International Journal of Mechanical and Electrical Engineering
ISSN: 3005-9615 (Print), ISSN: 3005-7132 (Online) | Volume 1, Number 1, Year 2023
DOI: https://doi.org/10.62051/ijmee.v1n1.11
Journal homepage: https://wepub.org/index.php/IJMEE/index

Research on Detection System for Machinery Parts Based on ZigBee Technology

Fanjia Liu

School of Engineering, Drew University, Madison, 07940, USA

ABSTRACT

ZigBee technology is a low-power, low-cost, short-range wireless communication technology for various IoT (Internet of Things) applications. Machinery parts detection system monitors the quality, size, shape, and other parameters of machinery parts in real time to ensure the accuracy and quality of the production process. In this article, we propose a machinery parts detection scheme based on ZigBee technology. By deploying wireless sensor networks, the detection data concerning machinery parts could be transmitted in real time, thus reducing the complexity of wiring and improving detection efficiency. ZigBee based machinery parts detection system would provide an efficient and convenient means of detection for the manufacturing industry, thus enjoying a wide range of application prospects.

KEYWORDS

ZigBee technology; Detection System; Machinery Parts.

1. INTRODUCTION

With the development of industrial automation and intelligence, the accuracy and real-time detection of mechanical parts become particularly important. Traditional detection methods have been difficult to meet the needs of modern industry, so seeking a new detection technology has become the focus of research. As a low-power and low-cost wireless communication technology, ZigBee technology has a wide application prospect. This paper aims to study the mechanical parts detection system based on ZigBee technology.

2. OVERVIEW OF ZIGBEE TECHNOLOGY

2.1. ZigBee technology definition

ZigBee is a short-distance wireless communication technology, which is a wireless LAN protocol based on IEEE802.15.4 protocol standard [1]. The working frequency band of ZigBee is mainly divided into three sections, mainly 2.4GHz, 868MHz and 915MHz, and its transmission distance is currently within the controllable range of 10-75 m. The distribution diagram of ZigBee working frequency band is shown in Figure 1.

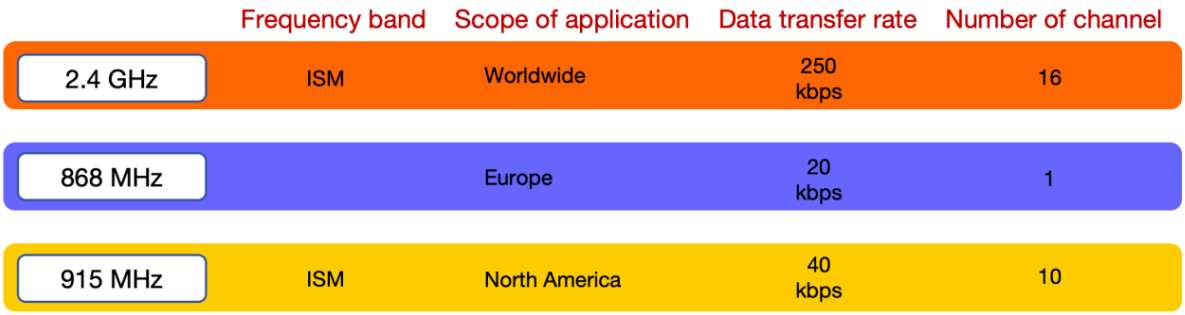

Figure 1. ZigBee working frequency band distribution diagram [2]

2.2. ZigBee technology features

ZigBee technology features could be specifically described as follows:

2.2.1. Low power consumption:

The ZigBee network node features a short work cycle and low energy consumption for sending and receiving data. Besides, it could turn itself into a sleep mode when not receiving data, and the power consumed during communication is low. According to experimental tests, 2 AA batteries can enable the terminal node to work for 6-24 months. At the same time, the sleep mode also extends the life of the battery, avoiding the frequent replacement of batteries and reducing maintenance costs[2].

2.2.2. Low cost

ZigBee protocol is based on an open-source technology without patent fees. Moreover, the protocol is not complicated to use, so the R&D and production costs are relatively low. With a large number of applications and industrialization, the cost of hardware will be further reduced. Therefore, using ZigBee technology could effectively reduce costs.

2.2.3. High reliability

Since a collision avoidance mechanism is adopted in the protocol, and the MAC layer uses fully confirmed data communication, i.e., each sent packet needs to receive a confirm information from the device, the protocol could ensure the reliability of the data transmission by using mechanisms above. Besides, data would be retransmitted once a mistake occurs during the transmission.

