

Intelligent Termite Prevention and Control System Based on Acoustic Monitoring and Chemical Repellency

Yolanda Jin¹, Shude Ye², Ruowen Yin³, Ruoyi Zhu⁴

¹YK Pao School, Shanghai, China

²Shanghai Weiyu International School, Shanghai, China

³YK Pao School, Shanghai, China

⁴Shanghai Pinghe School, Shanghai, China

Abstract: As ancient and wood-structured buildings require stronger protection, precise termite control has grown into an urgent industrial demand. Termite infestations are highly concealed and damaging, making early detection difficult for non-professionals using traditional manual inspections. Conventional approaches are inefficient, high-risk, or lack intelligent coordination, often resulting in irreversible structural loss. This study develops an intelligent green termite control system featuring precise monitoring, active intervention, green repellency and intelligent management. It uses a bionic piezoelectric sensor array, vibration interference modules, natural plant essential oils and an IoT cloud platform to achieve real-time detection, safe repellency and remote intelligent management. Experimental results show that the system greatly shortens detection time, improves control efficiency and achieves zero chemical pollution, providing a practical intelligent solution for termite prevention in wood-structured buildings.

Keywords: Termite Prevention and Control; Piezoelectric Sensing; Vibration Interference; Plant Essential Oil; Cloud Interconnection; Green Prevention and Control

1. Introduction

1.1. Research Background

In the practice of maintaining ancient and civil wooden buildings, I have realized the importance of precise termite control for structural safety. Termite infestation is highly concealed, and as shown in Figure 1, internal gnawing damage is difficult to detect early. Traditional manual inspection depends heavily on experience and often leads to delayed detection and irreversible damage, while conventional chemical and physical methods are either polluting or unable to form an effective control loop.

Most current termite control products rely on single chemical or physical measures, lacking accurate early monitoring and green active intervention. This hinders industrial upgrading and conflicts with the development of green and intelligent construction. Therefore, this study proposes an intelligent green termite control system integrating piezoelectric sensing, biological interference, plant essential oil repellency and cloud IoT. It aims to realize real-time detection and active intervention, reduce technical and cost thresholds, and promote the green and intelligent transformation of the termite control industry[1-2].



Figure 1 Damage caused by termite infestation

1.2. Solution

(1) Goal: Solve the concealment and difficulty of early termite monitoring.

Solution: A high-sensitivity piezoelectric sensor array and calibrated recognition algorithm are used to detect termite vibration signals in real time. The system achieves 24-hour non-destructive monitoring, shortening the detection cycle to second-level with a detection distance over 1.8 meters.

(2) Goal: Solve high pollution and passive intervention of traditional methods.

Solution: A dual active intervention system is designed: vibration interference simulating natural enemies to disrupt termite communication, and green plant essential oils released by ultrasonic atomization for safe repellency.

(3) Goal: Realize remote intelligent management.

Solution: A cloud IoT platform and mobile APP are built for real-time data upload, remote monitoring, early warning and automatic report generation, realizing integrated intelligent management..

1.3. Expected Results and Conclusions

The intelligent green termite control system will reduce technical and cost thresholds, transforming from "passive killing" to "active prevention". Integrating key technologies, it identifies early invasion, avoids environmental risks, and provides a new solution for wood-structure building protection, promoting industrial upgrading and heritage inheritance.

1.4. Research Significance and Innovation Points

1.4.1. Research Significance

This research solves wood-structure termite control problems (concealment, passive intervention, pollution). It establishes an intelligent closed-loop system, provides an eco-friendly tool, fills market gaps, drives industrial transformation, and supports heritage protection and wood-structure building promotion.

1.4.2. Innovation Points

Bionic Sensing Monitoring: Uses a piezoelectric ceramic sensor array (calibrated 2–8 kHz) to detect hidden termite activities, shortening detection to seconds and covering over 1.8 meters.

Dual Active Intervention: Pollution-free methods (natural enemy signals + ultrasonic atomized plant oils) block termite communication and repel termites ecologically.

Cloud Intelligent Management: IoT and mobile APP enable real-time data upload, early warning and digital management, replacing manual records.

2. Background and Demand Investigation

2.1. Research Status at Home and Abroad

2.1.1. Domestic Research Status

Domestic termite control research started late but developed rapidly, focusing on chemical agent improvement and physical monitoring devices. Low-toxic slow-release chemical agents reduce pollution but cannot eliminate chemical residues. Physical monitoring mainly relies on bait traps, which have long cycles and no real-time early warning. Recent studies have applied piezoelectric and acoustic sensors in laboratories, but few are practical due to poor sensor anti-interference and lack of linkage with intervention systems[3-4].

