# Research on Wireless Monitoring System for Sanitation Container Structure Based on ZigBee Technology

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## Abstract

**Anitation containers are special containers and are mainly used for the transportation of garbage in Shanghai. The traditional sanitation container structure health detection means has visual inspection and ultrasonic flaw detection. However, these methods are time-consuming, untimely, and complex, and can only detect the health of the container structure under static conditions, and cannot reflect the actual situation. The application of Zigbee wireless sensing technology to the sanitation container monitoring system compensates for the shortcomings of the traditional sanitation container in the structural health detection capability under actual working conditions. Aiming at the wireless monitoring system of sanitation container structure, this paper studies the three aspects of the whole structure of the system, the design of wireless monitoring hardware and the analysis method of wireless structure monitoring information. The terminal detection information is obtained through the wireless sensor network, and the structural health monitoring and diagnosis of the box is performed based on the strain data, so that the health condition of the sanitation container structure can be timely, quickly and truly diagnosed.**

## Keywords

**Sanitation container, Wireless monitoring system, ZigBee technology, Structure detection, Wireless transmission.**

## 1. Introduction

With the general improvement of people's material life in modern society, the production of domestic garbage is also increasing. In China's vast coastal and riverside cities, the use of sanitation containers as mobile carriers for domestic garbage operations has gradually become an indispensable and important part of urban domestic garbage removal. With the rapid increase in the number of containers and daily transportation of sanitation terminals, the working hours of the boxes have generally increased. In the case of more frequent high-intensity loading and transportation, how to ensure the health and reliability of the sanitation container structure has become a problem that cannot be ignored. Xu Shunji [1] et al. Studied the actual stress of this type of container during use through finite element calculation and experimental testing, and inferred the maximum load that the container may encounter during use. Based on the test results, the sanitation container The structure was optimized. Optimized containers have also been put into use. But how reliable is the optimized structure? This type of special container is used more frequently, and the container is overloaded from time to time during use. Under such high frequency and overload conditions, how can we ensure that we can timely and quickly detect and find structural health risks? Container. Regarding the structural detection methods, Chen Kai [2] and others summarized and researched that the commonly used structural health detection methods are mainly "manual" detection. For example, human eye visual inspection, ultrasonic flaw detection [3]. However, these methods are not only time consuming and untimely, but also can only detect the health of the container structure under static conditions and cannot reflect the actual situation. With the advancement of sensor technology, wireless transmission technology, and computer technology, computer-based automatic, continuous and even real-time structural health systems have been widely used and developed. But at present, there are few examples of the application of wireless structure monitoring systems to the monitoring and diagnosis of sanitation container structures. Therefore, the development of a sanitation container structure health monitoring system based on ZigBee technology [4] instead of the traditional sanitation container detection mode is not only of practical significance for real-time health monitoring and diagnosis of the sanitation container structure, but also maximizes the safety of sanitation container loading and transportation.

## 2. Overall system structure

The wireless connected sensor network system given by PAIK [5] and so on is connected to the Middleware server through a wired connection at the Router node. The BA-OFS30 fiber Bragg grating sensor arranged on the site will transmit the monitoring data to the processor module by bus. The FPGA processor and the radio frequency chip CC2430 are connected by SPI bus interface, and wirelessly transmitted to the monitoring center through the network node for data display and deal with.

The overall structure of the system is shown in Fig 1. Divided as a whole, the monitoring system can be divided into upper computer system and lower computer system. The structure monitoring node and cluster head node are the lower computer system; the wireless network unit and the monitoring terminal belong to the upper computer system. The lower computer collects each sensor structure monitoring node device in a bus way, and collects the data to the cluster head node in the monitoring area. It then performs digital-to-analog conversion, processes it through the FPGA processor, and then sends it to the monitoring terminal wirelessly through the router device. The monitoring terminal realizes real-time monitoring and diagnosis of the health status of the cabinet structure according to the data information.

