Design of Multifunctional Trash Can Based on Internet of Things

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Abstract. In recent years, the research field of the Internet of Things has been expanding, and the interdisciplinary development has been realized. Aiming at the problem that wet and dry garbage is difficult to classify in real life, this paper designs a multi-functional trash can, based on the Internet of Things with STM32 microcontroller and sensors. In this paper, the hardware and software design of the system is mainly completed, and the modules include temperature sensor, humidity sensor, smoke sensor, infrared sensor, ultraviolet disinfection lamp, buzzer and OLED display screen, so as to realize the classification of dry and wet garbage, sterilization and disinfection, garbage loading and smoke alarm, which can reduce the growth of bacteria caused by the accumulation of domestic waste due to inaccurate classification. This design can solve the related events of dry and wet garbage classification, reduce the burden of garbage disposal, and promote the development of urban environmental protection.

Keywords: Internet of Things · Sensor · Dry and Wet Waste · Smoke Alarm

1 Introduction

The term Industry 4.0 (I4.0), also known as the Fourth Industrial Revolution [1], is the result of technological innovation and multidisciplinary advances in research, with researchers focused on providing practical solutions using technologies such as the Industrial Internet of Things (IoT), artificial intelligence (AI), and edge computing (EC) [2]. In recent years, the Internet of Things (IoT), which connects physical objects with a variety of interconnected sensor and actuator devices, is becoming one of the key pillars of the ongoing technological revolution [3–6]. IoT is becoming more prominent in different industries, so that it is already applied in multiple fields such as healthcare, agriculture, monitoring and control [7–10].

With the rapid development of science and technology, and economy, and the continuous improvement of people's living standards, the amount of household garbage produced by residents has shown a rising trend. At present, China's domestic waste

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production is growing at a rate of nearly 10% per year according to statistics. Urban residents also have problems such as garbage accumulation and bacteria breeding due to work, life and other reasons.

China's urban household solid waste classification and treatment is still facing a certain pressure, there are a series of problems such as low recycling rate of solid waste, insufficient waste incineration treatment capacity, waste treatment structure to be optimized and landfill ratio is too high. In order to promote the comprehensive treatment of China's ecological environment and better respond to the strategy of carbon peaking, China should improve the accuracy of garbage classification and reduce a series of problems caused by incineration and landfill. Therefore, in order to improve the accuracy of garbage classification, this paper designs an economical multi-functional garbage can, which combines of Internet of Things and sensors.

2 System Scheme Design

Based on the problems of bacterial growth and environmental pollution caused by garbage accumulation, and to improve the accuracy of garbage classification, this paper studies and designs the multi-functional garbage can distinguish dry and wet garbage and achieve disinfection and sterilization.

STM32F103C8T6 minimum system board is used as control core. Relay, ultrasonic ranging module, steering gear module and ultraviolet disinfection lamp composed of the system switch circuit. Temperature sensor, humidity sensor, smoke sensor, infrared sensor, OLED display and buzzer constitute detection circuit of the system. The functional structure of the multifunctional trash can system is shown in Fig. 1, and the model is shown in Fig. 2.

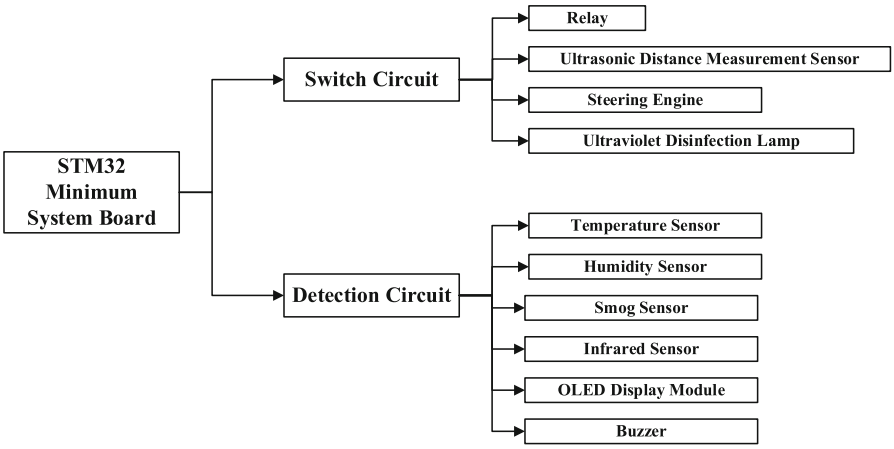

Fig. 1. Block diagram of the designed multifunctional trash.