2.2.4. Large capacity

Each ZigBee network contains up to 254 slave devices and 1 master device. ZigBee subnet contains up to 255 network nodes. In address selection, ZigBee network address could be defined as 64 bits or 16 bits. In this way, the number of nodes could be calculated as 2^16, i.e., a maximum of 65535 devices could be supported in a network.

2.2.5. Low delay

Compared with other technologies, ZigBee protocol performs better in terms of delay. Besides, it also has optimized the delay characteristics, and operations on the node to make it from state to activation owns a low delay due to the low sleep delay and communication delay. Specifically, the delays of these operations are within only 15ms.

2.2.6. High security

ZigBee provides three levels of security mode. By using the cyclic redundancy check, a careful and comprehensive checking function could be realized on the packet. Besides, the protocol supports authentication and security settings. It is also able to flexibly determine the security attributes of each application by using access control lists and advanced encryption standards, etc.

Table 1. Comparison of Zigbee, Bluetooth, and Wi-Fi [3]

	Zigbee	Bluetooth	Wi-Fi
Corresponding IEEE standards	802.15.4	802.15.1	802.11b
Operating frequency band	868M (Europe) 915M (US) 2.4G (Global)	2.4G	2.4G
Power consumption, battery life	Low, in years	Relatively high, in days	High, in hours
Communication range	10-75m	10m	100m
Transmission rate	250K	1M	11M
Device activation time	15ms	3s	3s
Network nodes	65000	7	32

3. PRESENT SITUATION AND TREND OF MECHANICAL PARTS DETECTION

3.1. Development Status of Mechanical Parts Testing Technology

3.1.1. Increasingly intelligent testing equipment

In recent years, with the advancement of Industry 4.0, the detection technology of mechanical parts has developed rapidly. Digital detection, intelligent detection, remote monitoring and other technologies are constantly emerging, which greatly improves the detection efficiency and accuracy. However, in some fields, traditional detection methods still occupy a dominant position, which restricts the development of detection technology.

3.1.2. Detection technology diversification

With the development of technology, new detection equipment is constantly emerging. High-precision measuring instruments and non-contact measuring systems have been widely used in production. However, equipment upgrading requires a lot of capital investment, so many small and medium-sized enterprises are under great pressure. In addition, the compatibility of new equipment and the replacement of old equipment also need to be solved urgently.

3.1.3. Application of artificial intelligence

The application of artificial intelligence in mechanical parts detection is increasingly extensive. AI algorithm can automatically process and analyze complex data, and improve detection accuracy and efficiency. However, the application of AI technology in mechanical parts inspection is still in the primary stage, and it faces challenges such as data acquisition, model training and algorithm optimization in practical application.

3.1.4. Signal processing technology

Signal processing technology plays an important role in the detection of mechanical parts. Through the analysis of vibration, sound, temperature and other signals, the performance and state of mechanical parts can be accurately evaluated. However, in practical application, signal processing technology is faced with noise interference, signal attenuation and other problems, which affect the reliability of detection results.

3.1.5. Nondestructive testing technology

Non-destructive testing technology is of great significance in mechanical parts testing. This technology can detect without damaging parts and ensure the integrity of products. However, the high cost of nondestructive testing technology and the high skill requirements for operators limit its popularization and application in small and medium-sized enterprises.

3.2. The problems existing in the detection of mechanical parts

3.2.1. Testing equipment and technology are relatively backward

At present, the testing equipment and technology of some mechanical parts are relatively backward, and it is difficult to meet the needs of modern manufacturing industry. The detection equipment has low automation, complicated operation and limited detection efficiency and accuracy.

3.2.2. The detection method is single

The existing inspection methods of mechanical parts are relatively simple, and it is difficult to meet the inspection requirements of various types and scenes. In addition, a single detection method is easily influenced by external factors, such as environmental temperature and humidity.

3.2.3. The testing standards are not uniform

There are differences in standards and specifications of different countries and regions in the detection of mechanical parts. This leads to different acceptance of products in different markets and affects the international competitiveness of products. The promotion of standardization and standardization is of great significance to solve this problem.

3.3. Development trend of mechanical parts detection technology

3.3.1. Application of machine learning

In the future, the application of automatic detection technology will gradually develop to the level of machine learning, and the detection standards will be continuously updated and optimized by using the intelligent learning ability of the machine itself.