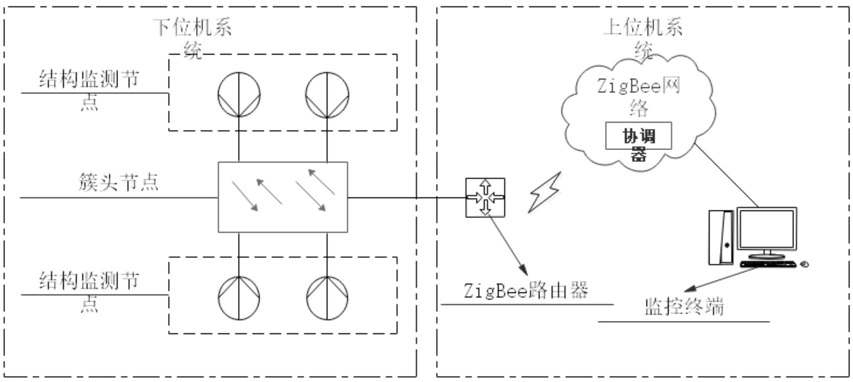


Fig 1.The overall structure of the system

The block diagram of the lower system design is shown in Fig 2. The lower computer system is mainly composed of a BA-OFS30 fiber grating sensor, an FPGA processor module and a CC2430 wireless radio frequency module arranged on the cabinet. In the whole wireless monitoring system, in order to ensure the sensors are fully arranged in the key positions of the box. The system designed 12 BA-OFS30 fiber Bragg grating sensors to collect the box strain data. The collected data was then processed by the processor. The amount of data collected by multiple sensor nodes is heavy and uninterrupted. This requires the processor to achieve fast processing of tasks and provide necessary hardware support for the real-time requirements of the system. Therefore, the lower computer system uses Xilinx's Spartan-3 FPGA as the core logic processor. It receives the voltage signal corresponding to the box strain information collected by the field sensor, and performs digital-to-analog conversion processing on it. The RF CC2430 module is sent to the monitoring terminal for subsequent operations.

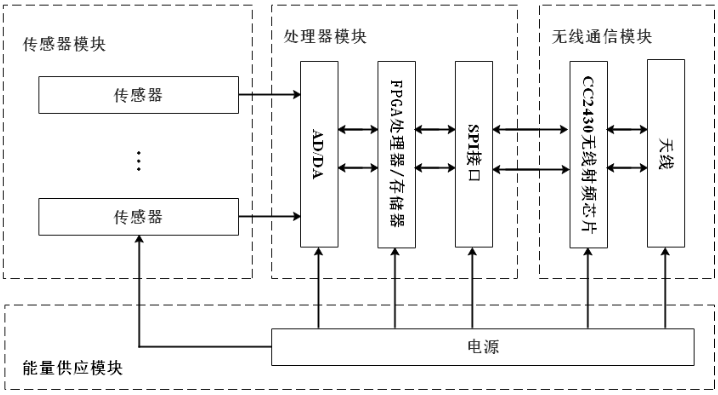


Fig 2 .Block diagram of the system design

## 3. System hardware design

In the whole design and application project of the sanitation container structure wireless monitoring system, considering that the sanitation container itself has a safe service life, and the terminals are intermittent, the batch purchase method, so the actual number of containers to be monitored and diagnosed each year is limited. In this paper, when designing a sanitation container structure wireless monitoring system, on the premise of ensuring the system function and accuracy, it is necessary to maximize cost savings and ensure the practicability of the monitoring system. At the same time, in view of the fact that the working environment of the sanitation container is relatively harsh, and it is basically in the working state for 24 hours, it is also required that the monitoring system should be as simple as possible in each component, efficient and low energy consumption.

### 3.1 Sensor selection

The main job of the sensor is to collect the strain signal of the box structure. The BA-OFS30 fiber Bragg grating sensor is a new type of welding strain sensor. This sensor has the characteristics of small size and easy installation. It only needs to be welded with a welding gun during installation. For the environmental protection container with the steel structure of the box itself, this welding installation method can not only simplify the installation process, but also avoid the influence of the traditional strain gauge sensor on the strain measurement of the sensor caused by the application of an adhesive layer; at the same time, the sensor itself It has a low temperature sensitivity coefficient, which reduces the impact of changes in the external temperature environment on the data collected by the sensor when the container is often in the open air.

