Online ISSN: 3104-9338
Print ISSN: 3104-932X

Design of Intelligent Disinfection Doormat System Based on STM32

Biyuan Tang, Xu Wang*

Chengdu College of University of Electronic Science and Technology of China, China

Received: March 10, 2026

Revised: March 15, 2026

Accepted: March 17, 2026

Published online: March 24, 2026

To appear in: *International Journal of Advanced AI Applications,* Vol. 2, No. 4 (April 2026)

* Corresponding Author: Xu Wang (34106831@qq.com)

Abstract. At present, disinfection at the entrances and exits of public places relies heavily on manual operation. To improve the disinfection efficiency and intelligent level of areas with high-frequency personnel flow, this study adopts a modular design method and a centralized control strategy of the main control chip. Taking the STM32 chip as the system's core control unit, it integrates a stress sensing module, an alcohol atomization disinfection module, an OLED status display module, a Bluetooth communication module and a buzzer prompt module. The system structure is optimized via modular division and function integration, with reasonable control logic and execution process designed to achieve coordinated and stable operation of each module. Finally, a physical prototype is fabricated and performance tests are conducted. Test results demonstrate that the system offers fast response, stable operation and high disinfection efficiency, enabling automatic induction disinfection. It is suitable for high-traffic public places and exhibits excellent practicality and promotional value.

Keywords: *STM32F103 Microcontroller; Intelligent Disinfection Doormat; Alcohol Atomization; Stress Sensing; Performance Test*

1. Introduction

With the development of the times, the public's health awareness has been significantly enhanced, and the prevention and control of health and safety are urgent. Selecting a safe and efficient disinfection method for public place entrances has become an urgent practical engineering challenge.

Considering the requirements for intelligence, safety and convenience in disinfection, many researchers have proposed the design concept of intelligent disinfection doormats in recent years. As early as 2021, a research team has proposed a design idea that integrates gravity sensing technology with ultraviolet disinfection technology, achieving ideal disinfection effect [1]. In 2022, relevant researchers took the STM32 chip as the core control unit, constructed a basic framework of intelligent disinfection doormat including disinfection execution module and human-computer interaction module, providing important technical support for the engineering implementation of the system [2]. In 2023, relevant scholars optimized the design of intelligent alcohol atomization disinfection equipment based on the TRIZ inventive principles, effectively addressing the safety shortcomings of traditional disinfection methods and further enhancing the operational reliability of intelligent disinfection devices [3]. From the above research, it can be seen that the design method of intelligent disinfection doormat has an important impact on the overall performance, structural rationality and development cycle of the product.

Therefore, this study adopts the design idea combining function and structural form, optimizes the matching relationship between system functions and hardware structure, and while shortening the design cycle, enables the system to meet the actual needs of efficient, safe and automatic disinfection in public places.

2. Overall Design of the Intelligent Doormat Control System

The smart doormat disinfection system is primarily designed for the entrance areas of public places with high foot traffic and density, such as hotels, shopping malls, and hospitals. These areas serve as mandatory passageways for personnel entry and exit, and their floor hygiene directly impacts the risk of pathogens spreading into the indoor environment, making them a critical point for infection prevention and control. To address this issue, this system aims to develop an intelligent doormat with automated operation capabilities and efficient sterilization, to minimize the possibility of pathogens carried on soles entering the indoor space, thereby strengthening the hygienic protection of public areas.

Table 1. Correspondence between system core functions and hardware modules.

Core Functional Module	**Automatic Sensing**	**Disinfection Processing**	**Human-Computer Interaction**	**Wireless Communication**	**System Power Supply**
Hardware Implementation Unit	Stress Sensing Module	Alcohol Disinfection Module	Display Module	Bluetooth Module	Power Module

To meet practical application requirements, the product is endowed with the following key functions: First, the system needs a highly sensitive step-sensing mechanism, capable of detecting personnel entry and exit in real-time and autonomously initiating the disinfection process, achieving unattended fully automated operation. Second, it must integrate an immediate and harmless disinfection mechanism to ensure effective sterilization of the soles. Third, it should be equipped with an intuitive human-computer interaction interface, displaying the working status in real-time and providing clear operational feedback for users and administrators. Additionally, the system needs to support short-range wireless communication functionality, facilitating remote status monitoring and parameter setting by staff via mobile terminals or a management backend. Finally, the system should have a continuous and stable power supply solution to meet the demands of long-term, uninterrupted operation.