3.3.2. Man-machine interaction technology

Modern automatic detection technology also emphasizes man-machine interaction technology more and more. In the future development, the interactive interface of automatic detection technology will become more and more friendly, and the level of automation will gradually improve.

3.3.3. Auxiliary decision-making function

Modern automatic detection technology is not only for testing products, but also for helping manufacturing enterprises to improve production efficiency and reduce costs. In the future development, automatic detection technology will develop stronger auxiliary decision-making function to assist manufacturing enterprises to carry out more efficient management.

3.3.4. Big data and intelligent analysis

With the accumulation of a large amount of data in automatic detection technology, data analysis will become intelligent, with more accurate and refined analysis ability, so as to improve the accuracy and efficiency of detection.

4. APPLICATIONS OF ZIGBEE TECHNOLOGY IN MECHANICAL PARTS DETECTION SYSTEM

4.1. Wireless Sensor Network Construction

4.1.1. Wireless sensor network node deployment

1)ZigBee Coordinator

ZigBee coordinator is a device to start and configure the network, which includes all network information, and is mainly responsible for the normal and stable work of the network and ensuring the communication status of other devices under the same network.

2)ZigBee Router

ZigBee router is a device that supports association, and it can forward information of other nodes.

3)ZigBee terminal equipment (End-device)

The terminal equipment of ZigBee can convert the collected analog signals into digital signals, compress the data, and then send signals to the controller through the router [4].

4.1.2. Wireless Sensor Network Communication Protocol

ZigBee protocol is established on the basis of IEEE802.15.4 standard, that is, its PHY and MAC directly use the definition of IEEE 802.15.4. Later, the ZigBee Alliance added protocols, and defined the protocols of NWK , APS and APL. So the complete ZigBee protocol includes: application layer, application support sublayer, network security layer, media access layer and physical layer. The following figure shows the ZigBee protocol framework:

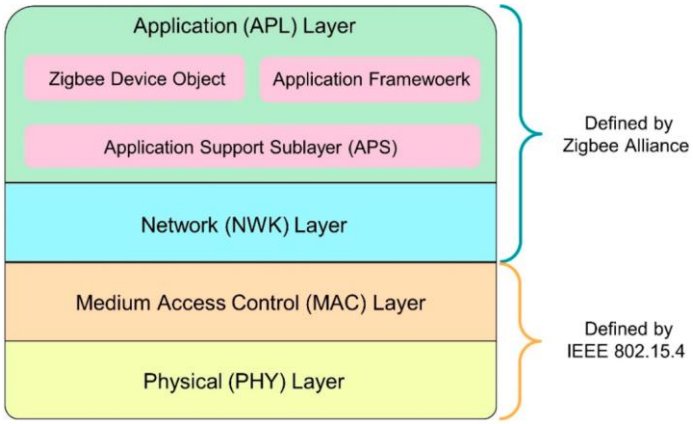

Figure 2. Zigbee protocol stack [5]

4.1.3. Wireless Sensor Network Routing Algorithms

Wireless sensor network routing algorithms are mainly classified into the following categories: hierarchical routing algorithms, geographic routing algorithms, data-driven routing algorithms, greedy routing algorithms, etc. Hierarchical routing algorithms are a hierarchical network structure, typically represented by LEACH (Low Energy Adaptive Clustering Hierarchy) and PEGASIS (Power-Efficient Gathering in Sensor Information Systems). These algorithms equalize node energy consumption by dividing the network into different clusters, aiming at extending the network lifetime. Geographic routing algorithms are based on the geographical location of nodes such as GPSR (Greedy Packet State Routing) and GAF (Geographical Adaptive Fidelity). These algorithms utilize the geographic location information of the nodes to select the best path for efficient data transmission. Data-driven routing algorithms are data-centric routing algorithms such as DCN (Data Driven Networks) and SPIN (Sensor Protocols for Information Routing through Networks). These algorithms reduce ineffective data transmission and improve data transmission efficiency by pre-processing and

filtering data. Greedy routing algorithms are routing algorithms in which each node independently selects neighboring nodes for data transmission such as NEAR (Neighbor Energy Aware Routing) and EEUC (Energy Efficient Unenen Clustering). These algorithms are simple and easy to implement but may lead to uneven energy consumption in dense networks [6].