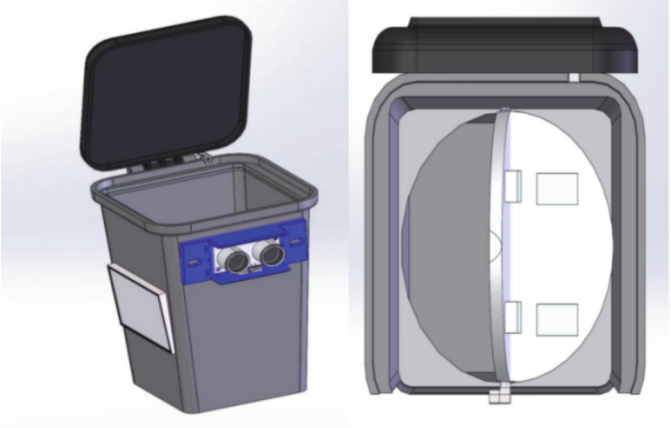

Fig. 2. Model diagram of multifunctional trash can.

3 Design of the Hardware in the System

3.1 STM32 Minimum System

STM32 chip has the characteristics of high performance and low power consumption. STM32F103C8T6 as a member of the STM32 series of microcontrollers, is a 32-bit microcontroller based on ARM Cortex-M3 kernel, which is widely used in embedded systems and electronic devices.

STM32F103C8T6 minimum system board is packaged by 48 pins, with 7 timers including 2 basic timers, 3 general timers and 2 advanced timers, two 12-bit digital-to-analog converters and pulse width modulation and other peripheral interfaces, while supporting USART, I^2C and SPI three communication interfaces. Two advanced timers can be used to trigger DAC and ADC, generate interrupts or DMA requests when updating events, triggering events, input capture, and output comparisons, and use external signals to control timers to implement synchronous circuits for multiple timers to interconnect. Compared with the traditional STC89C51 microcontroller, it is necessary to connect peripheral chips and devices to achieve some more complex functions. STM32 has a large number of peripheral interfaces and its high integration, which can realize the connection with a variety of devices and sensors, and a variety of communication methods can realize a variety of complex functions. The pin structure diagram of the STM32 minimum system board is shown in Fig. 3.

3.2 Control Circuit

1) ***HC-SR04 Ultrasonic Ranging Module***

In theory, the measurement range of the ultrasonic ranging module is 2 cm~450 cm, and the measurement accuracy is 3 mm. There are four external pin ends on the module, namely VCC at the power end, GND at the grounding end, Trig at the triggering control signal end and Echo at the receiving echo signal end [11]. Ultrasonic ranging principle is: with transmitting ultrasonic wave, start timing, ultrasonic wave