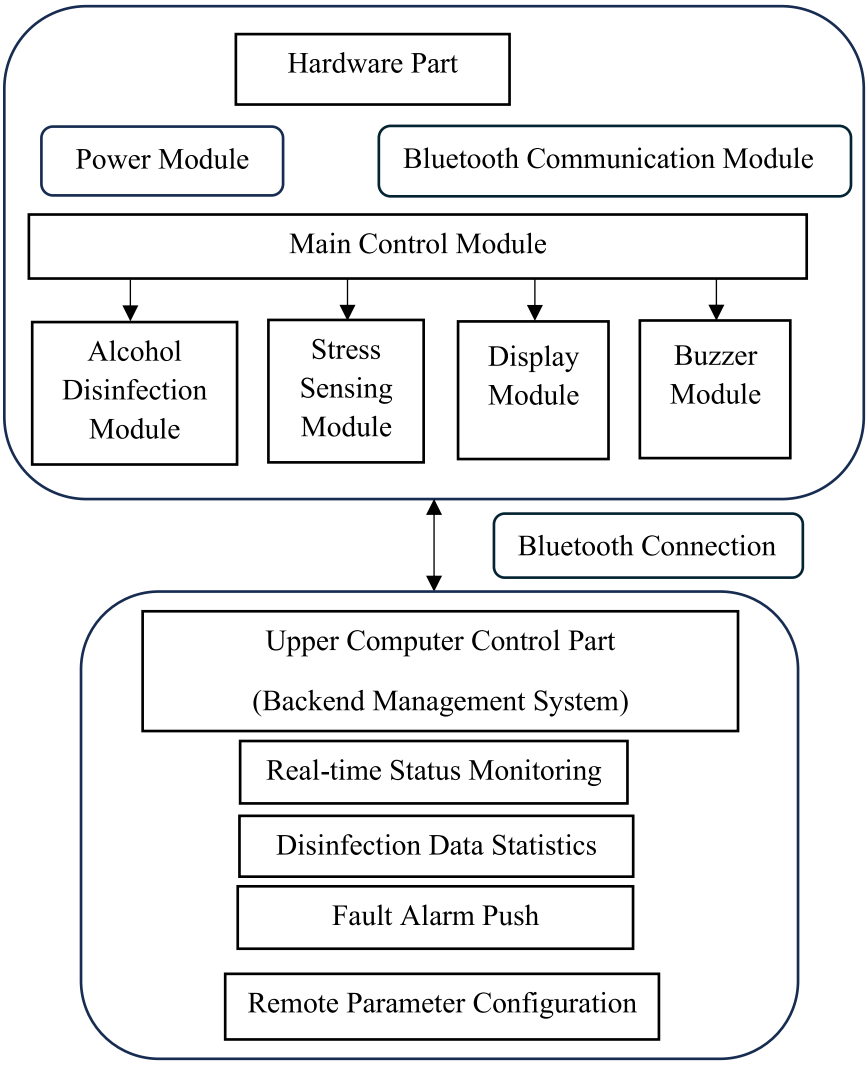

Figure 1. Overall layout of the system.

At the hardware implementation level, this system adopts a modular design concept, establishing a hardware architecture centered around an STM32 main controller. Each core function is realized by a dedicated hardware module, with the specific correspondences shown in Table 1. Specifically, the automatic sensing function is accomplished by the stress sensing module, the disinfection processing function is achieved by the alcohol disinfection module, human-computer interaction is conducted via the display module, the wireless communication function is supported by the Bluetooth module, and stable power supply for the entire system is ensured by the power module.

Through the collaborative work of each module and the organic integration via the system bus, a fully functional and efficient intelligent disinfection doormat system is collectively formed.

3. Hardware Design of the System

The hardware design of the smart disinfection doormat system is based on the overall system architecture shown in Figure 1. A comprehensive discussion is carried out closely around core functional units such as the STM32 main control chip, the alcohol atomization disinfection module, and the stress sensing module. The work sequentially covers the selection of key components for each module, performance matching, and the schematic design of the hardware circuits, while also considering interface compatibility between modules and circuit stability. This forms a complete and implementable hardware solution, laying a solid and reliable hardware foundation for the subsequent software programming development, program debugging, and the fabrication, assembly, and testing of the physical prototype.

3.1. Main Control Module Design

As the core unit of the entire system, the main control module must possess strong processing capability, rich peripheral interfaces, and excellent real-time response performance to realize the coordinated scheduling and stable operation of multiple modules such as stress sensing, disinfection control, status display, and wireless communication. Based on a comprehensive consideration of the system's processing performance requirements, development cost control, and development ecosystem support, combined with the relevant research results in References [4-5], this design selects the STM32F103C8T6 microcontroller as the main control chip, and its minimum system is shown in Figure 2.

This type of microcontroller is based on the high-performance ARM Cortex-M3 core with a main frequency of up to 72 MHz Compared with traditional 8-bit or 16-bit single-chip microcomputers (such as the 51-series single-chip microcomputers, which usually have a main frequency of 12 MHz), its data processing speed is significantly improved. It can efficiently complete real-time multi-task scheduling, ensuring the system's rapid collection and response to sensor signals, as well as the coordinated and smooth operation of each functional module.

Rich peripheral resources are the core basis for the selection of the main control chip: first, the chip integrates multiple advanced timers, which can generate high-precision PWM signals to accurately control the atomization volume of the alcohol atomization module and ensure the stability of disinfection effect; second, it has built-in various standard communication interfaces such as I2C, SPI, and USART, which can realize seamless connection with OLED display screen, Bluetooth communication module, and digital sensor, simplifying the complexity of hardware connection;

third, the chip has a built-in ADC conversion unit, providing convenient and reliable hardware support for the collection of analog signals output by the stress sensor.

Table 2. STM32F103C8T6 Main Parameters.

Kernel	Flash Capacity	CCM	Main Frequency	Peripheral Resources	Kernel
Cortex-M3	64 KB	20 KB	72 MHz	PWM,SPI,I2C,USART,etc.	Cortex-M3

In addition, the STM32F103C8T6 is equipped with 64KB Flash storage space and 20KB SRAM running memory, and its storage capacity is sufficient to carry the complex program logic and data cache requirements of the system. This type of chip has an extremely high popularity in the market. It not only has the advantages of low cost and stable supply, but also has a mature STM32Cube development ecosystem and abundant technical data and development cases, which can effectively reduce development difficulty and significantly shorten the product development cycle.

