Journal of Electronic Research and Application, 2025, Volume 9, Issue 6
http://ojs.bbwpublisher.com/index.php/JERA
ISSN Online: 2208-3510
ISSN Print: 2208-3502

Design and Implementation of Inductive Intelligent Garbage Recycling System Based on Dual Recognition Fusion

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Abstract: To solve the problems of traditional garbage classification relying on manual work, low recognition accuracy, and unhygienic contact-based disposal, an inductive intelligent garbage recycling system based on a micro-controller is designed. The system takes STM32F103ZET6 as the core, integrates speech recognition, visual recognition, and infrared induction modules, and adopts a dual recognition fusion strategy of "speech priority + visual verification" to realize contactless induction lid opening, accurate garbage classification, and remote status monitoring functions. Speech recognition completes keyword matching through the LD3320 module, visual recognition realizes image feature extraction and classification based on the BP neural network, and the ESP8266 module is responsible for uploading device status to the Cloud platform. It is applicable to multiple scenarios such as households and communities, effectively improving the efficiency and convenience of garbage classification, and has good practical value.

Keywords: Garbage recycling; Dual recognition fusion; STM32; BP neural network; Contact-less disposal

Online publication: December 16, 2025

1. Introduction

With the full implementation of garbage classification policies, the problems of low classification efficiency, poor disposal accuracy, and hygiene risks of contact-based operation in traditional garbage recycling methods have become increasingly prominent [1]. Currently, intelligent garbage bins with a single recognition mode mostly rely on either speech or vision technology alone, which are susceptible to interference in complex environments, leading to recognition failure [2,3]. The introduction of inductive technology can realize contactless disposal, but existing products generally lack multi-modal recognition fusion and full-status monitoring functions [4].

Therefore, this paper designs an intelligent garbage recycling system integrating speech, visual dual recognition and infrared induction. With the STM32 single-chip microcomputer as the control core, it integrates the LD3320

speech recognition module, OpenMV visual module and TRCT5000 infrared sensor. Through the collaborative work of multiple modules, it realizes human body induction lid opening, dual-mode garbage recognition and classification, overflow monitoring and remote status feedback functions. The system adopts a fusion strategy of "speech priority + visual verification" to improve recognition stability in complex environments, and reduces hygiene risks through contactless design, providing an efficient solution for intelligent garbage classification.

2. Overall system design

2.1. Design architecture

The system adopts a four-layer architecture of "perception-processing-execution-communication", which is composed of the main control module, recognition module (speech + vision), induction module, execution module, communication module and power supply module. The details of the layers are as follows:

(1) Perception layer: Composed of infrared induction module, speech collection module and visual collection module, completing the collection of human body presence, garbage information and equipment status data;

(2) Processing layer: The STM32F103ZET6 single-chip microcomputer analyzes and processes the collected data to realize recognition result fusion, induction signal judgment and control command generation;

(3) Execution layer: Controls the opening and closing of the bucket lid through the servo, feeds back the classification result through the speech broadcast module, and displays the equipment status through the LED indicator light;

(4) Communication layer: The ESP8266 module uploads equipment status (temperature, overflow degree) to the Ali-baba Cloud platform to realize remote monitoring.

2.2. Core working principle

After the system is powered on and initialized, the infrared induction module real-time detects whether there is a person approaching. When a human body is detected (distance ≤ 20cm), both the speech and visual modules are triggered to start simultaneously, the user inputs the garbage name through speech, and the LD3320 module completes keyword recognition and transmits it to the single-chip microcomputer. At the same time, the OpenMV camera collects garbage images, which are processed by the BP neural network to output classification results. The single-chip microcomputer performs fusion verification on the dual recognition results. If consistent, it controls the corresponding SG90 servo to open the bucket lid and broadcasts the garbage category through speech; if the results conflict, the visual recognition result is taken as the benchmark and a second broadcast confirmation is performed. The infrared induction module synchronously monitors the height of garbage in the bucket. When the overflow threshold (80% capacity) is reached, an alarm is issued through the LED indicator light and uploaded to the cloud to remind the staff to clean up.