### 3.2 Wireless communication module hardware design

The hardware design framework of wireless communication module is shown in Fig 3. The wireless communication module of the monitoring system includes a micro control module, a wireless transceiver module and an antenna part. This article selects the CC2430 radio frequency device as the wireless communication module part. On the one hand, it integrates a wireless transceiver and an 8051 core, which can implement the functions of the microcontroller part and the wireless transceiver part of the wireless communication module. On the other hand, the internal core controller CC2430 chip [6] in the receiving and transmitting modes, the current consumption is lower than 27 mA or 25 mA, respectively, and the energy consumption is very low. Its superior anti-interference ability and sensitivity, as well as the fast conversion characteristics from sleep mode to active mode, are suitable for the long-term uninterrupted rest of the container.

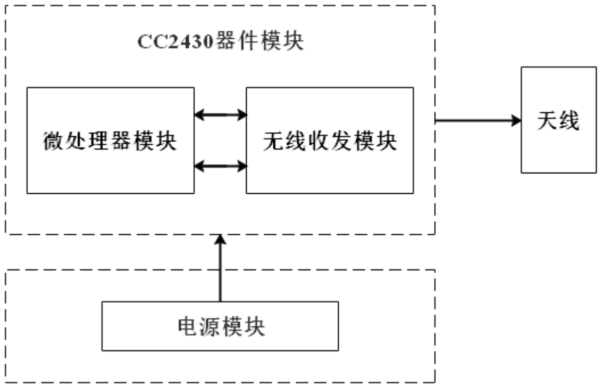


Fig 3 .Wireless network node hardware design framework

## 4. Analysis method of wireless structure monitoring information processing

In the sanitation container structure wireless monitoring system, the box strain information is collected by the sensor device, analyzed and processed by the processor module, and then sent by the wireless transmission module to the monitoring terminal for box structure health monitoring and diagnostic operations. For the sanitation container structure health monitoring project, it is easier to rely on the strain data to monitor the condition of the cabinet, but to make a diagnosis of the health of the cabinet structure based on the strain data requires a new method.

### 4.1 Theoretical basis

Hou Qiaoqiao, Zhang Qingyong [7] and others proposed a test system theory based on strain data for structural health monitoring and load monitoring in the study of aircraft fatigue experiments based on mechanics and control theory principles. As shown in Fig 5, there is a one-to-one correspondence between load, structure, and strain response. Theoretically, a third party can be judged based on obtaining any two pieces of information. In this paper, if a sanitation container is defined as a structure, it must have a corresponding load and response strain. If the box undergoes unrecoverable changes such as breakage, the corresponding strain response will inevitably change. Therefore, this article judges the change of the box structure by monitoring the load and strain response of the sanitation container.

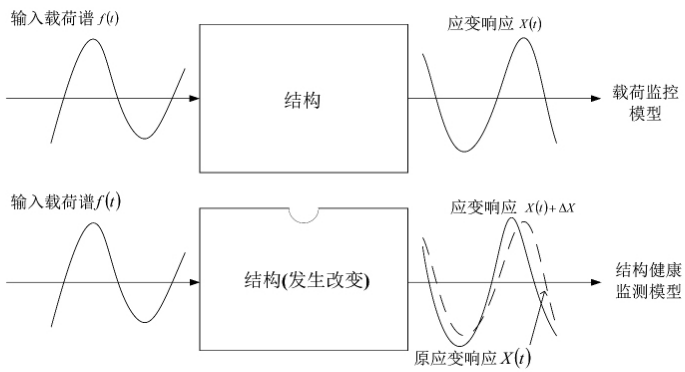


Fig .5.Simplified diagram of load spectrum, structure, and response

### 4.2 Structural health monitoring model

Define the load state as the function $\boldsymbol{Z} = \boldsymbol{f}(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{t})$. For the convenience of processing, the time characteristic is ignored, and the load f is discretized into a vector form, as shown in equation (1):

$$\boldsymbol{f} = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_m \end{bmatrix} \quad \boldsymbol{x_f} = \begin{bmatrix} x_{f1} \\ x_{f2} \\ \vdots \\ x_{fm} \end{bmatrix} \quad \boldsymbol{y_f} = \begin{bmatrix} y_{f1} \\ y_{f2} \\ \vdots \\ y_{fm} \end{bmatrix} \quad \boldsymbol{T_{fx}} = \begin{bmatrix} T_{fx1} \\ T_{fx2} \\ \vdots \\ T_{fxm} \end{bmatrix} \quad \boldsymbol{T_{fy}} = \begin{bmatrix} T_{fy1} \\ T_{fy2} \\ \vdots \\ T_{fym} \end{bmatrix} \tag{1}$$