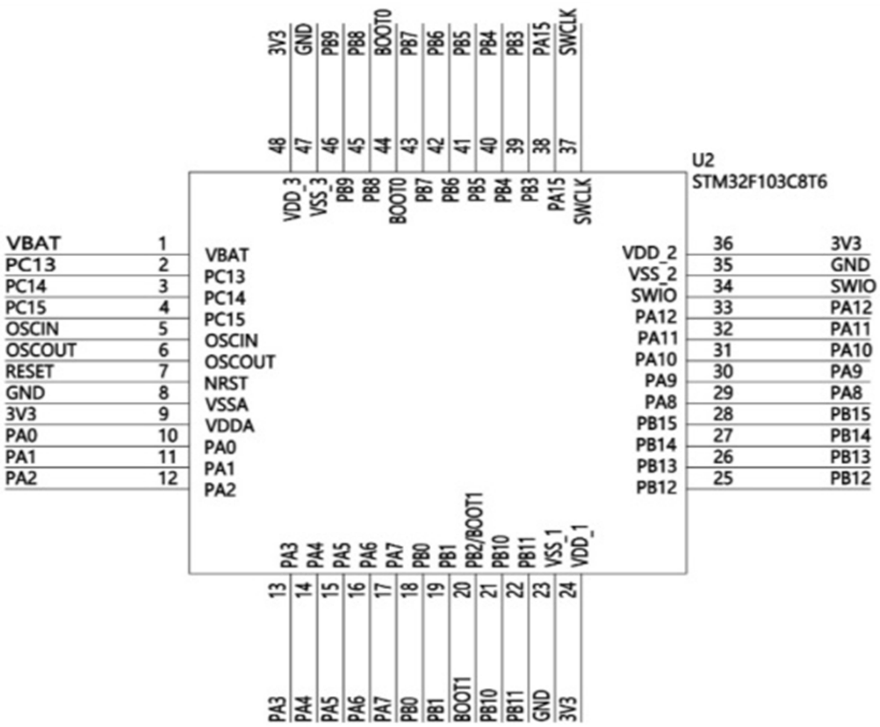

Figure 2. STM32F103C8T6 main controller.

In summary, the STM32F103C8T6 microcontroller achieves the optimal balance between performance, function, and cost, can fully meet the main control requirements of the intelligent disinfection doormat system, and is the optimal selection for this design.

3.2. Alcohol Disinfection Module Design

This module utilizes ultrasonic atomization technology. Compared to traditional liquid spraying disinfection methods, it offers the advantages of uniform atomization, no residue, and high disinfection efficiency, effectively preventing issues such as slippery floors and disinfectant waste.

.

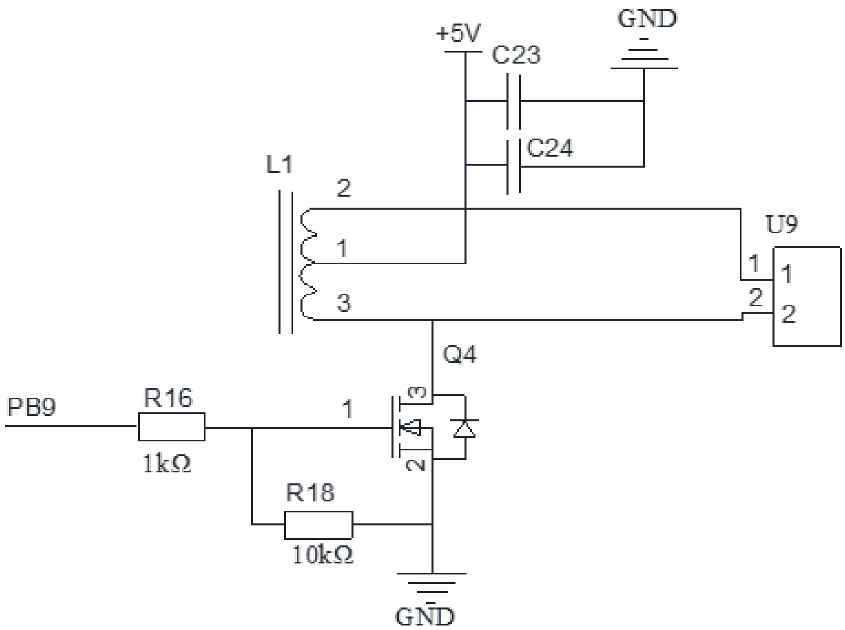

Figure 3. Alcohol disinfection module.

To achieve efficient atomization and ensure that disinfectant particles uniformly cover the disinfection area, this design employs a high-performance piezoelectric ceramic transducer as the core atomization component. The mechanical vibration frequency generated during its operation ranges from 1.7 to 2.4 MHz Within this frequency range, a 75% concentration alcohol disinfectant can be efficiently broken down into fine particles of 1–5 μm [6]. Droplets of this particle size ensure the disinfection effect while evaporating quickly to avoid residue. The system's main controller precisely adjusts the spray volume by regulating the PWM signal. The specific circuit design of the alcohol disinfection module is shown in Figure 3.

