fig. 12, the sensor node will send the moisture, viscosity, and electrical conductivity data by turns, and then judges whether or not the serial port data from the gateway side is received. Since the node side can only accept one bit of data at a time, to determine whether the command data is complete or not, the line break symbol, i.e. “\n”, is used as the end of a command data. After receiving a complete data, the node uses this data to compare the beginning

Fig. 12 The two-way communication flow at the sensor node side for the Ver. A1 and Ver. A2 schemes.

Fig. 13 The two-way communication flow with the proposed Ver. B scheme at the gateway side.

character of the command. For example, if the data request by the incoming command from the gateway is for moisture, and the moisture data will be sent to the gateway. If the command cannot be judged, the sensor node side will display “not match” and continue to wait for the next command from the gateway.

The sequences of the two-way protocol flow used in the Ver. B scheme are briefly described as follows:

- Step 1: The gateway side sends the command to the sensor node for data request.
- Step 2: Compare the content of command at the sensor node.
- Step 3: Collect the sensing data at the node side according to the command content, and then the node sends the data to the gateway side.
- Step 4: At the gateway side, after a certain period of time, if no data is received, start the process from Step1 again.

Figure 13 depicts the two-way communication flow by the proposed Ver. B scheme at the gateway side. The main feature of the Ver. B scheme for the application scenario is that when the sensor node transmits a critical sensing data every a long time period by requests, the correctness of the received packet data at the gateway side will become very important. Therefore, for the Ver. B scheme, the gateway confirms whether the sensing data returned by the node is correctly received or not, and then it continues to send the

next command to the node. If the return data is not received correctly, the gateway will resend the command to the node side, and request the node side to resend the data. Thus, the used protocol scheme can be guaranteed that when the gateway side sends the request command, the node side will return the corresponding sensing data correctly. Although the Ver. B scheme requires more communication time than the Ver. A1 and A2 schemes, the average packet data loss rate by the Ver. B scheme is much lower. Unlike the previous A1 and A2 schemes, for the Ver. B scheme, after the gateway sends out the request command, it is continuously receiving the sensing data. If the data returned from the node is not received within a certain period of time, the gateway will send the request command again. If the data is received correctly, after delaying 3 minutes, the gateway will send the next command to request the other data. Similarly, the order of requesting the data is the moisture, viscosity, pH value, and electrical conductivity in turn. In Fig. 13, for the simply functional evaluation, the order of requesting the data is arranged to the moisture, viscosity, pH value, and electrical conductivity. However, the order of requesting the data can be changed for the practical application. In addition, in Fig. 13, the delay time is only to simulate the general application scenario for requesting and receiving data every 3 minutes as an example. To simulate the situation of requesting and receiving data once a time period during the experiment, the time of these delays can be changed according to the time required to react and the priority in process that the factory needs to apply, e.g. these delays can be ranged from 10 to 30 seconds.

At the sensor node, the two-way communication flow by the proposed Ver. B scheme is shown in Fig. 14. After the data transmission is completed at the node side, the node will check whether any serial command data, which is sent from the gateway, has been received or not. If not, the algorithm of the sensor node side starts to check if there is any update in the data from its sensor, and then if there is an update, the updated data will be sent again immediately. If the sensor node reads different values of sensing data from the previous one, it will automatically update the obsolete data and send the updated data to the gateway. However, if the sensor node does not have a new data value to be updated but it receives a command from the serial port, the node will judge whether the command data is complete or not. After the node receives a complete request data, it uses the data to compare the beginning character of the command. If the command cannot be judged, the node side will display “not match” and continue to wait for the next command from the gateway.

3.5 Cloud Database Design and Production Commands

In this work, the MySQL technology [27] is used for building the database management system of the factory. Then the Apache technology is used for the development of web server, and the application software at the server side is Python. Table 5 shows the proposed production commands

Fig. 14 The two-way communication flow with the proposed Ver. B scheme at the node side.

Table 5 The proposed production commands for sensing data.

