Research and Development of Intelligent Classification Garbage Bin Based on Machine Vision

Jinting Liang[1], Ningliang Chen[2], Sheng Ouyang[2], Jingyu Xing[1], Chaogang Zhang[3, *]
[1]School of Intelligent Manufacturing, Jianghan University, Wuhan 430056, China
[2]School of Artificial Intelligence, Jianghan University, Wuhan 430056, China
[3]Jianghan University, Wuhan 430056, China
*Corresponding email: zhchg0406@jhun.edu.cn

Abstract

Aiming at the problems of low efficiency and poor accuracy in traditional garbage classification, this paper designs an intelligent classification garbage bin. The design integrates mechanical structure and intelligent control technology, constructs seven core mechanisms, and adopts a control system centered on a single-chip microcomputer/embedded development board to realize the full-process automation of garbage temporary storage, identification, separation and storage. It also integrates functions such as full-load detection, garbage compression and information visualization, meeting the requirements of four types of garbage classification, with core performance indicators up to standard and convenient maintenance. The design features automation, intelligence and expansibility, and has a wide range of application scenarios. Subsequent efforts will optimize the algorithm and lightweight the structure to promote large-scale application.

Keywords

Waste classification, Smart sorting trash can, YOLO v5, Full-load detection

Introduction

Against the dual backdrop of accelerated urbanization and increased environmental awareness among residents, traditional trash bins that rely on manual sorting can no longer meet the requirements of refined waste classification. This leads to problems such as low sorting efficiency, poor accuracy, and insufficient resource recovery, as shown in Figure 1. To address these issues, this design develops an intelligent sorting trash bin that integrates mechanical structures with intelligent control technology to achieve automatic temporary storage, identification, separation, storage, and information visualization of waste. It also includes extended features such as full-load detection and recyclable waste compression, aiming to enhance the automation and intelligence of waste sorting and promote the upgrade of urban household waste management systems [1]. Such an intelligent system not only reduces the labor intensity of manual sorting but also significantly improves the purity of recyclable materials, thereby maximizing resource recovery efficiency.

Figure 1. Current status of traditional trash can classification.

This design needs to meet the classification requirements for four types of garbage: recyclable waste, kitchen waste, hazardous waste, and other waste. It must achieve automatic separation and disposal of at least two types of garbage, and display classification information through a visual interface. Thus, it provides an efficient waste classification solution for homes, offices, public places, and other scenarios.

Overall design concept

The core design logic of the physical model of smart sorting trash can is to complete the entire process of automatic garbage sorting. This is achieved through the collaborative work of multiple modular mechanical structures and an intelligent control system. The physical model of smart sorting trash can is shown in Figure 2.