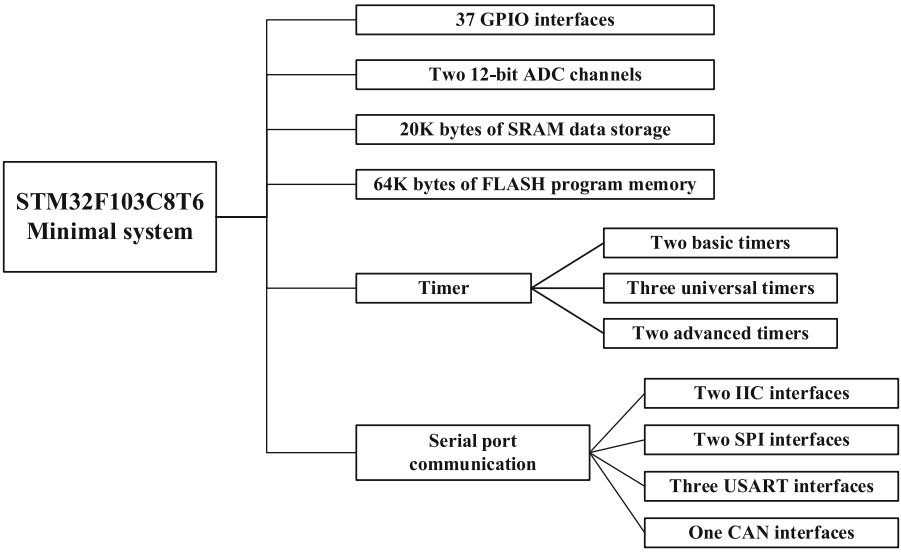

Fig. 3. Pin structure diagram of the STM32 minimum system board.

propagates in the air, in the process of encountering obstacles, it will return the signal to the ultrasonic receiver, stop timing after receiving the signal, and get the time. The working principle of ultrasonic ranging module is shown in Fig. 4.

The Trig Pin is connected to the microcontroller pin, and the microcontroller provides at least 10us pulse signal to HC-SR04, and the Echo Pin is connected to the microcontroller pin. When the ultrasonic wave detects an obstacle, the high level is fed back to the microcontroller, the timer is cleared, and the timer is started until the high level is fed back to the microcontroller again to stop counting. According to Eq. (1), the test distance can be calculated and the distance to the obstacle can be obtained,

$$d = (Th \times v) \div 2. \tag{1}$$

where d represents the test distance, T_h represents high level time, v represents the speed of sound. Test distance is measured in centimeters, the unit of high level time is seconds and the magnitude of the speed of sound is 340 m per second.

2) ***SG90 Steering Gear Module***

The multi-functional garbage can use three steering gear modules, the module used in the switching circuit is the No. 1 steering gear, which is used to control the automatic switch of the garbage can. The module used in the detection circuit is the No. 2 steering gear. The No. 3 steering gear is used to transport wet and dry garbage. The working principle of the steering engine is shown in Fig. 5.

The control signal of the steering gear is PWM signal. The positive and negative rotation of the steering gear is adjusted by controlling values of ARR and CCRx to control difference of duty cycle. For the SG90 type steering gear used, the rotation angle of the steering gear is set to 0° when the pulse is set to 0.5 ms. When the pulse

is set at 2.5 ms, the rotation angle of the steering gear is set to 180°. By controlling the high level time of the pulse, the switch control of the trash can be realized. The value of duty cycle can be obtained according to Eq. (2),

$$d = v \div (a + 1). \tag{2}$$

where d represents duty ratio, v represents the value of the input capture/output capture register, a represents the value of the automatic reload register.

3) ***Relay***

Relay is an electrical control device. When the change of input quantity meets the specified requirements, the electrical output circuit make the controlled quantity occur a predetermined step change of an electrical appliance. The relay has the control system and the controlled system, and plays the role of automatic regulation, safety protection and conversion circuit in the circuit.

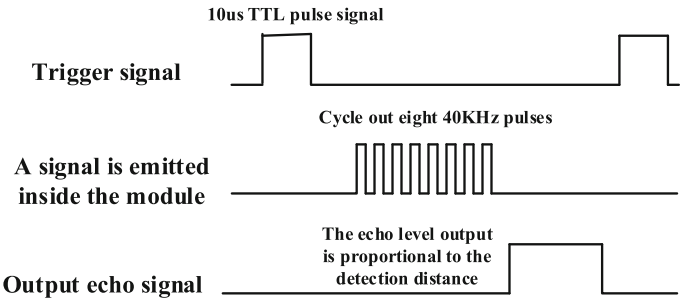

Fig. 4. The working principle diagram of ultrasonic ranging module.