2.1.2. Foreign Research Status

Foreign termite control research started earlier with diverse directions: biological control (using natural enemies like nematodes and fungi, eco-friendly but environment-dependent and hard to popularize), pheromone interference (unstable effect and high cost), and acoustic monitoring (accurate professional systems but large, costly and unsuitable for civil buildings).

2.2. Research Status of Related Technologies

In recent years, China has issued policies supporting green, low-carbon and intelligent construction, creating a favorable policy environment for intelligent and green termite control systems. Driven by the protection of ancient buildings and the application of wood-structure buildings, the termite control industry is moving towards greenization, intelligence and integration. Non-chemical and IoT-based monitoring technologies have become research hotspots, and the market demand for efficient and eco-friendly solutions continues to rise.

2.3. Analysis of Related Market Products

Intelligent termite monitoring devices mainly include bait-type and sensor-type ones. Bait-type devices are low-cost and easy to install but cannot provide real-time early warning, while sensor-type devices support real-time monitoring yet feature high environmental requirements, poor anti-interference and high cost, mostly for large ancient building complexes.

Traditional chemical termiticides act fast but cause serious pollution and safety risks. Although low-toxic and eco-friendly products have become mainstream, their residue still makes them unsuitable for ancient buildings and indoor scenes.

Natural plant-derived repellents are safe and eco-friendly, but suffer from short effective duration and unstable efficacy. Most spray-type products need regular manual application, resulting in high labor costs and difficulty in large-scale application.

3. Prototype Design

3.1. Concept Diagram

3.1.1. Source of Inspiration

The system is designed based on the bionic principle of a stethoscope and the biological characteristics of termites. Its high-sensitivity piezoelectric sensor array captures weak vibrations generated by termites inside wood. Using termites' vibration-based communication, the vibration interference module disrupts their behavior and repels them. Combined with plant essential oil repellent technology, a green barrier is formed to realize dual protection..

3.1.2. Concept Structure Diagram

The concept structure of the system is divided into three layers: perception layer, intervention layer and management layer , as shown in Figure 2.

Perception Layer: It is composed of piezoelectric ceramic sensor array, silica gel shock-absorbing gasket and signal acquisition module, which is responsible for collecting and transmitting vibration signals from termite activities.

Intervention Layer: It is composed of vibration interference module and plant essential oil atomization module, which is responsible for implementing active intervention measures after identifying termite invasion signals.

Management Layer: It is composed of cloud platform and mobile APP, which is responsible for data storage, analysis, early warning and remote control.

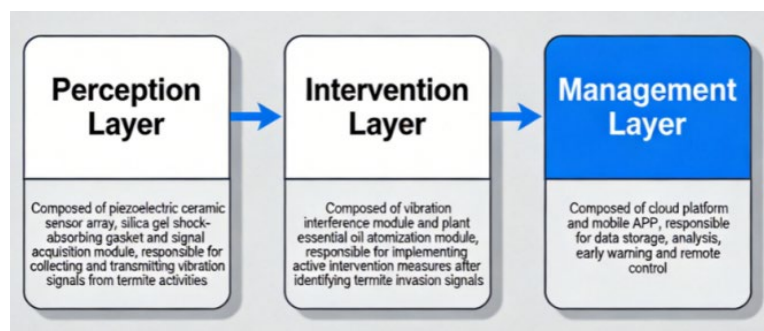


Figure 2: Concept structure diagram

3.2. Flow Chart

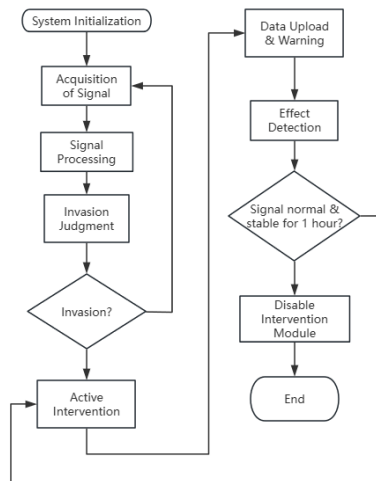


Figure 3: Flowchart

The logic flow of the system is as follows:

(1) System Initialization: The sensor array, intervention module and communication module are self-checked, and the recognition threshold of termite activity signals is preset.

(2) Signal Collection: The sensor array collects vibration signals inside the wood in real time and transmits them to the main control module.