3. Hardware system design

3.1. Main control module

The STM32F103ZET6 single-chip microcomputer is selected as the main control chip. Based on the ARM Cortex-M3 core, the chip has a maximum operating frequency of 120MHz, built-in 512KB Flash and 64KB SRAM, and supports multiple communication protocols such as multi-serial port, SPI and IIC, which can meet

the needs of multi-module collaborative control and data processing [5]. The single-chip microcomputer connects to speech, vision, induction and other modules through GPIO ports to realize command transmission and status feedback.

3.2. Recognition module design

3.2.1. Speech recognition module

The LD3320 speaker-independent speech recognition module is adopted. The module integrates sound collection and processing units, supports 100 custom keyword lists, and can realize speech recognition without pr-training. The recognition distance is ≤ 10m, and the accuracy rate is over 95% [6]. The module communicates with the single-chip microcomputer through the UART serial port, presetting four core keywords: “recyclable garbage”, “kitchen garbage”, “harmful garbage” and “other garbage”, as well as 20 common garbage names (such as “plastic bottle”, “peel”, “battery”, etc.) to realize rapid matching of speech commands.

3.2.2. Visual recognition module

The OpenMV4 H7 Plus visual module is selected, equipped with an OV7725 camera and an ARM Cortex-M7 core, supporting image collection, preprocessing and machine learning algorithm deployment [7]. The module communicates with the single-chip microcomputer through the IIC interface. After collecting garbage images, it performs preprocessing such as grayscale conversion and denoising, extracts features such as garbage shape and color based on the BP neural network model, and outputs classification results by comparing with the preset dataset.

3.3. Induction module design

The TRCT5000 infrared induction module is adopted, divided into two groups: human body detection and overflow detection. The details are outlined below:

(1) Human body detection module: Installed outside the garbage bin, with a detection angle of 35° and a detection distance of 2~30cm. When a human body signal is detected, it outputs a low level to trigger the system to start;

(2) Overflow detection module: Installed inside the bucket lid. When the garbage height reaches the preset threshold, the infrared reflection triggers a signal, and the single-chip microcomputer starts an overflow alarm after receiving it.

3.4. Overall system hardware circuit diagram

Figure 1 shows the overall system hardware circuit diagram, covering the core connection relationships of the main control module, recognition module, induction module, execution module and communication module. The pin assignment complies with the STM32F103ZET6 chip manual specifications, and key signals adopt anti-interference design (such as parallel connection of 100nF decoupling capacitor at the power supply terminal).

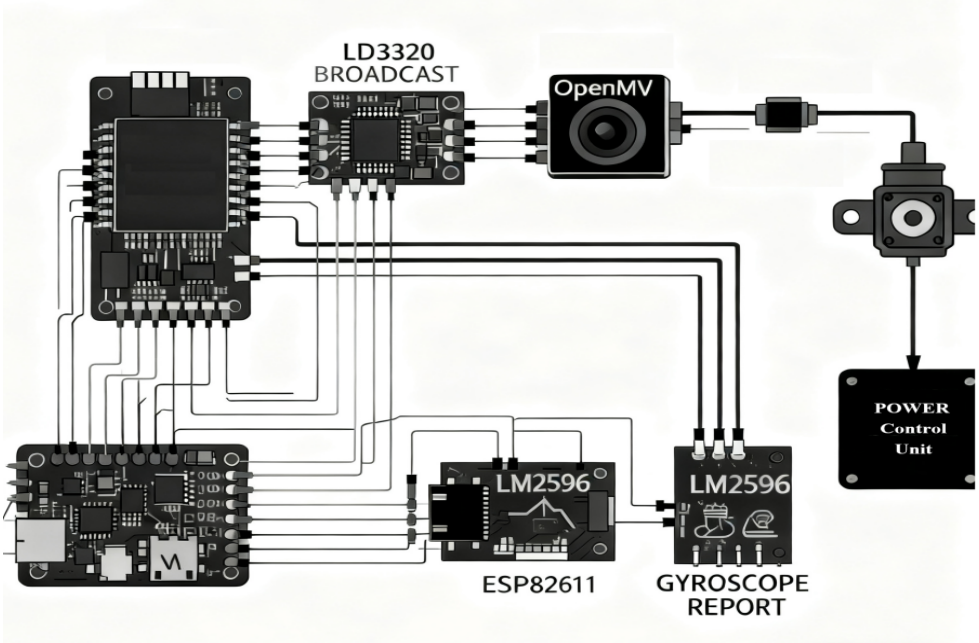

Figure 1. Hardware circuit diagram.