Item	DN	ID	T.V.U.	T.V.L.
Command name	Device Name	Device ID	Standard Value (Upper Limit)	Standard Value (Lower Limit)
Data format	ASCII	ASCII	ASCII	ASCII
Data length	1 Byte	4 Bytes	3 Bytes + 2 Bytes	3 Bytes + 2 Bytes
Item	A.V.	A.C.	ERR	E.C.
Command name	Actual measurement value	Actuation code	Error code	End code
Data format	ASCII	ASCII	ASCII	HEX
Data length	3 Bytes + 2 Bytes	1 Bytes	1 Bytes + 2 Bytes	2 Bytes

at the server side, and the proposed production commands is designed for collecting sensing data to be used at the cloud database side. The purpose of utilization of the production command is that the commands can assist the wireless sensor system to verify and detect the corresponding sensing

data values during the production of organic fertilizers.

In Table 5, “DN” defines the device name of the sensing data, “ID” defines the device ID of the measurement instrument for sensing data, “T.V.U” defines the upper limit of detected standard sensing value, “T.V.L” defines the lower limit of detected standard sensing value, “A.V” defines the actual detected sensing value, “A.C” notes whether the system is active or not, “ERR” notes whether the sensing data has some errors or not, and “E.C” means the end code of the string command.

The string format of the production command is cascaded by the order as follows:

“DN_ID.T.V.U.T.V.L.A.V.A.C.ERR.E.C”.

For example, when the production command is “A_1234_00650_00720_00694_A_E00_(0x0d)(0x0a)”, and then “A” means the pH value, and “1234” means the ID of the pH measurement instrument. In the above mentioned example of the production command, “00650” means that the upper limit of detected standard pH value is 6.5, “00720” means that the lower limit of detected standard pH value is 7.2, and “00694” means that the detected standard pH value is 6.94. Besides, “A” means the system is active, “E00” means no error is detected for measurements, and “(0x0d)(0x0a)” means the end of data string of the production command.

The novelty of the proposed design is that by the LoRa based wireless sensor network, the effective multiple data transmission functions, e.g. one-way and two-way modes, are constructed to assist the remote data sensing activity for the state-of-the-art and smart-manufacturing based smart agricultural recycling rapid processing factory.

4. Experimental Results and Performance Comparison

In the experiments, by using the proposed LoRa-based wireless sensor network design, the data transmission between the sensor node and the gateway side is not error-free, and the system performs some packet data loss. During transmission processes, the multipath interference, channel blocking effect, and packet damage will cause the potential packet data loss. Besides, the possible collision of the packet data between the request command and the sensing data transmission leads to the packet data loss. Then the possible comparison error on Arduino UNO at the sensor node may result in some packet data loss. In addition, when the gateway side has received the sensing data but cannot identify the message, the situation will causes the packet data loss. To evaluate the system performance for data transmission, the average packet data loss rate is defined by

$$\text{Packet data loss rate} = \frac{N_{\text{total}} - N_{\text{received}}}{N_{\text{total}}} \quad (1)$$

where “ N_{total} ” means the total number of the transmitted packet data, and “ N_{received} ” means the received number of the transmitted packet data. In the experiments, the number of “ N_{total} ” is set to 1000. Table 6 shows the average packet data loss rates by the used one-way transmission scheme.

Table 6 Comparisons of average packet data loss rates by the applied one-way transmission scheme.

One-way transmission architecture	
2 secs/data	2%
5secs/data	0%

Table 7 Comparisons of average packet data loss rates by the proposed two-way communication schemes without the data-received confirmation at the gateway.

Two-way communication architecture	Ver. A1	Ver. A2
10 secs/data	15%	4.8%
20 secs/data	17%-18%	7.4%
30 secs/data	16%	3.7%

Table 8 Comparisons among the three proposed LoRa-based data communication schemes.

Applicable communication schemes	One-way transmission mode	Two-way communication mode (Ver. A2)	Two-way communication mode (Ver. B)
Power consumption	Low	Low	Very Low
Packet rate	Low	Low	Very Low
Frequency of sending data	High	Middle	Low

When the sensor node sends the packet sensing data to the gateway side every 2 seconds, the average packet data loss rate at the gateway side is about 2%; however, when the sensor node sends the packet sensing data to the gateway up to every 5 seconds, the average packet data loss rates at the gateway side will be reduced to near 0%. Table 7 lists the average packet data loss rates by the proposed two-way communication schemes without data-received confirmation in the gateway side. For the proposed Ver. A1 scheme, after a delay time with 30 seconds, the average packet data loss rates at the gateway side are about 16%; however, for the proposed Ver. A2 scheme, when an extra 5 second interval is inserted between sending a request command and receiving sensing data each time at the gateway side, the average packet data loss rates at the gateway side will be reduced to about 3.7%. For the proposed Ver. B scheme, since the two-way communication scheme uses the data-received confirmation scheme at the gateway side, the average packet data loss rates are near 0%.