(3) Signal Processing: The main control module processes the collected signals, filters out environmental noise, and extracts characteristic values.

(4) Invasion Judgment: The main control module compares the extracted characteristic values with the preset threshold. If the threshold is reached, it is judged as termite invasion; otherwise, it returns to the signal collection stage.

(5) Active Intervention: After judging termite invasion, the main control module starts the vibration interference module and the plant essential oil atomization module at the same time to implement double intervention.

(6) Data Upload and Early Warning: The main control module uploads the invasion information and intervention records to the cloud platform, and the cloud platform pushes early warning information to the mobile APP.

(7) Effect Detection: The sensor array continues to collect signals to detect whether termites have evacuated. If the signals return to normal and remain stable for 1 hour, the intervention module is closed; otherwise, the intervention is continued, as shown in Figure 3.

3.3. Hardware Block Diagram

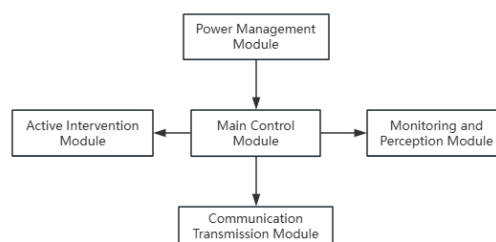


Figure 4: Hardware Block Diagram

The hardware of the system is composed of five modules: power management module, main control module, monitoring and perception module, active intervention module and communication transmission

module.

(1) Power Management Module: It is composed of lithium battery pack and voltage stabilizing circuit, which provides stable power supply for each module.

(2) Main Control Module: It adopts an expandable core chip, which is responsible for signal processing, invasion judgment, intervention control and data transmission.

(3) Monitoring and Perception Module: It is composed of piezoelectric ceramic sensor array, silica gel shock-absorbing gasket and anti-interference shielded wire, which is responsible for collecting vibration signals from termite activities.

(4) Active Intervention Module: It includes vibration interference sub-module and plant essential oil atomization sub-module, which is responsible for implementing active intervention measures.

(5) Communication Transmission Module: It adopts WIFI/Bluetooth wireless communication module, which is responsible for data interaction between the main control module and the cloud platform , as shown in Figure 4.

4. Prototype Development

4.1. Development Process

(1) Hardware Development Environment: 3D printer, oscilloscope, soldering station, multimeter, etc.

(2) Software Development Environment: Arduino IDE, Python, Android Studio, etc.

4.2. Development Process

(1) Hardware Selection and Purchase: According to the system design requirements, select and purchase core hardware such as piezoelectric ceramic sensors, STM32 main control chips, vibration motors, ultrasonic atomization sheets, stepping motors and WIFI modules , as shown in Figure 5.

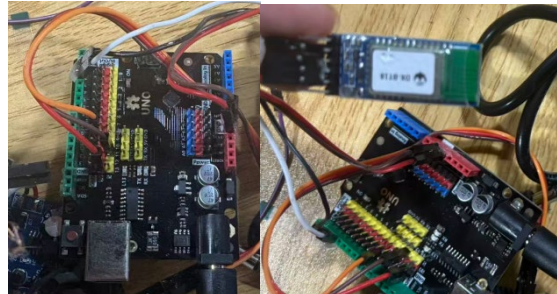


Figure 5: Hardware Selection

(2) Hardware Design and Processing: Use CAD software to design sensor fitting bases, liquid storage chamber brackets and device shells, and process them through 3D printing; complete the circuit design of each module, and weld and assemble the hardware , as shown in Figure 6.



Figure 6: Hardware Design and Processing

(3) Software Development: Use Arduino IDE to develop the control program of the main control module, including signal collection, signal processing, invasion judgment and intervention control; use Python to develop the cloud platform data management program; use Android Studio to develop the mobile APP , as shown in Figure 7.

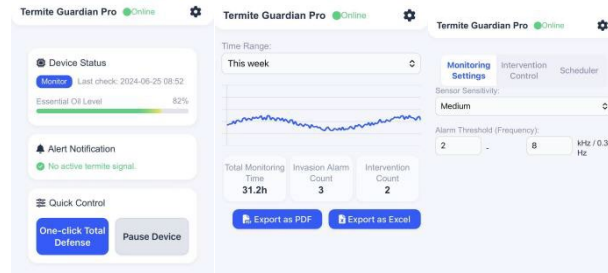


Figure 7: APP Interface

(4) Software and Hardware Joint Debugging: Connect the hardware and software, test the function of each module, and adjust the parameters according to the test results to ensure the stable operation of the system , as shown in Figure 8.