Where: $\boldsymbol{f}$—load vector; $\boldsymbol{f_1}, \boldsymbol{f_2} \cdots \boldsymbol{f_m}$—action component of the load vector on the discretization node; $\boldsymbol{x_f}$—load on the $\boldsymbol{x}$-axis component; $\boldsymbol{y_f}$—load on the$\boldsymbol{y}$-axis component; $\boldsymbol{T_{fx}}$—load on the $\boldsymbol{x}$-axis Moment vector; $\boldsymbol{T_{fy}}$—Moment vector of load to $\boldsymbol{y}$ axis.

(1) In the formula, 5 vectors define the load state at a certain moment. For the load spectrum at different times, according to the above formula, a vector sequence about the load state is formed. And each load vector in the sequence has one and only one strain response corresponding to it. The strain response can also be expressed in a vector form, as shown in equation (2):

$$\boldsymbol{\varepsilon} = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_k \end{bmatrix} \tag{2}$$

In the formula: $\boldsymbol{\varepsilon}$—response strain, $\boldsymbol{\varepsilon_1}, \boldsymbol{\varepsilon_2} \cdots \boldsymbol{\varepsilon_k}$—strain output. Under the same structure, the load state and the strain response at a certain moment correspond uniquely. If there is an error in the load vector $\boldsymbol{f}$ during the loading process, the response strain ε will also fluctuate within a certain range after the structural transfer, and the two behaviors still correspond. However, if the structure undergoes unrecoverable changes such as damage at a certain time, even in the same structural state, the response strain $\boldsymbol{\varepsilon}$ will inevitably change greatly. So if you can define the "same structure state", and then observe whether there is a significant change in the corresponding response strain vector $\boldsymbol{\varepsilon}$ when different load vectors $\boldsymbol{f}$ are applied, then you can judge whether the structure has unrecoverable changes such as damage. Normalize the vector [9]. Taking $\boldsymbol{\varepsilon}$ as an example, dividing each component of equation (2) by a factor $\sqrt{\boldsymbol{\varepsilon}_1^2 + \boldsymbol{\varepsilon}_2^2 + \cdots + \boldsymbol{\varepsilon}_k^2}$,, we get:

$$\bar{\boldsymbol{\varepsilon}} = \begin{bmatrix} \boldsymbol{\varepsilon}_1 \\ \boldsymbol{\varepsilon}_2 \\ \vdots \\ \boldsymbol{\varepsilon}_k \end{bmatrix} \Bigg/ \sqrt{\boldsymbol{\varepsilon}_1^2 + \boldsymbol{\varepsilon}_2^2 + \cdots + \boldsymbol{\varepsilon}_k^2} \tag{3}$$

Where $\bar{\boldsymbol{\varepsilon}}$ represents normalized $\boldsymbol{\varepsilon}$.

$$\cos \boldsymbol{\theta}_i = \boldsymbol{\varepsilon}_i \Big/ \sqrt{\boldsymbol{\varepsilon}_1^2 + \boldsymbol{\varepsilon}_2^2 + \cdots + \boldsymbol{\varepsilon}_k^2} \qquad (\mathbf{1} \ll \boldsymbol{i} \ll \boldsymbol{k}) \tag{4}$$

Where: $\cos \boldsymbol{\theta}_i$—cosine component, the value of which varies between [0, 1]. Obviously, after the structure has undergone irreversible changes and expanded to a certain extent, the cosine component corresponding to the strain $\boldsymbol{\varepsilon}_i$ in the vicinity must change accordingly. If the change exceeds the fluctuation range of the error, it can be determined that a nearby structure has changed.

## 5. Experimental application and result analysis

After the wireless monitoring system is completed in hardware and theory, it still needs one step to verify the comprehensive reliability of the entire system through experiments. With the support of Shanghai Logistics Co., Ltd., we tested the on-line monitoring system of sanitation container wireless transmission at the Hulin refuse transfer terminal.