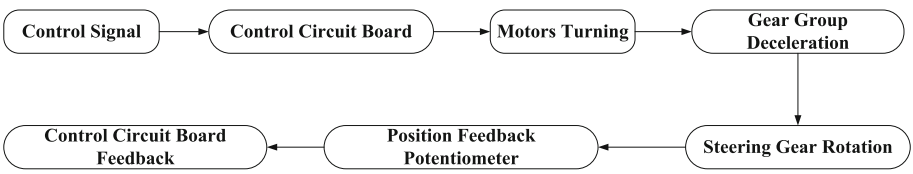

Fig. 5. Steering gear working flow chart.

3.3 Detection Circuit

1) ***DS18B20 Temperature Sensor***

The DS18B20 temperature measuring system has the advantages of simple temperature measuring system, high measurement accuracy, convenient connection, and less I/O interface. DS18B20 is a single data line communication, TX and RX are on the same pin, the input is high when receiving data, and it does not have the ability to output high level. The output low power level can be pulled down to low level

through MOS-FET, and the output high power level needs to pull up resistance to pull it up, otherwise it cannot output high level. The advanced features of the temperature sensor used are 1-wire interface, 64-bit serial storage in on-board ROM, and no external components required. It runs on a 3.0V–5.5 V power supply [12]. DS18B20 operating current is 1mA, VCC is 5 V, resistance can be obtained as 5 KΩ, I/O interface select a relatively close 4.7 kΩ pull-up resistance to ensure the output of high and low levels, a communication line to achieve two-way data transmission.

2) ***DHT11 Humidity Sensor***

DHT11 digital temperature and humidity sensor has advantages of small size, low power consumption, high cost performance, high sensitivity and strong anti-interference ability. At present, humidity sensors are widely used in agriculture, environmental protection, medicine and other fields [13]. The communication between DHT11 and single chip microcomputer can be carried out by simple single bus, and only one I/O interface is required. The sensor internal humidity data 40Bit data is transmitted to the MCU at one time, and the data is verified by the checksum method, which effectively ensures the accuracy of data transmission.

3) ***MQ-2 Smoke Transducer***

The smoke detection alarm of MQ-2 sensor has characteristics of fast response time, excellent stability, high cost performance, long life, high sensitivity, adjustable sensitivity, and can respond to most smoke [14]. STM32 control board realizes the conversion of analog signal and digital signal through its own ADC digital-to-analog converter, and monitors combustible gas in real time. When the concentration of combustible gas is higher than the set value, the signal is sent to the main control board, and the alarm is realized through the buzzer.

4) ***Buzzer Module***

A buzzer is an electroacoustic transducer that produces a continuous sound or buzz of the same tone (usually acute) and is used as a signal or warning mechanism [15]. When no alarm is triggered, the I/O interface remains high, and if the temperature sensor, smoke sensor or infrared sensor receives a value higher than the set rating through the digital-to-analog converter, the alarm is triggered, and the level is flipped so that the I/O interface is low, triggering the buzzer alarm.

5) ***Infrared Sensor***

Infrared sensor is composed of infrared transmitter part and infrared receiver part. Infrared LED is used in the transmitter part and photodiode is used in the receiver part to receive infrared signals. By rotating the potentiometer, adjust to the maximum distance of signal reception, the TTL logic output of 5 V on the OUT pin. If the garbage is not full, keep the low level output between the OUT pin and the single chip microcomputer pin. If the infrared detects that the garbage is full, the MCU receives the signal, sent by the infrared sensor and outputs the high level, triggering the buzzer alarm later.

4 Software System Design

4.1 System Software Development Environment

The system software development environment uses Keil uVision5 software platform equipped with STM32CubeMX and Proteus for collaborative development, and uses C language for programming. As the basic high-level language, it has good integration,

and its cross-platform application features enable users to debug the system in different environments. Compared with the traditional standard library, HAL library is used to initialize the required pins and parameters on the STM32CubeMX platform, and generate hex files, which greatly improves the accuracy and efficiency of development. Compile and debug modules one by one on the Keil uVision5 software platform, and add the hex file generated at the end to Proteus software for simulation to verify the accuracy of the program.