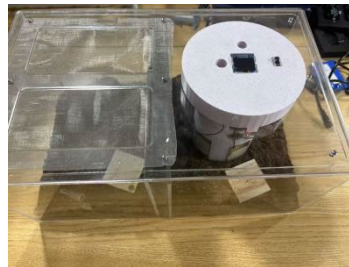


Figure 8: Final Physical Prototype

5. Experimental Design and Test Analysis

5.1. Experiment 1: Accuracy Experiment of Vibration Monitoring Module

5.1.1. Experiment Preparation

Samples: 3 groups of *Coptotermes formosanus* (50 each), 1 group of wood-boring beetles and 1 group of ants (30 each), 6 pine test pieces (20cm×10cm×5cm).

Equipment: System sensor array (4 sensors), main control module, shielded wire, shock-absorbing gasket, noise generator, high-speed camera, signal acquisition instrument.

Environment: Constant temperature and humidity laboratory (25°C±1°C, 70%±5%), 6 independent experimental boxes with humus soil and test pieces[5].

5.1.2. Experiment Steps

- (1) Deploy equipment, set recognition thresholds, and link instruments to record signals and results.
- (2) Conduct control tests: monitor 3 termite groups, 2 control insect groups and 1 blank group for 24 hours, recording recognition results and response time.
- (3) Conduct interference tests: simulate wind noise and personnel vibration for 6 hours per box, recording accuracy and false alarms.
- (4) Sort out data including recognition accuracy, average response time and false alarm rate.

5.1.3. Experimental Results

Table 1: Performance data of vibration monitoring module in different scenes.

Experimental Scene	Group	Recognition Accuracy (%)	Average Response Time (s)	False Alarm Rate (%)
Non-interference (termite)	Termite group 1	96.7	2.1	0
Non-interference (termite)	Termite group 2	97.2	1.9	0
Non-interference (termite)	Termite group 3	95.8	2.3	0
Non-interference	Wood-boring	0	-	3.2

(other insects)	beetle group			
Non-interference (other insects)	Ant group	0	-	2.8
Non-interference (blank)	Blank group	-	-	1.5
Interference (termite)	Mean of termite groups 1-3	92.3	2.7	4.1

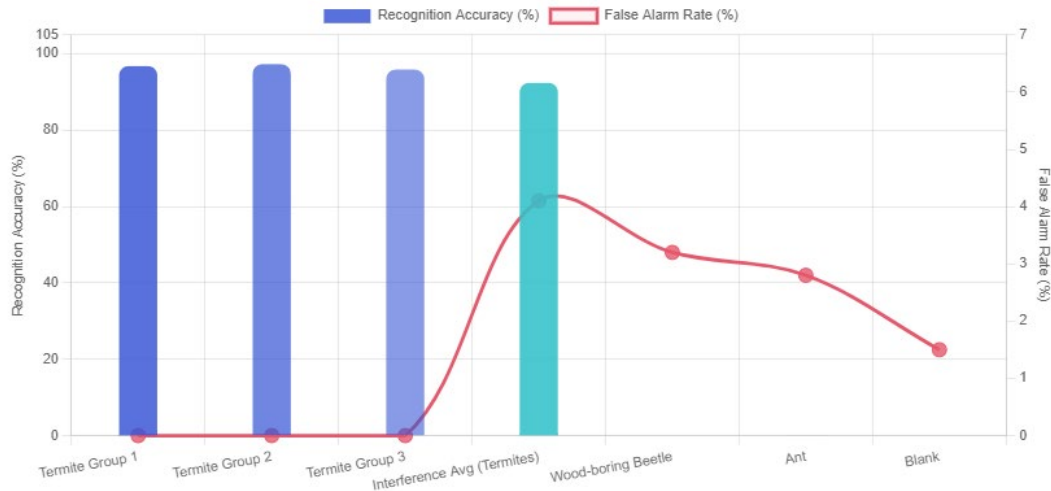


Figure 9: Vibration Module Recognition Performance.

5.1.4. Experiment Conclusion

Under non-interference conditions, the sensor array achieves 96.6% recognition accuracy for termite activity with a 2.1s average response time and no missing reports, meeting second-level monitoring requirements. The false alarm rate is below 3.2% for non-target insects and 1.5% in the blank test. With environmental interference, accuracy drops to 92.3% and false alarm rate rises to 4.1%, while remaining reliable. The noise reduction algorithm needs optimization for better anti-interference performance, as shown in Table 1 and Figure 9.