The system test experiment object is a sanitation container with a size of 6058mm × 2438mm × 2438mm. Material Q235, weight 2.840t. The box body is composed of a skeleton and a panel, the box skeleton is welded by square steel, and the box panel is welded on the box skeleton. A total of 12 BA-OFS30 fiber grating sensors are installed symmetrically on both sides of the box.

As shown in Fig 6, the processor module and the wireless terminal are installed and fixed on the top of the box. Using a laptop computer for channel detection, confirm that the 12 sensors are properly connected to the processor. And set the IP, turn on the power, and the system runs.

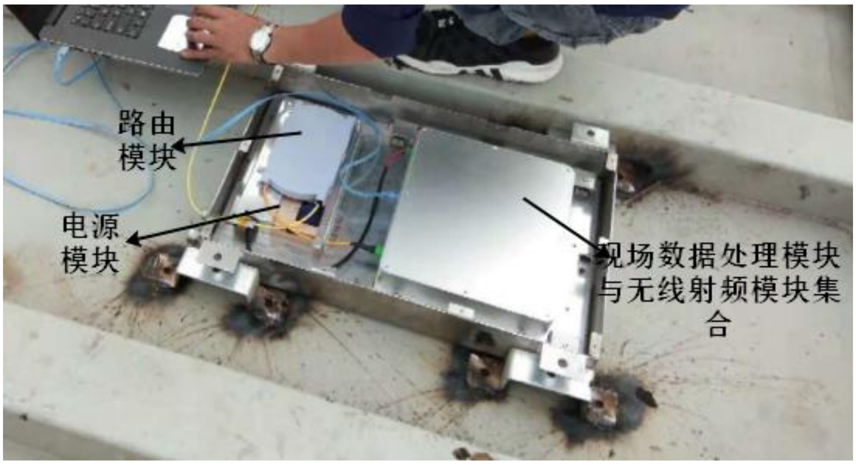


Fig .6. Experimental site

### 5.1 Experiment Log

In the experiment, we took the strain data at two different load percentages in the sanitation container test experiment. As shown in Table 1.

Table 1 Strain test results of sanitation containers

| Case number | Measuring point | Strain（$10^{-6}$） | Strain（$10^{-6}$） |
|---|---|---|---|
| 1556 | 1 | 109.746 | 109.746 |
| | 2 | 1151.04 | 1151.04 |
| | 3 | 488.04 | 488.04 |
| | 4 | 508.956 | 508.956 |
| | 5 | 1147.98 | 1147.98 |
| | 6 | 892.928 | 892.928 |
| | 7 | 512.148 | 512.148 |
| | 8 | 1054.52 | 1054.52 |
| | 9 | 585.312 | 585.312 |
| | 10 | 214.389 | 214.389 |
| | 11 | 992.94 | 992.94 |
| | 12 | 361.008 | 361.008 |

In the test, the box should be placed vertically during compression loading, and the garbage is compacted by the pressure from the top of the external pressure head. The load is gradually loaded from 0% to 90% level. A 2D load vector and a 3D strain vector are constructed. Obviously, the state of the load vector is not changed from 0 to 90%. as follows:

$$\boldsymbol{f} = \begin{bmatrix} \boldsymbol{f_1} \\ \boldsymbol{f_2} \end{bmatrix} = \begin{bmatrix} \mathbf{25} \\ \mathbf{75} \end{bmatrix}$$

$$\bar{\boldsymbol{f}} = \begin{bmatrix} \mathbf{0.316} \\ \mathbf{0.949} \end{bmatrix}$$

According to the state of the load vector of the structural health inspection model, there is no change throughout the loading process. Under two different load percentages, the normalized strain vector of the box measurement point is:

$$\bar{\varepsilon}_1 = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_{12} \end{bmatrix} \Big/ \sqrt{\varepsilon_1^2 + \varepsilon_2^2 + \cdots + \varepsilon_{12}^2} = \begin{bmatrix} 0.042 \\ 0.440 \\ 0.187 \\ 0.195 \\ 0.439 \\ 0.342 \\ 0.196 \\ 0.404 \\ 0.224 \\ 0.082 \\ 0.380 \\ 0.138 \end{bmatrix} \bar{\varepsilon}_2 = \begin{bmatrix} 0.091 \\ 0.486 \\ 0.241 \\ 0.172 \\ 0.395 \\ 0.313 \\ 0.195 \\ 0.359 \\ 0.206 \\ 0.059 \\ 0.415 \\ 0.167 \end{bmatrix}$$

For the normalized strain vectors for two different load percentages next time, it was found that no cosine component corresponding to the measured point component changed beyond the [0,1] error fluctuation range. This shows that no irreversible structural changes occurred in this measurement point, and the cabinet structure is safe. After the actual test was over, after inspection, no unrecoverable structural changes such as cracks were indeed found at the measuring points of the box.