4.2. Detection methods

In the mechanical parts inspection system, it is necessary to inspect different types of mechanical parts, including metal materials, plastic materials and other special materials. Therefore, it is necessary to select the corresponding detection methods and algorithms for different material types. First of all, for metal materials, magnetic resonance imaging (MRI) can be used to detect its internal structure. This method can effectively identify the defects of metal materials, such as cracks and corrosion. Secondly, plastic materials can be detected by X-ray transmission method. Because of the high density of plastic materials, X-rays can penetrate into the inner part and show the information of its inner structure. Finally, for special materials, such as ceramic materials, ultrasonic testing is needed. This method can determine the internal structure of an object by measuring the change of the reflected signal on its surface. First of all, we need to install multiple wireless sensors on mechanical parts to obtain the information of their state changes. Then, these sensors will send signals to a central control unit, which will process and store them. Finally, we can use machine learning algorithm to analyze the collected data, so as to determine whether there is a fault or an abnormal situation. In a word, this new detection algorithm can effectively improve the accuracy and reliability of mechanical parts detection and provide strong support for the maintenance of mechanical equipment [7].

5. DESIGN AND IMPLEMENTATION OF MECHANICAL PARTS DETECTION SYSTEM BASED ON ZIGBEE TECHNOLOGY

5.1. System architecture design

5.1.1. Overall system architecture

When the detected mechanical parts enter the inspection process, the ID of the parts is obtained by the scanning gun and recorded in the database, and the system queries the name, product type and standards of various parameters of the parts from the database. In the detection process, the part must be detected by the sensor first. When the product passes through the sensor area, the data obtained by the sensor is transmitted to the cluster head node through the extended communication module node, and then transmitted to the coordinator. The coordinator sends the collected data to the server through WiFi, 3G and other networks, and judges whether the part is qualified by analyzing and comparing the collected data with the standard data of the part. And write the relevant information into the RFID tag of the part. When the product passes through the sorting mechanism, the system will query the detection result of the product from the server, thus realizing the function of detecting mechanical parts. The system structure diagram is as shown in the figure.

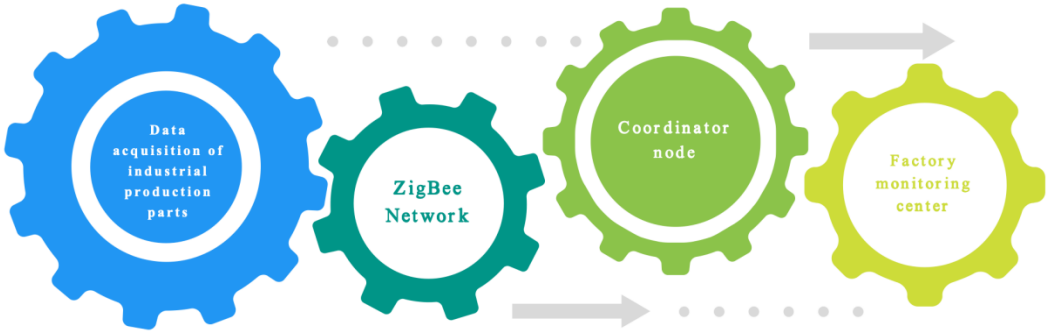

Figure 3. System Structure Diagram

5.1.2. Functional division of modules

The whole system is divided into three main parts: sensor acquisition module, data processing module and control module. Among them, the sensor acquisition module is responsible for collecting data from the sensor and sending it to the data processing module; The data processing module processes it through an algorithm and stores it in the database; Finally, the control module will send an alarm signal to the sensor assembler regularly to remind them to check whether the equipment is running normally. In the specific module function division, the sensor acquisition module mainly includes three parts: sensor connection circuit, power management circuit and communication interface circuit. Wherein, the sensor connection circuit is a hardware unit for connecting the sensor; The power management circuit is a circuit board designed to ensure the stability of the sensor. The communication interface circuit is used to transmit sensor data to the data processing module.

5.2. Hardware module design

The hardware part of mechanical parts detection system based on ZigBee technology is composed of sensor nodes, routing nodes and control nodes. The core of the three nodes is ZigBee module. For the sensor node, the node not only collects data but also sends data, so it adds the upper sensor module on the basis of ZigBee module; As the relay of data transmission, the routing node is responsible for forwarding the data collected by the sensor node to the control node. The hardware structure of the node is relatively simple, and the sensor module can be removed on the basis of the sensor node. However, due to the large amount of data forwarded, the data storage space required is larger than that of the sensor node. The control node receives the data from the routing node or directly from the sensor node, processes the data and drives the solenoid valve to act.