4.2 System Workflow

The system starts to run after power supply, the main program starts to work, and each module is initialized. Before entering while function, if function is used to determine whether the garbage is full. If the infrared sensor does not detect that the garbage is full, OLED display screen will show that Rubbish not full on its first line, then enter the while function, and the ultrasonic ranging module will start to detect. When detecting someone is near the trash can, when the distance is less than or equal to 200 cm, the ultrasonic ranging module will feedback the signal to the MCU, control the No. 1 steering engine to rotate 180°, open the trash can, and wait for the garbage to be placed. The temperature sensor sends a signal to STM32 MCU to compare with the set rating value in the if function, if it does not exceed the rated value, the next test will be carried out. The smoke sensor sends a signal to STM32 MCU to determine whether the gas concentration reaches the set rating value in the if function. If not, the next test will be carried out. The humidity sensor sends 40Bit data to STM32 MCU, and then distinguishes the dry and wet garbage by judging in the if function. If it is the dry garbage, the No. 2 steering engine will rotate and the tray will tilt to the left; if it is wet garbage, the No. 3 steering engine will rotate and the tray will tilt to the right. If the garbage is not full, the ultrasonic ranging module will detect it again. If there is no obstacle within 200 cm, it can judge that the person has left, and the feedback signal will be sent to STM32 MCU, the No. 1 steering engine will turn, the trash can will be closed, and the system will enter a 5 s delay function. The system enters the while loop again to achieve the effect of real-time monitoring, the multifunctional trash main program flow chart is shown in Fig. 6.

5 System Function Test

5.1 System Test Method

System testing is divided into two parts: testing each single module, compiling it on the Keil uVision5 platform, and observing whether the function is implemented on the Proteus platform. If this function can be achieved, it means that there is no problem with this module; If it is not realized, check the program and circuit diagram, compile and simulate again to observe the realization of the function. After all functions are tested, the required modules are initialized in the main function, and the implementation of each function is observed and recorded in the while loop one by one. If all functions can be realized, it means that there is no problem in the design scheme. The specific testing conditions are shown in Table 1.

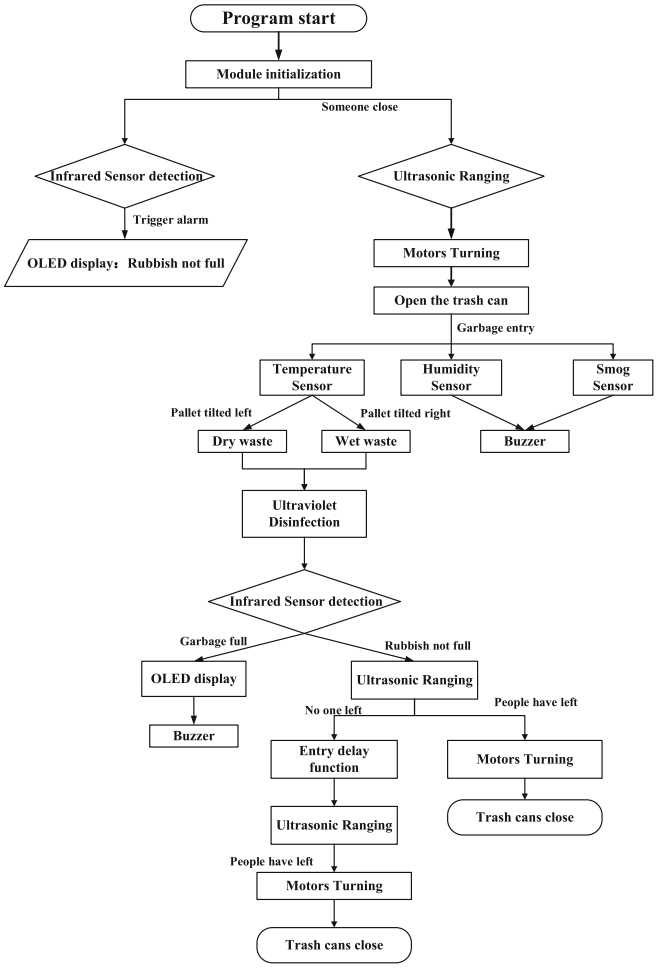

Fig. 6. Multifunctional trash main program flow chart.