3.5. Cloud communication module circuit design

The ESP8266 module is the core of communication between the system and the Alibaba Cloud platform, responsible for uploading garbage bin overflow status, internal temperature and equipment fault information. Its circuit design must focus on ensuring communication stability and power supply reliability.

4. Software system design

4.1. Development environment

The hardware development environment is Altium Designer 21, and the software development environment includes Keil uVision5 (MCU program), OpenMV IDE (visual algorithm) and PyCharm (neural network training). The programming languages are C language, MicroPython and Python.

4.2. Main program design

The main program adopts a modular design. The core logic pseudocode is as follows, with the flow:

System initialization → Induction monitoring → Dual recognition fusion → Execution control → Status monitoring → Cyclic standby

The core operational workflow of the embedded intelligent waste-sorting system is summarized in the following pseudocode, which outlines the initialization procedures and the cyclic execution logic of the device:

```
// Main Program Core Logic Pseudocode
Initialization:
    Configure STM32 system clock, serial port, timer and other basic peripherals
```

Initialize functional modules such as infrared induction, servo, ESP8266, and speech broadcast
Load BP neural network model and initialize speech keyword list
System startup prompt (speech broadcast + serial port log)

Cyclic Operation:
Detect human body induction signal:
If human body is detected and garbage bin is not full:
Start dual recognition fusion process
Open the lid and close all bucket lids after 5 seconds of delay
If no human body is detected:
Maintain low-power standby state

Detect overflow status:
If overflow is detected:
Upload overflow alarm information to Alibaba Cloud
Activate LED red light alarm
If no overflow:
Upload normal status information to Alibaba Cloud
Turn off the alarm

4.3. Core function module design

4.3.1. Dual recognition fusion module

The dual recognition fusion module is the core of the system. It improves the recognition accuracy in complex environments through a weighted fusion strategy of "speech recognition + visual recognition". The main functions include speech recognition (timeout 3 seconds), visual recognition (multi-frame average denoising), fusion judgment (speech weight 0.6, visual weight 0.4), execution control.

4.3.2. Infrared induction and servo control module

The infrared induction module is responsible for human body detection and overflow monitoring, and the servo control module realizes the precise opening and closing of the bucket lid.

4.3.3. Cloud communication module

The ESP8266 module is responsible for realizing communication between the device and the Ali-baba Cloud platform, including Wi-Fi connection, Ali-baba Cloud configuration and data upload.

4.3.4. BP neural network training and deployment module

The BP neural network is used for garbage image classification, which is divided into two stages: training (PC terminal) and deployment (OpenMV terminal).The main functions of the code include: dataset loading and preprocessing, model construction, model training and evaluation, and OpenMV model deployment.

5. Conclusion

The test results show that the system maintains a high recognition accuracy rate in different environments. The dual recognition fusion strategy effectively makes up for the shortcomings of a single recognition mode, where speech recognition responds quickly in quiet environments, and visual recognition has stronger anti-interference in noisy environments. After fusion, the system can still work stably in complex scenarios. Compared with traditional single recognition systems, this system has significant improvements in recognition stability and environmental adaptability. In the future, optimization can be carried out from two aspects as follows:

(1) Introduce the YOLOv5 algorithm to improve the recognition ability of garbage with complex shapes;

(2) Add weight sensors to realize the statistics of garbage recycling volume and big data analysis.

Funding

2024 Ministry of Education Supply-Demand Docking Employment and Education Projects (Project No.: 2024101679202, Project No.: 2024121116066); 2023 Ministry of Education Supply-Demand Docking Employment and Education Projects (Project No.: 2023122927732, Project No.: 2023122925618); 2024 "Innovation Strong Institute Project" Construction Project (Project No.: 2024CQ-29); Talent Project of the Open University of Guangdong: Research on key technologies for improving the performance of blockchain application platforms (Project No.: 2021F001).

Disclosure statement

The authors declare no conflict of interest.

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