3.3. Stress Sensing Module Design

The stress sensing module serves as the signal acquisition core of this intelligent disinfection doormat system. It is primarily responsible for real-time detection of pressure signals generated when a person steps on the doormat. Once an effective gravity trigger signal is sensed, it immediately sends a trigger command to the main controller to initiate the subsequent disinfection action. The detection performance of this module directly determines the timeliness and reliability of the system's response. Therefore, during the design process, key considerations such as detection sensitivity, linearity, and anti-interference capability must be prioritized to ensure accurate identification of valid stepping signals, thereby avoiding false triggers or missed detections.

This system employs the IMS thin-film resistive sensor as the core stress detection component. This device offers excellent linear characteristics and detection accuracy, along with a wide sensing range. It is well-suited for various stress detection scenarios encountered in the practical use of the doormat, meeting the system's requirements for precise acquisition of stepping signals [7]. The specific circuit design of the stress sensing module is shown in Figure 4.

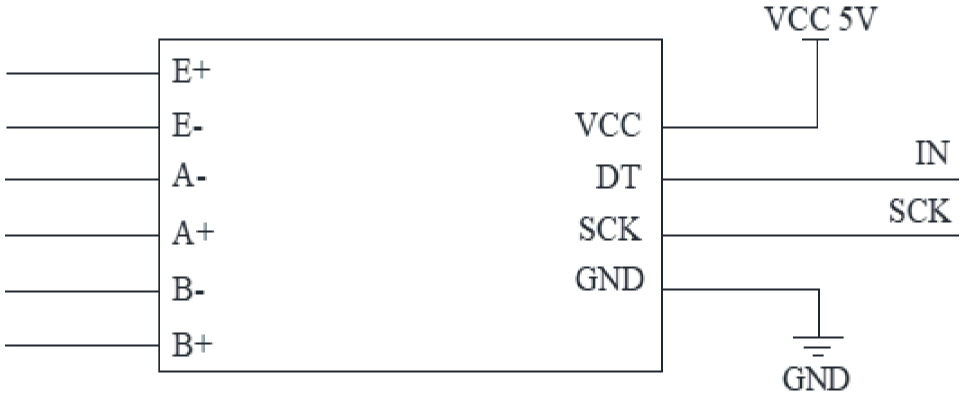

Figure 4. Stress sensing module.

3.4. Bluetooth Module Design

This wireless communication module is mainly used to realize short-range data interaction between the system and mobile devices, facilitating on-site operation and status checking of the doormat by staff. From the perspective of actual application scenario characteristics, intelligent disinfection doormats are mostly deployed at indoor entrance areas of public places such as hotels, shopping malls and hospitals. Such spaces are relatively enclosed, and the typical operation radius of staff is usually no more than 10 meters. Therefore, the system has no stringent requirements for wireless communication indicators such as transmission distance and wall-penetrating capability, but instead prioritizes communication stability, low power consumption, and hardware compatibility with the STM32F103C8T6 main control chip. Based on this application requirement, this study finally selected Bluetooth communication technology as the wireless interaction solution, and precisely adopted the E104-BT5032A Bluetooth module [8]; this module adopts the BLE5.0 low-power Bluetooth protocol, which can effectively reduce the overall power consumption of the system while ensuring the reliability of data transmission, and is highly compatible with the low-power operating modes of the STM32F103C8T6.

In terms of hardware adaptation, the E104-BT5032A Bluetooth module achieves seamless connection with the STM32F103C8T6 main control chip through the USART serial communication interface — the STM32F103C8T6 has 3 built-in USART peripheral interfaces, and USART2 is selected as the communication port in this design. This port supports full-duplex asynchronous communication and configurable hardware flow control, fully meeting the data receiving and transmitting requirements of the Bluetooth module. The effective communication distance of this module can reach 50-70 meters in an open environment, and even in actual indoor application scenarios with multiple wall obstructions, the effective communication distance can still cover the operating range around the disinfection doormat, which is sufficient to meet the needs of staff to complete parameter setting, status query and other operations through mobile devices. The core technical parameters of this module are shown in Table 3. Its supply voltage of 3.6V is compatible with the output of the 3.3V/5V power module of the STM32F103C8T6 system, eliminating the need for additional level conversion circuits and simplifying the complexity of hardware integration.

Table 3. Basic parameters of E104-BT5032A.

Maximum Transmit Power	Bluetooth Protocol	Effective Distance	Receiving Sensitivity	Supply Voltage	Maximum Transmit Power
3.8dBm	BLE5.0	50-70m	-96dBm	3.6V	3.8dBm

3.5. Display Module Design

To provide real-time feedback on the operational status of the disinfection doormat—such as disinfection start/stop status, disinfection duration, and equipment operation status—the system is configured with a display module as the human-computer interaction interface. Based on the system's human-computer interaction requirements and installation space constraints, this study selects a 0.96-inch OLED display with a resolution of 128×64, paired with an SSD1306 driver chip, as the core hardware of the display module.