5.2 System Function Realization

After checking the module to be used, compile a detection function in the while loop function to verify each function. After compiling by Keil uVision5, simulation verification was carried out on Proteus platform without error and warning. Simulation results were shown in Figs. 7 and 8. Observe the implementation of the function, if all the functions can be realized, it means that the multi-functional trash can design is correct.

5.3 System Function Test and Results

1) ***Automatic lid test of garbage can***

After the completion of the initialization of each module, the automatic lid opening function of the trash can is tested. By verifying different distance values, the

Table 1. Functional test result.

Function test	Test mode	Function request	Actual testing result	Does the function conform to design
Automatic uncapping	300 cm away from ultrasonic module 100 cm away from ultrasonic module	No response Automatic uncapping	No response Automatic uncapping	No Yes
Auto-alarm	Place unextinguished cigarette butts Place unlit cigarette butts Place high temperature objects Place a room temperature object	Buzzer alarm No response Buzzer alarm No response	Buzzer resound No response Buzzer resound No response	Yes No Yes NO
Garbage full	Place cartons	Buzzer alarm	Buzzer resound	Yes
Dry and wet waste separation	Dry paper Damp sponge	Pallet tilted left Pallet tilted right	Pallet tilted left Pallet tilted right	Yes Yes

verification results fluctuate near the theoretical straight line in the form of scatter points after multiple tests and comparisons. The simulation results are shown in Fig. 9. The theoretical induction distance of automatic cover opening is 200 cm, and several sets of data are tested. When the test distance is greater than the theoretical induction value, the ultrasonic ranging module does not feedback the high level to the MCU, and the steering engine has no response. When the test distance is less than the theoretical induction value, the ultrasonic ranging module sends a signal to STM32 MCU. If STM32 MCU calculates the distance which is less than the induction value, the steering gear rotates 180°, realizes the automatic cover opening, and after the man who throwing the garbage leaves, calculating the distance is greater than the theoretical induction value, realizes the automatic cover closing.

2) ***Trash can automatic alarm function test***

After the completion of initialization of each module, the automatic alarm function of the trash can is tested from the aspects of temperature and humidity. In the first group, the unextinguished cigarette end is placed, the smoke sensor sends the signal to the single-chip computer, the buzzer pin turnover level is output low level,

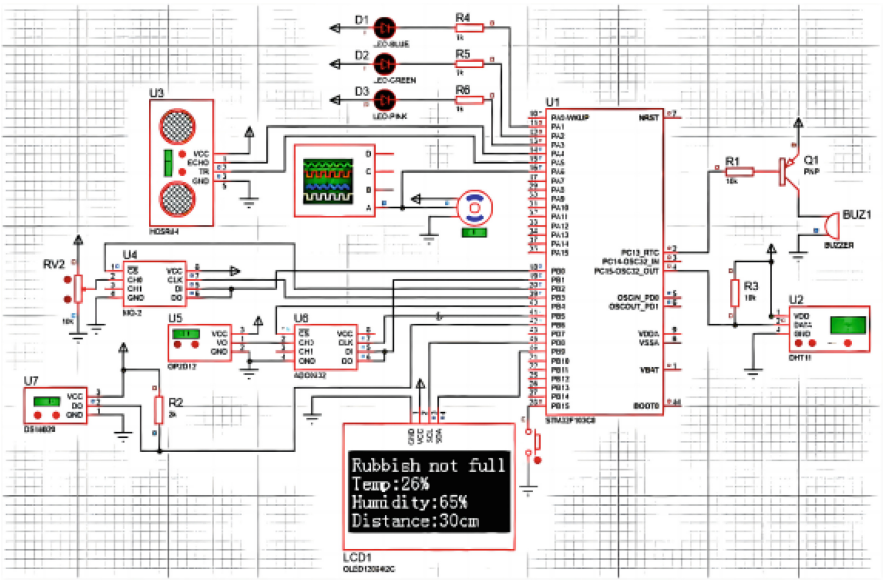

Fig. 7. Simulation results without alarm figure.