### 5.2 Result analysis

According to the above experimental results, according to the theory of structural health monitoring, although the above measurement points do not exceed the range of error fluctuations, the cabinet structure is safe. However, considering the actual situation, the number of measuring points is limited, and the structural safety of the limited measuring points does not mean that the overall structure of the container is not abnormal. In view of this situation, on the one hand, you can choose to install the measuring points at positions where the container is prone to structural damage according to experience. In the case that the cosine variation component does not exceed the error range, the set measuring point component $\boldsymbol{\varepsilon_i}$ corresponds to the cosine component variation range. If the variation value exceeds the set range, an alarm prompt function is made. The smaller the setting change range, the larger the monitoring area, and the larger the setting change range, the smaller the monitoring area. The specific range can be adjusted according to the accuracy requirements of the wireless monitoring system.

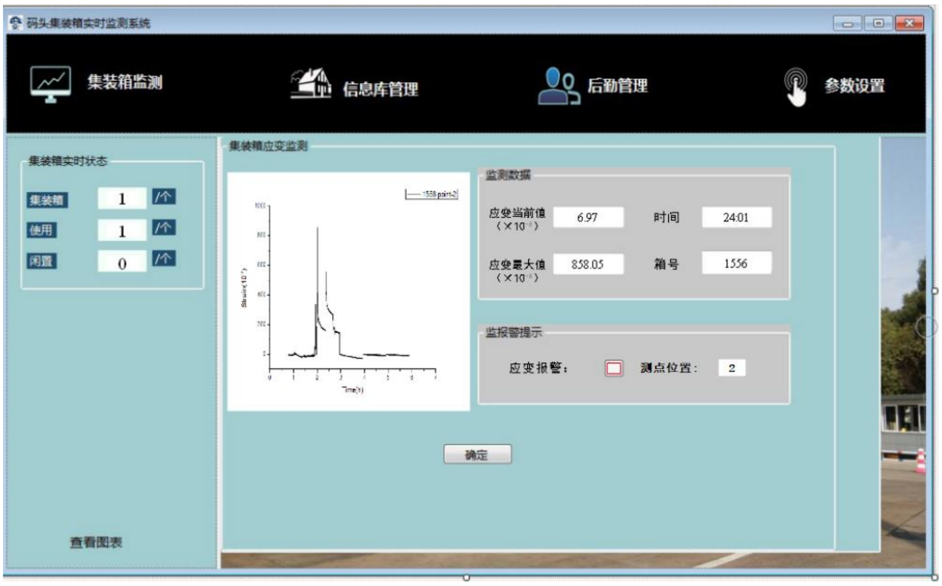


Fig. 7. Interface diagram of sanitation container structure health monitoring system

### 5.3 Experimental results show

The interface of the sanitation container structure health monitoring system is shown in Fig 7. The above-mentioned experimental logic principle is displayed in the form of program software in the monitoring center. Real-time reflect the change of strain at the measuring point of the monitoring box, and present the historical maximum, minimum strain, and real-time strain. Based on the above structural health monitoring theory, the box strain data collected at the front end is processed, and the measurement points for which the system judges structural abnormal changes in the calculation results are alerted. Alarms, etc. turn red and the measuring point position is displayed.

## 6. Conclusion

In this paper, ZigBee wireless sensing technology is applied to the health monitoring of sanitation container structures, and a wireless monitoring and diagnostic system is designed. Basically solve the problem that the traditional sanitation container detection method takes a long time, is not timely, and can only detect the health of the container structure under static conditions, which cannot reflect the actual situation. The wireless monitoring system improves the existing sanitation special container reliability inspection mode, and can make a timely judgment on the health status of the sanitation container structure. The device has a simple structure, reliable performance and strong practicability. It is a set of low-cost solution examples for a wireless monitoring system and has certain market value.

Acknowledgements

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