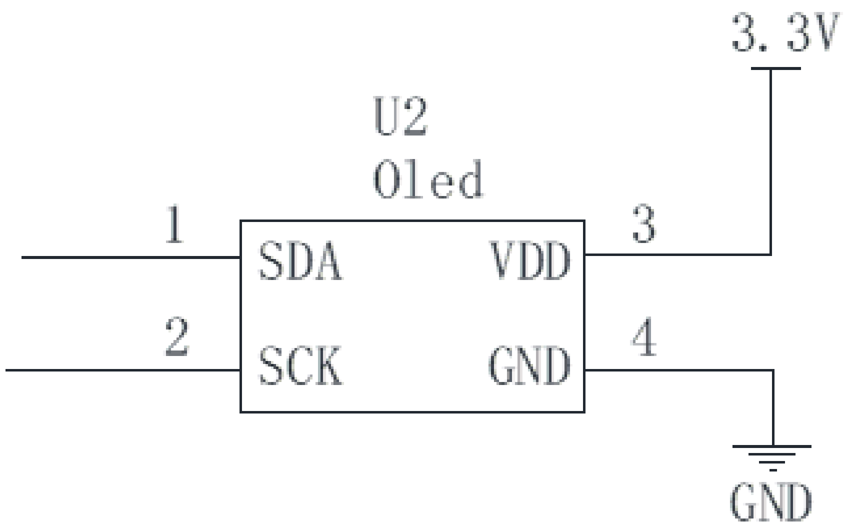

Figure 5. Display module.

The display module is directly driven by the STM32F103C8T6 main control chip through the I2C serial communication interface (one of the built-in peripheral interfaces of the STM32F103C8T6). This chip supports standard I2C communication protocols, enabling stable and low-power data transmission between the main controller and the SSD1306 driver chip, which perfectly matches the low-power characteristics of the OLED display. The display module features self-luminous properties, eliminating the need for an additional backlight unit, and can clearly present information even in the absence of backlighting. It also offers fast response times and low power consumption, enabling timely and accurate feedback on various operational statuses of the disinfection doormat [9].

The specific circuit design of the display module is shown in Figure 5.

3.6. Buzzer Module Design

The buzzer module, as a crucial status feedback unit of the smart disinfection doormat system, is primarily used to provide clear auditory cues at the start or end of disinfection, or when system malfunctions occur. It assists personnel and entrants in quickly identifying the system's operational status, thereby further enhancing the human-computer interaction functionality.

Table 4 . Main parameters of the buzzer module.

Drive Mode	**Operating Frequency**	**Operating Temperature Range**	**Operating Voltage**	**Drive Mode**	**Operating Frequency**
High/Low Level Triggering	2.3KHz	-20℃~+70℃	4~8V	High/Low Level Triggering	2.3KHz

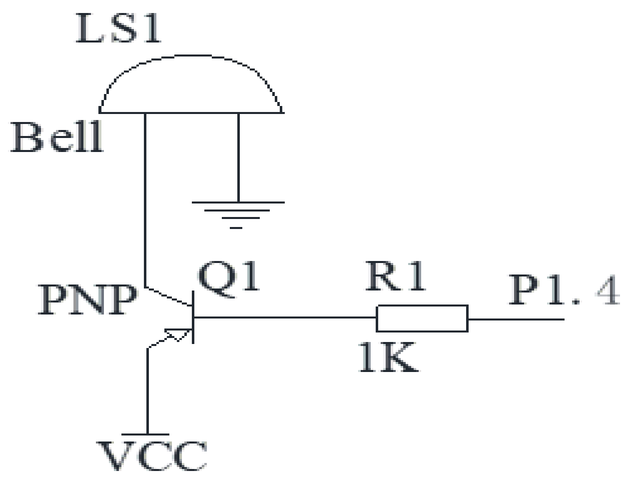

Figure 6. Buzzer module.

This design employs an active buzzer [10], which integrates an internal oscillation circuit, eliminating the need for an additional oscillation driving circuit. Its simple structure helps reduce the number of peripheral components, simplifies the hardware circuit design, and lowers the difficulty of system development and debugging. The driving circuit of the buzzer utilizes a 9012 transistor as the switching element. The main controller outputs control signals through an I/O port to manage the buzzer's operation, with a driving current of up to 30 mA, ensuring stable performance. The buzzer emits a fixed frequency of 2.3 kHz, producing a clear and distinguishable sound. With a sound pressure level, no less than 85 dB measured at 1 meter directly in front, its acoustic characteristics ensure that the alert tones are effectively recognizable against background noise in typical environments. The main parameters of the buzzer module are listed in Table 4, and its circuit design is illustrated in Figure 6.

4. Software Design of the System

4.1. Workflow of the System

After the system is powered on, the main controller STM32F103C8T6 first performs system initialization, sequentially configuring the I/O ports, interrupt parameters, timers, and operating modes of each peripheral module to ensure that all modules can respond correctly to the commands of the main controller.

After the initialization is complete, the system enters the main loop mode, continuously monitoring signals from the force sensing module and waiting for a valid trigger. When a person steps onto the disinfection doormat, the sensor within the force sensing module detects the pressure change in real time, and the collected signal is conditioned and transmitted to the main controller. The main controller performs software filtering on the received force value to eliminate interference and then compares it with a preset threshold. If the detected force value exceeds the preset threshold, it is determined as a valid step trigger, and the disinfection process is immediately initiated.

This process specifically includes:

(1) System Initialization: After the system is powered on, the main controller STM32F103C8T6 first performs system initialization, sequentially configuring the I/O ports, interrupt parameters, timers, and operating modes of each peripheral module to ensure that all modules can respond correctly to the commands of the main controller.

(2) Standby Monitoring: Once the initialization is complete, the system enters the main loop mode, continuously monitoring signals from the force sensing module and waiting for a valid trigger.