5.2. Experiment 1: Accuracy Experiment of Vibration Monitoring Module

5.2.1. Experiment Conclusion

To verify the repellent and blocking effect of the “vibration interference + plant essential oil atomization” dual intervention module, compare the efficacy of single and combined interventions, and evaluate its environmental performance and practicality.

5.2.2. Experiment Preparation

Samples: 4 groups of *Coptotermes formosanus* (50 per group), 4 wood test pieces (20cm×10cm×5cm).

Equipment: Vibration module, essential oil atomization module (5% camphor-eucalyptus compound), integrated module, electronic balance, high-speed camera, 4 experimental boxes, activated carbon device.

Environment: Constant temperature and humidity, same as Experiment 1, with feeding and activity zones.

5.2.3. Experiment Steps

(1) Group setup:

Group 1 (control): no intervention;

Group 2: vibration only (1.2kHz continuous);

Group 3: essential oil atomization only (5ml/h, 5min each);

Group 4: dual intervention.

- (2) **Acclimatization:** termites adapt for 24 hours to ensure normal feeding.
- (3) **48-hour test:** record feeding inhibition rate, repelling time, and activity ratio every 6 hours.
- (4) **Environmental test:** detect essential oil residue via activated carbon adsorption and gas chromatography.

5.2.4. Experimental Results

Table 2: Prevention and control effect data of different intervention methods.

Group	48h Solid Wood Mass Loss (g)	Feeding Inhibition Rate (%)	Average Repelling Time (min)	8h Average Ant Colony Activity (%)	Essential Oil Residue (mg/m ³)
Control group (no intervention)	3.26	0	-	68.5	-
Experimental group 1 (only vibration)	1.42	56.4	42.3	27.8	-
Experimental group 2 (only essential oil)	1.15	64.7	35.6	22.1	0.82
Experimental group 3 (dual intervention)	0.48	85.3	18.9	8.7	0.79

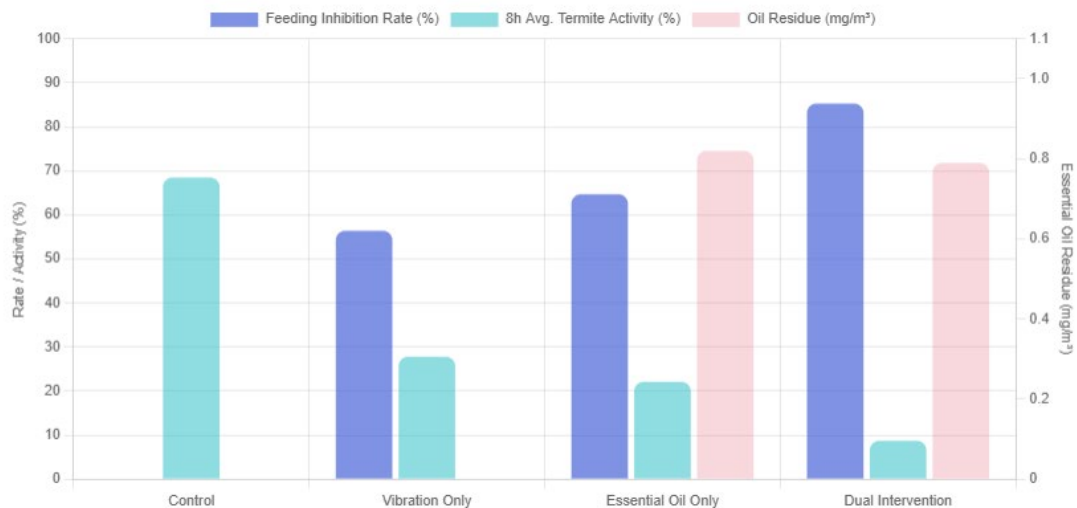


Figure 10: Efficacy of Dual Intervention Methods.

5.2.5. Experiment Conclusion

The dual intervention performs best with an 85.3% feeding inhibition rate, 18.9 min average repelling time and 8.7% termite activity—significantly better than single intervention (inhibition rate < 65%) due to a synergistic effect—while plant essential oil residue is below 0.85 mg/m³ (eco-friendly for sensitive scenes); single interventions cannot fully block feeding, so dual intervention is necessary for efficient control, as shown in Table 2 and Figure 10.