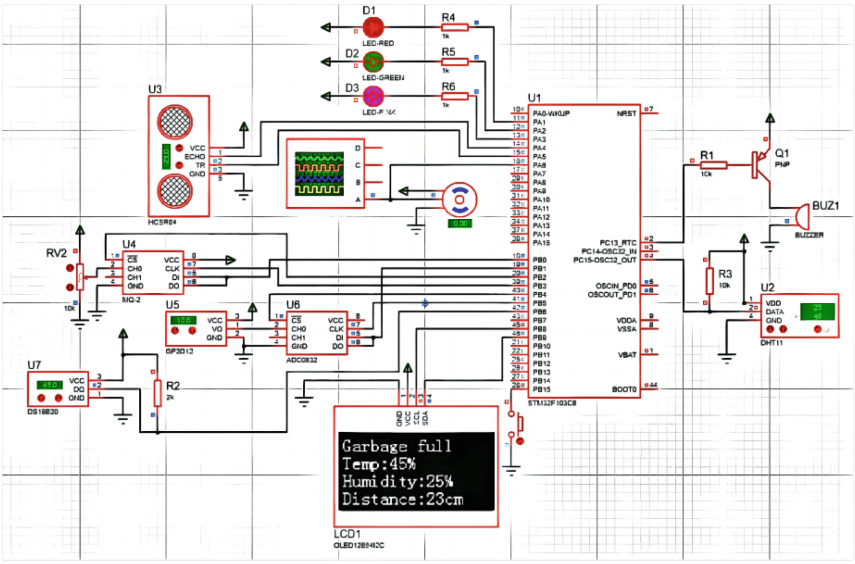

Fig. 8. Simulation results with alarm figure.

and the alarm is generated. In the second group, the unlit cigarette end is placed, the smoke sensor does not respond, the pin remains high, and the buzzer does not alarm. In the third group, the high temperature object is placed, the temperature sensor sends the signal to the MCU, the buzzer pin turnover level, then outputs low level,

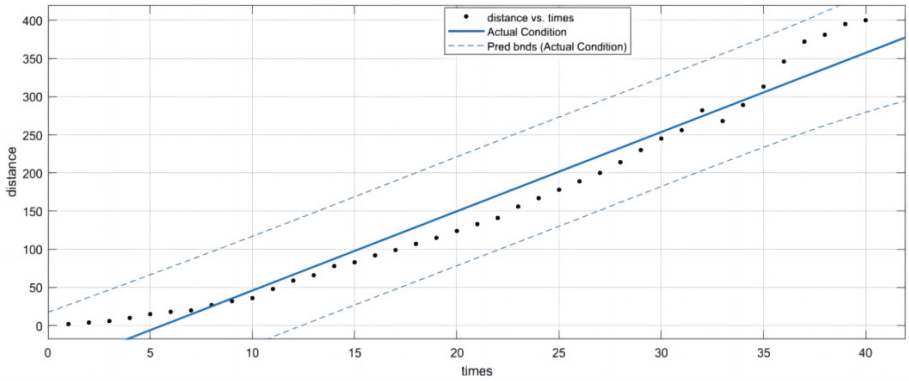

Fig. 9. MATLAB simulation results.

and the alarm occurs. In the fourth group, place the normal temperature object, the temperature does not reach the set temperature rating, the temperature sensor does not respond, the pin of buzzer remains high, and the buzzer does not alarm. The working condition of buzzer is verified from two aspects of smoke and high temperature object, and automatic alarm of garbage can be realized.

3) ***Garbage filled functional testing***

After completion of the initialization of each module, the infrared detection filling function of the trash can is tested, the potentiometer on the infrared sensor is rotated, and the signal receiving distance is adjusted to the maximum through multiple groups of debugging. When the carton is used to simulate the garbage can be full, the infrared sensor sends a signal to the MCU, and the OLED display screen displays: Garbage full. The buzzer sounded and realized the test of the bin filling function.