(3) Signal Detection and Judgment: When a person steps onto the mat, the sensor within the force sensing module detects the pressure change in real time. The collected signal is conditioned and transmitted to the main controller. The main controller performs software filtering on the received force value to eliminate interference and then compares it with a preset threshold. If the detected force value exceeds the preset threshold, it is determined as a valid step trigger, and the disinfection process is immediately initiated.

(4) Disinfection Process Execution: The disinfection process specifically includes: the main controller activates the alcohol atomization module by outputting precise PWM signals to achieve spray disinfection; controls the display module to clearly show "Disinfecting" on the OLED screen; drives the buzzer to emit an audible alert, informing personnel that disinfection is in progress; and simultaneously starts a timer to precisely control the disinfection duration according to preset

parameters.

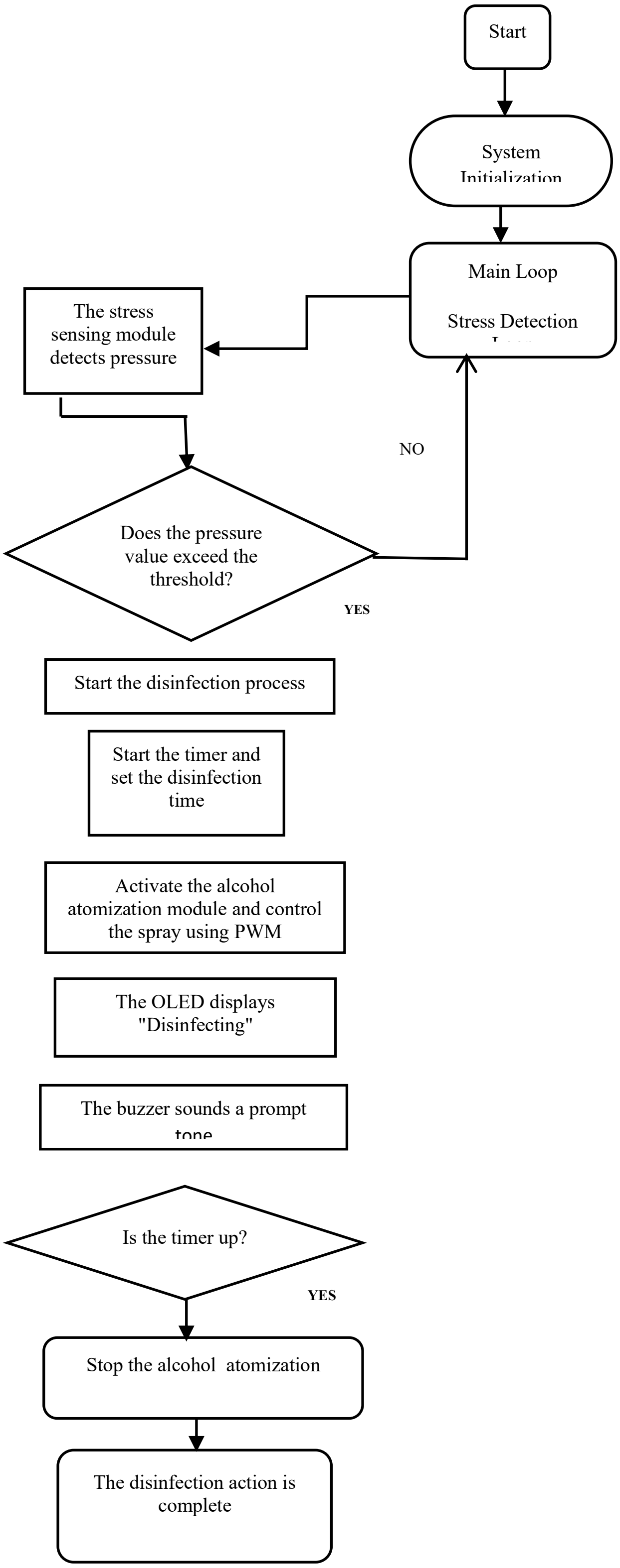

Figure 7. System workflow.

(5) Disinfection Completion and Reset: Once the disinfection duration reaches the preset value, the process automatically ends: the buzzer emits another alert to indicate completion; the OLED display updates to show "Disinfection Complete"; the system then returns to the main loop, continuing to monitor signals from the force sensing module for the next valid trigger.

(6) Remote Control Monitoring: Throughout the system's operation, the Bluetooth module remains in a stable listening state, capable of receiving remote control commands from mobile devices in real time. Personnel can use mobile devices to manually start disinfection, adjust parameters, and perform other operations, enhancing the convenience of system control.

The specific software workflow of the system is shown in Figure 7.

4.2. Upper computer Design

To further enhance the convenience and intelligence of system management, and to meet the requirements for centralized management of the disinfection doormat in the background, this system is equipped with a companion upper computer management platform. The upper computer is primarily designed to facilitate background monitoring of the disinfection doormat's operation by management personnel, enabling real-time insight into the core status of the doormat (such as whether the alcohol level is sufficient, daily disinfection user count, equipment operation faults, etc.) and its operational dynamics, thereby achieving refined management of the equipment.