5.3. Experiment 3: System Overall Stability and Scene Adaptability Experiment

5.3.1. Experiment Preparation

Three test scenes: ancient building mortise-tenon joints, indoor wood beams, outdoor garden components.

Equipment: full system, spare battery, APP terminal, recorder.

Samples: termite-attached wood test pieces in each scene.

5.3.2. Experiment Steps

- (1) Install the system suitably for each scene (non-destructive, high-altitude, waterproof).
- (2) Run continuously for 30 days, recording stability, data transmission, battery life and adaptability.

(3) Test under extreme weather in the outdoor scene.

5.3.3. Experimental Results

Table 3: System stability and adaptability data in different scenes.

Experimental Scene	30-day Failure Rate (%)	Data Upload Success Rate (%)	APP Early Warning Response Time (s)	Lithium Battery Endurance Time (h)	Installation Adaptability Score (1-5 points)	Extreme Environment Operation Status
Ancient building mortise and tenon	1.2	98.5	3.2	72.3	5	- (no extreme environment)
Residential wood beam	0.8	99.1	2.8	73.5	4	- (no extreme environment)
Outdoor garden	3.5	96.8	4.1	68.7	4	Normal operation under rainstorm, high and low temperature, data upload success rate decreased to 92.1%

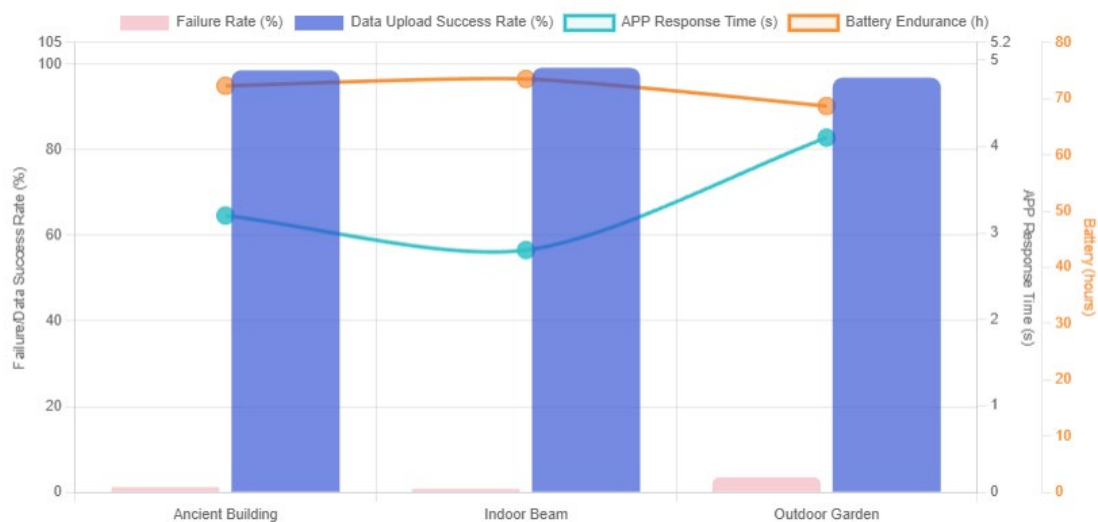


Figure 11: System Stability & Adaptability in Real Scenarios

5.3.4. Experiment Conclusion

The system has excellent stability: 30-day average failure rate 1.8%, data upload success rate 98.1%, APP warning response <4.1s, battery life >68h, meeting long-term operation needs. It adapts well to all scenes—non-destructive installation (5-point score) for ancient buildings, waterproof outdoor resistance to extreme weather (core functions unaffected), and good durability (no core component loss, only slight outdoor sensor dust removable by cleaning), suitable for large-scale promotion as shown in Table 3 and Figure 11.

5.4. Experiment Summary

Three experiments verify the system has high monitoring accuracy, good intervention effect and strong scene adaptability. It achieves second-level termite invasion identification; the dual intervention mode is highly effective and eco-friendly, and it is applicable to ancient buildings, residences, gardens and other wood-structure scenes.

6. Conclusion

This study developed an intelligent green termite prevention and control system integrating

monitoring, intervention and management. It features a closed-loop triple-defense design, high-precision second-level monitoring, and lightweight non-destructive installation suitable for multiple scenarios. The work includes system design, module optimization, scene verification and effect quantification.

Defects include outdoor sensor contamination, limited essential oil capacity and imperfect anti-interference algorithm; future improvements will involve protective design, supply upgrade and AI recognition.

The system has broad application prospects in wood structure protection and provides a reference for green pest control, supporting ecological and building safety.

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