4) ***Dry and wet refuse identification function test***

After completion of the initialization of each module, the dry and wet garbage recognition function is tested. The first group is to place dry paper, detected by humidity sensors, send signals to the single chip computer, change the high level time, rotate the No. 2 steering engine, and tilt the tray to the left. In the second group, the wet sponge is placed, detected by humidity sensor, the signal is sent to the single chip computer, the No. 3 steering engine rotates, the tray tilts to the right, and the separation of dry and wet garbage is realized.

6 Conclusion

In this paper, based on the Internet of Things, a low-cost multi-functional trash can is designed. Compared with the existing garbage can, it can realize the functions of automatic switch, classification of dry and wet garbage, automatic alarm and sterilization of bacteria and poison. The feasibility of the design is verified by the functional test of multiple groups. The design and application of multi-functional garbage can, may effectively improve the accuracy of dry and wet garbage classification, and then improve the efficiency of garbage disposal.

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References

1. Schwab K.: The fourth industrial revolution. Crown Currency, 2017 Jan 3
2. Stadnicka, D., Sęp, J., Amadio, R., Mazzei, D., Tyrovolas, M., Stylios, C., at al.: Industrial needs in the fields of artificial intelligence, internet of things and edge computing. *Sensors*, *22*(12), 4501 (2022)
3. Chettri, L., Bera, R.: A comprehensive survey on Internet of Things (IoT) toward 5G wireless systems. IEEE Internet Things J. **7**(1), 16–32 (2019)
4. Erboz, G.: How to define industry 4.0: Main pillars of industry 4.0. *Managerial trends in the development of enterprises in globalization era*, *761*, 761–767(2017)
5. Bigini, G., Freschi, V., Lattanzi, E.: A review on blockchain for the internet of medical things: Definitions, challenges, applications, and vision. Future Internet **12**(12), 208 (2020)
6. Guerrero-Ulloa, G., Rodríguez-Domínguez, C., Hornos, M.J.: Agile methodologies applied to the development of Internet of Things (IoT)-based systems: A review. Sensors **23**(2), 790 (2023)
7. Palmer, G.A., Tomkin, G., Martín-Alcalá, H.E., Mendizabal-Ruiz, G., Cohen, J.: The Internet of Things in assisted reproduction. Reprod. Biomed. Online. Biomed. Online **47**(5), 103338 (2023)
8. Khan, M.A., Din, I.U., Majali, T.E., Kim, B.S.: A survey of authentication in internet of things-enabled healthcare systems. Sensors **22**(23), 9089 (2022)
9. Lim, H.R., Khoo, K.S., Chia, W.Y., Chew, K.W., Ho, S.H., Show, P.L.: Smart microalgae farming with internet-of-things for sustainable agriculture. Biotechnol. Adv.. Adv. **57**, 107931 (2022)
10. Chong, J.L., Chew, K.W., Peter, A.P., Ting, H.Y., Show, P.L.: Internet of things (IoT)-Based environmental monitoring and control system for home-based mushroom cultivation. Biosensors **13**(1), 98 (2023)
11. Zhao, J., Fang, J., Wang, S., Wang, K., Liu, C., Han, T.: Obstacle avoidance of multi-sensor intelligent robot based on road sign detection. Sensors **21**(20), 6777 (2021)
12. Saha, R., Biswas, S., Sarmah, S., Karmakar, S., Das, P.: A working prototype using DS18B20 temperature sensor and arduino for health monitoring. SN Computer Science **2**(1), 33 (2021)
13. Hernández-Rivera, D., Rodríguez-Roldán, G., Mora-Martínez, R., Suaste-Gómez, E.: A capacitive humidity sensor based on an electrospun PVDF/graphene membrane. Sensors **17**(5), 1009 (2017)
14. Chi, H., Chi, Y.: Smart home control and management based on big data analysis. Comput. Intell. Neurosci.. Intell. Neurosci. **2022**(1), 3784756 (2022)
15. Luque-Vega, L.F., Michel-Torres, D.A., Lopez-Neri, E., Carlos-Mancilla, M.A., González-Jiménez, L.E.: Iot smart parking system based on the visual-aided smart vehicle presence sensor: SPIN-V. Sensors **20**(5), 1476 (2020)