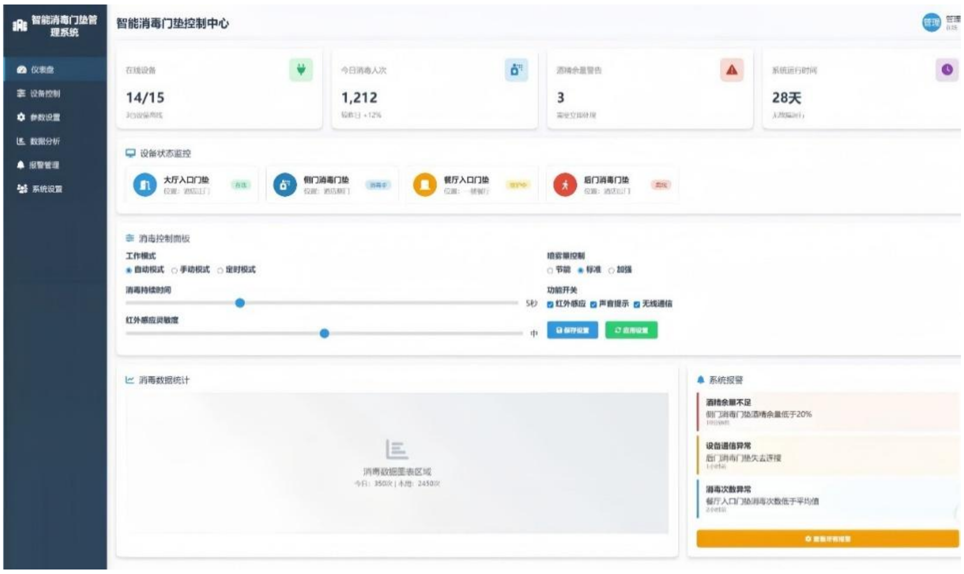

Figure 8. Disinfection doormat management system.

The interface of the disinfection doormat management system us shown in Figure 8. (Chinese Interface)

Based on actual management requirements, the upper computer design is mainly divided into six core modules, each with clear functional positioning and collaborative operation. These modules include:1. Dashboard Module, 2. Device Control Module,3. Parameter Setting Module, 4. Data Analysis Module, 5. Alarm Management Module, 6. System Setting Module. Each module performs its specific functions, collectively enabling comprehensive background control of the disinfection doormat system. [11-12]

5. System Performance Testing

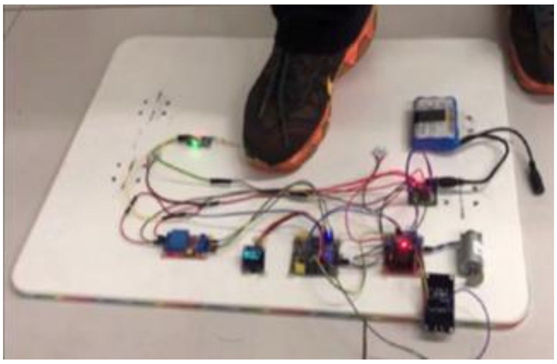

Figure 9. Test process.

After successfully completing the intricate hardware assembly and comprehensive software debugging of the innovative smart disinfection doormat, an initial prototype model was developed to verify the rationality and overall feasibility of the system structure design. This prototype aimed to assess the reliability and smooth collaboration among each individual module, as well as the effectiveness of the core functions integrated within the complete system. Following this important development phase, systematic performance testing was conducted on the prototype to ensure its stable operational capabilities. The primary tests focused on four key performance indicators: response time, operational stability, sensor measurement accuracy, and disinfection efficiency, all of which are essential for evaluating the practical performance and usability of the doormat in various real-world applications. This thorough evaluation process is crucial to ensuring that the doormat meets the necessary standards for modern disinfection solutions.

Table 5. Performance Test Results provides a comprehensive quantitative verification and evaluation of the core performance of the smart disinfection doormat system designed in this study. The table systematically presents the test methods, test results, and preset standards for four key performance indicators: response time, operational stability, sensor measurement accuracy, and disinfection efficiency, clearly reflecting the compliance status of each indicator. From the verification results presented in the table, all test indicators strictly meet the preset design requirements, with no deviation from the preset standards. This fully demonstrates that the system meets design expectations in terms of real-time response, long-term operational reliability, signal detection accuracy, and disinfection effectiveness, making it suitable for practical application scenarios such as hotels and other public places. In summary, the test results in Table 5 effectively validate the scientific nature, rationality, and engineering feasibility of the smart disinfection doormat system designed in this study, providing support for the practical application and promotion of the system, as well as offering insights for the optimization design of similar smart disinfection devices.

Table 5. Performance test results.