5.2.1. Sensor Module Design

Sensor module, a miniature embedded system, usually consists of four parts: sensor unit (data acquisition unit), processor unit (data processing unit), wireless communication unit (data transmission unit), and energy supply unit, as shown in the figure. The sensor unit is responsible for the collection of information and data conversion in the monitoring area. The processor unit, including CPU, memory, embedded operating system, etc., is responsible for the operation of the entire sensor node. It is able to store and process the collected data as well as the data sent from other nodes for data fusion. The wireless communication unit is used to communicate with other sensor nodes wirelessly, exchange control information, and send and receive collected data. The energy supply unit provides the required energy for the sensor nodes, usually using miniature high-energy batteries. A sensor is a kind of measuring device that converts the measured non-physical quantity into the corresponding physical quantity with a certain degree of accuracy. Sensor, the input of the measuring device, is an important link to the whole detection system. Its performance would directly affect the accuracy of detection. The main sensors in our system include Hall sensor, ultrasonic sensor, and infrared sensor.

5.2.2. ZigBee Module Design

According to the demand for the terminals in the machinery parts detection system, we should choose an appropriate ZigBee chip. After checking the parameters of different ZigBee chips to make a comparison. Table 5-1 shows the comparison of common ZigBee chip parameters.

CC2530 is a low-power wireless SoC (System on Chip) chip introduced by Texas Instrument, which consists of an 8051-core microprocessor, a 2.4GHz IEEE 802.15.4/Zigbee RF transceiver and various interface components. CC2530 has the characteristics of low power consumption, high reliability and long-distance communication, and is widely used in Internet of Things devices.

Table 2. Comparison of ZigBee chip parameters[8]

Parameter	MC13202	MRF24J40	CC2530
Wireless protocol standard	802.15.4	802.15.4	802.15.4
Operating voltage (V)	2-3.4	2.4-3.6	1.8-3.8
Transmit power	27dBm—+3dBm	-30dBm—0dBm	-3dBm—+5dBm
	Programmable	Programmable	Programmable
Adjacent channel rejection r atio	31	30	49
(dB)			
Receiving sensitivity (dBm)	Maximum -95	Maximum -95	Maximum -98
Power consumption	Sleep minimum1uA	Sleep 2uA	Sleep <1uA
	Idle 800uA	Receive 19mA	Receive 18.5mA
	Transmit 35mA	Transmit 23mA	Transmit 25.8mA@0dBm
	Receive 42mA		33.6mA@5dBm
ZigBee protocol stack	Not open source	Not open source	Open Source
Security	AES-128	AES-128	AES-128

5.2.3. Power module design

The ZigBee module of this system collects the data of each node and transmits it to the central platform through wireless mode. Intelligent adaptation forms a wireless transmission network covering local area network. You can also access the Internet, and through the use of gateway equipment, you can remotely control the mobile terminal. Table 5-2 is the specific index parameters for ZigBee module.

Table 3. ZigBee module performance index parameter

Input voltage	DC3.3V
Temperature range	-40°C–85°C
Temperature range	38400bps(acquiesce) Can be set to 9600bps,
	19200bps,38400bps,115200bps.
Radio frequency	2.4GHz
Wireless protocol	ZigBee2007/PRO
Transmission distance	Visual range 400 meters
Emission current	34mA (Max)
Receiving current	25mA (Max)
Receiving sensitivity	-96DBm
Master chip	CC2530F256
Standard data transmission module	Can be configured as Coordinator, Router

Figure 4 below for the peripheral circuit of CC2530 chip:

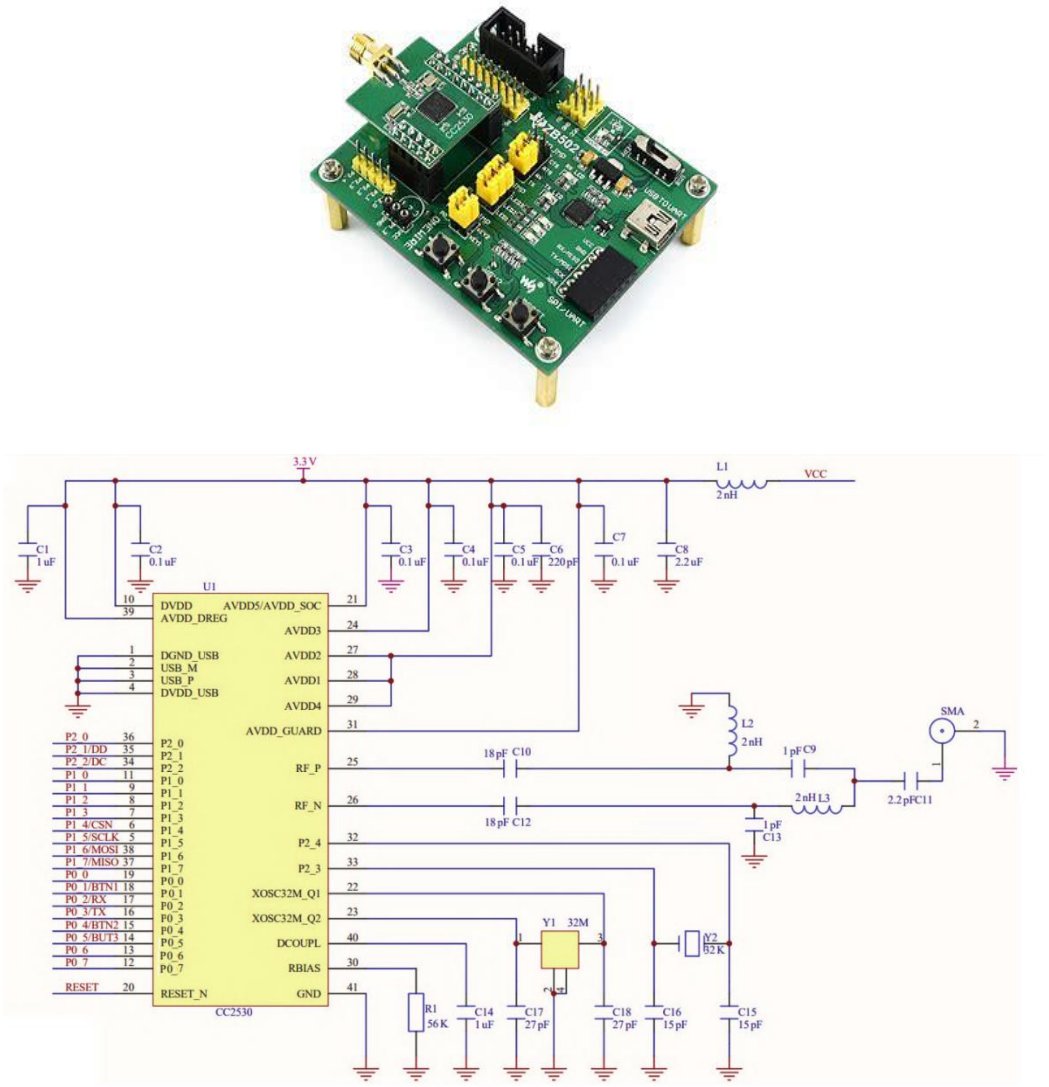

Figure 4. CC2530 chip and peripheral circuit diagram

6. CONCLUSION

To sum up, according to the problems existing in the detection of mechanical parts at this stage, this study designs an intelligent detection system of mechanical parts based on the widely used zigbee technology as a model, combined with sensor module and wireless data transmission module. The mechanical parts detection system based on ZigBee technology has the advantages of low power consumption, low cost and high precision, which can meet the needs of modern industry. In the future, we will further optimize the system to improve its stability and reliability, so as to be more widely used in actual production.

REFERENCES

[1] Zhang Zhenxiang. Design of Automatic Sorting System in Surface Defect Detection of Micro Bearings [J]. Electromechanical Engineering, 2010 (5): 35-37.

[2] Xinhua. Zigbee-based wireless sensor network positioning technology [J]. Shandong Industrial Technology .2019.3.

[3] Zhong Yongfeng et al. zigbee wireless sensor network [M]. Beijing University of Posts and Telecommunications Press, 2010.

[4] Xu Yi. Principles and methods of wireless sensor networks [M]. Tsinghua University Publishing House, 2011.

[5] Wei Kaibin, Su Heping. Design and implementation of production line monitoring system based on ZigBee [J]. Automation and Instrumentation, 2011 (3): 49-53.

[6] Gislason D. Zigbee wireless networking[M]. Newnes, 2008.

[7] Tomar A. Introduction to ZigBee technology[J]. Global Technology Centre, 2011, 1: 1-24.

[8] Komilov D R. Application of zigbee technology in IOT[J]. International Journal of Advance Scientific Research, 2023, 3(09): 343-349.