Table 8 describes the comparisons among the three proposed LoRa-based communication schemes. The usage scenarios for the three proposed LoRa-based communication schemes are: (1) To frequently measure the important properties of the mixed material in the storage tanks, the simple one-way data transmission scheme, which performs a high frequency of sending the sensing data and has a low data package loss rate, is selected to be used. In the storage tanks, the sensing data of moisture, viscosity, pH, and electrical

Table 9 Comparisons among three different designs by LoRa-based wireless sensor networks.

	Firdau [9]	Kumar [10]	The proposed design
System Architecture	Node +Gateway	Node +Gateway +Server	Node +Gateway +Server
Data Transmission mode	One-way mode	Two-way mode	One-way and Two-way modes
Cloud	Yes	Yes	Yes
Packet data loss rate	One-way mode: 3.3% at 2.6 secs/data	N/A	One-way mode: 2% at 2 secs/data 0% at 5 secs/data Two-way mode: 3.7% at 30 secs/data for Ver. A2 0% for Ver. B

conductivity will be transmitted to the gateway side whenever the crushed agricultural organic wastes are fed into the storage tanks for the pre-process. (2) To transmit the sensing data, such as the pH value and electrical conductivity in the reaction tanks whenever the gateway requests the sensing data, the proposed two-way data communication Ver. A2 scheme, which performs a middle frequency of sending the sensing data and shows an acceptable low data package loss rate, is designed and selected for the application. (3) To transmit the crucial sensing, e.g. the pH value and electrical conductivity at the final customized organic fertilizer manufacturing process for fertilizer management regulations, or the on/off statuses of gas/power switches in the factory, the two-way data communication Ver. B scheme, which provides a low frequency of sending the sensing data and has a very low data package loss rate, is selected for the condition.

Table 9 describes the comparisons among the three different designs based on the LoRa-based wireless sensor network. The design in [9] only considers the one-way communication mode in their application, and the average packet data loss rate in [9] by the one-way operational mode is about 3.3% when the sensing data is transmitted every 2.6 seconds at the node side. In [10], the Raspberry Pi platform is used for collecting and transmitting data at the node side to communicate with the gateway side. Compared with the existing LoRa-based designs in [9] and [10], the proposed system provides both one-way and two-way data transmission scheme to transmit sensing data depending on different properties and importance of data. Specially, the proposed two-way data transmission Ver. B scheme can provide a very low data package loss rate, i.e. approximately 0% for the crucial data transmission. By the proposed simple one-way transmission scheme, the average packet data loss rate can be near zero when the sensing data is sent every 5 seconds at the node side. By the proposed two-way transmission schemes under the condition of sending one packet data every thirty seconds, the average packet loss rates, without

and with the data-received confirmation at the gateway side, achieve at 3.7% and 0%, respectively.

5. Conclusion

In this paper, the effective LoRa-based wireless sensor network is designed and implemented to provide the remote data sensing functions for the smart agricultural recycling rapid processing factory. In the proposed wireless sensor network system, the RYLR896 LoRa transceiver module is used to provide the data transmission function at the sensor node, and the Raspberry Pi module is used for providing the gateway functions. The developed wireless sensor network supports one simple one-way data transmission scheme and three two-way data communication schemes. By experiments, for the proposed one-way data transmission scheme under the condition of sending one packet data every five seconds, the packet data loss rate achieves to near 0%. For the proposed two-way data communication schemes, under the condition of sending one packet data every thirty seconds, the average packet data loss rates, without and with the data-received confirmation at the gateway side, are 3.7% and 0%, respectively.

In future works, the production commands for sensing data transmission will be verified, and then the cloud data server will be joined into the system for the integrated function evaluations.

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