Test Indicators	Test Method	Test Results	Preset Standards
Response Time	Simulate normal stepping, record the total time from signal detection to deactivation initiation and display update, repeat the test 30 times, and calculate the average.	The response time (0.32 s on average, maximum 0.5 s) is defined as the total duration from pressure signal exceeding the preset threshold to the initiation of alcohol atomization and OLED status display update. (including the 0.08 s sliding mean software filtering time for stress sensor signals)	Response Time≤1s
Alcohol Consumption	Test the alcohol consumption under continuous effective trigger (one trigger per 5 minutes), record the consumption for 1 hour and calculate the hourly average.	Average consumption: 8.5mL/h, no alcohol leakage	≤10mL/h (economical and practical)
Sensor Measurement Accuracy	Use loads of 40kg, 60kg, and 80kg to simulate stepping, repeating the test 10 times for each weight.	Measurement error≤±2%.	Measurement error≤ ±3%, capable of distinguishing between valid stepping and false triggers.
Disinfection Efficiency	Use 75% alcohol to disinfect samples contaminated with E. coli for 5 seconds, and test the disinfection rate.	Disinfection rate≥99.2%.	Disinfection rate ≥ 99%, complies with relevant standards for disinfection in public places.
False Trigger Rate	Set 4 interference scenarios: light stepping (≤20kg), pet stepping (5-15kg), rolling luggage (10-30kg), environmental vibration; repeat 100 times for each scenario, count the false trigger times.	False trigger rate =0.02%,no missed detection of valid triggers (≥40kg)	≤0.5%
Power Supply Durability	Test with DC 5V/2A power supply (mains power) and 3.7V 10000mAh lithium battery (backup power); record continuous operation time under battery power.	Battery power: continuous operation for 36h (standby) / 12h (continuous trigger); no power supply interruption	Standby ≥24h, continuous trigger ≥ 10h
Response Time	Simulate normal stepping, record the total time from signal detection to deactivation initiation and display update, repeat the test 30 times, and calculate the average.	The response time (0.32 s on average, maximum 0.5 s) is defined as the total duration from pressure signal exceeding the preset threshold to the initiation of alcohol atomization and OLED status display update. (including the 0.08 s sliding mean software filtering time for stress sensor signals)	Response Time≤1s

6. Conclusion

During the design process of the intelligent disinfection doormat control system based on STM32, guided by the actual application scenario requirements of public places such as hotels and the preset core functions of the system, the responsibilities and positioning of main functional modules including alcohol atomization disinfection, stress sensing, OLED display prompt, Bluetooth communication and buzzer status prompt were clarified, and the overall system architecture layout and the logical connection design between various modules were completed. On this basis, the hardware circuit design, component selection and debugging work with STM32F103C8T6 microcontroller as the core were focused on, and the compilation, debugging and optimization of supporting control programs were completed synchronously, thus constructing a complete and implementable intelligent disinfection doormat control system. The performance test results show that all functions of the system operate stably, trigger accurately, respond quickly and have good disinfection effect, basically achieving the expected design goals and being fully capable of meeting the daily disinfection application needs of public places.

In future research, I will further optimize the functional and structural design of the doormat, improve the detailed issues such as false trigger protection and energy consumption control, continuously enhance the comprehensive performance, practicality and economy of the product, and promote the extensive popularization and application of the intelligent disinfection doormat in more public places such as hotels, shopping malls and hospitals.

References

[1] Zhang, S. Q., & Wang, X. (2021). 基于专家评价法的智能消毒门垫设计 [Design of Intelligent Disinfection Door Mat Based on Expert Evaluation Method]. *Electromechanical Technology*, 28–30. [in Chinese]

[2] Pan, J. X. (2022). 基于 STM32 的智能消毒门垫控制系统设计 [Design of an Intelligent Disinfection Door Mat Control System Based on STM32]. *Electronics making,* 30(23), 32–34, 79. [in Chinese]

[3] Guo, Y. Y., & Wang, X. (2023). 基于 TRIZ 发明原理的智能消毒门垫设计 [Intelligent Disinfection Door Mat Design Based on TRIZ Inventive Principles]. *Electromechanical Technology,* (2), 20–22. [in Chinese]

[4] Zhang, P. (2020). 工业产品形态设计(第 3 版) [Industrial Product Form Design (3rd Edition)]. *Beijing Institute of Technology Press.* [in Chinese]

[5] Zhu, R. L., Xiao, Y. L., Chen, R. X., & Liu, Y. (2023). 基于 STM32F407 的 IBP 仿真系统设计与实现 [Design and Implementation of IBP Simulation System Based on STM32F407]. *Communication World,* 32(6), 175–177. [in Chinese]

[6] Zhang, H., Pan, Y. C., Zhang, Z. F., & Li, T. (2024). 基于 STM32 单片机的智能加湿器设计 [Design of an Intelligent Humidifier Based on STM32 Microcontroller]. *Technological innovation,* (19), 103–106. [in Chinese]

[7] Zhang, Y. J., & Wang, X. (2022). 传感器基础与应用 [Fundamentals and Applications of Sensors]. *Sichuan Science and Technology Press.* [in Chinese]

[8] Sun, L. M., & Mou, K. C. (2025). 基于蓝牙传输的音叉物位开关的设计 Design of a Tuning Fork Level Switch Based on Bluetooth Transmission]. *Automation and Instrumentation,* 40(5), 105–107. [in Chinese]

[9] Ma, H. W. (2024). 基于 FPGA 的 OLED 显示屏控制电路设计 [Design of FPGA-based OLED Display Control Circuit]. *Beijing Jiaotong University*. [in Chinese]

[10] Qu, M. (2025). 基于 PLC 的变频蜂鸣器音频调速自动控制系统 [PLC-based Variable Frequency Buzzer Audio Speed Automatic Control System]. *Automation and Instrumentation,* 40(1), 210–213. [in Chinese]

[11] Zhang, H., Tang, J., Tang, C. W., & Yang, J. (2025). 基于 STM32 的高性能温度控制器算法研究与实现 [Research and Implementation of High-Performance Temperature Controller Algorithm Based on STM32]. *Automation Technology and Applications,* 44(4), 2–5. [in Chinese]

[12] Deng, H. (2022). 虚拟仿真平台在嵌入式系统课程中的应用 [Application of Virtual Simulation Platform in Embedded Systems Courses]. *Computer Programming Skills and Maintenance,* (10), 145–147. [in Chinese]