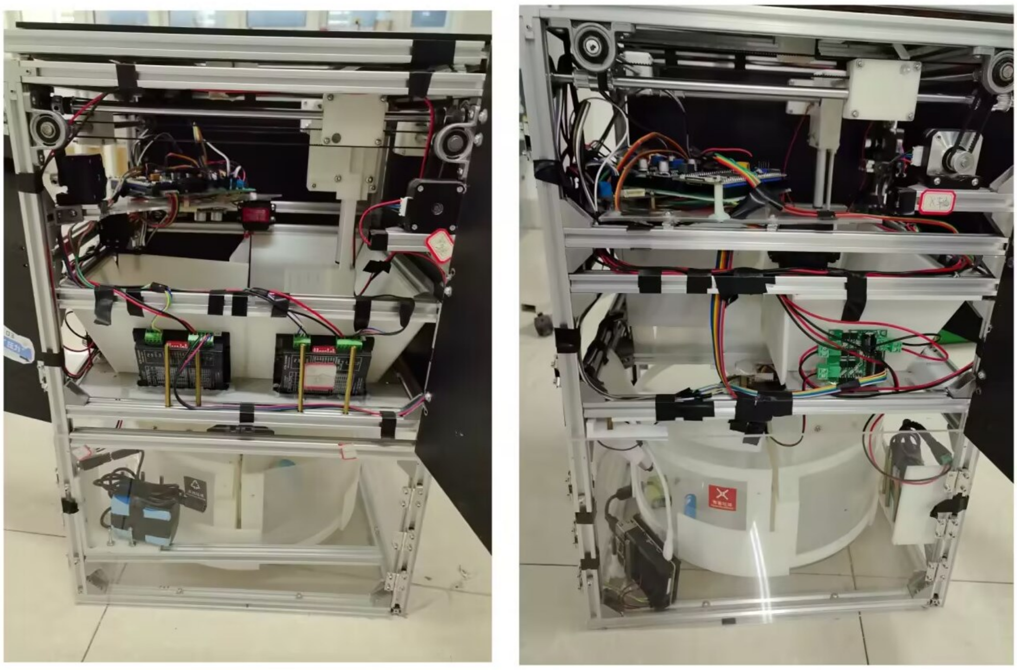

Figure 2. Physical model of smart sorting trash can.

The overall process follows the main line of temporary storage → recognition → separation → storage → information display, while integrating auxiliary functions such as full-load detection and waste compression. The specific design concept is as follows:

(1) Temporary storage module: After the garbage is thrown in, it is first uniformly stored temporarily, providing a stable operational foundation for subsequent recognition and separation.

(2) Recognition module: Image processing technology is used to accurately identify the garbage and determine its type.

(3) Separation module: Different types of garbage are separated and directed to specific disposal locations through telescopic push rods and moving mechanisms.

(4) Storage module: An independent compartmentalized storage structure is designed to meet the classification storage requirements of four types of garbage.

(5) Information display module: A display screen visualizes the order of waste disposal, the names and quantities of garbage, and task completion status.

(6) Auxiliary function module: Equipping ultrasonic distance measurement devices for full-load detection, and a compression mechanism for volume reduction of recyclable waste.

Modules are linked through a control program to achieve automation and intelligence in classification process, reducing manual intervention while improving classification accuracy and efficiency [2]. This design minimizes operational errors and enhances system reliability. It also lowers labor costs and supports sustainable waste management.

Core organization design

Temporary storage device

Structural design: The temporary storage device adopts an open-slot structure as shown in Figure 3. The main body is made of hard plastic or a metal frame, with an internal anti-slip and cushioning layer to prevent splashing and jamming when garbage is thrown in. The device's entrance is designed with a flared opening to enhance the convenience of garbage disposal; the bottom is inclined to facilitate the sliding of garbage towards the identification area. This design effectively reduces waste accumulation and operational delays.

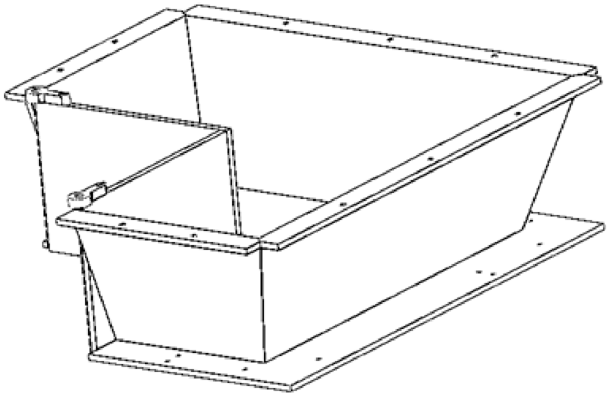

Figure 3. Temporary storage device.

Working principle: After the garbage is thrown in, the temporary storage device acts as the "initial buffer" for garbage sorting, collecting garbage in a unified manner. Once bag-breaking processing (for whole bags of garbage) is completed, the garbage is scattered into the recognition area, providing clear objects for subsequent image recognition. The capacity of the temporary storage device should be designed to accommodate multiple pieces of garbage at a time, avoiding frequent interruptions in the sorting operation [3].

Image processing and recognition device

Hardware selection: The YOLO v5 recognition module is used in combination with a high-definition industrial camera, as shown in Figure 4. YOLO v5 features real-time detection, high recognition accuracy, and fast processing speed, meeting the requirements for rapid identification of waste types. The camera is installed on the top surface of the trash bin, with its field of view covering the area where trash falls from the temporary storage device, ensuring the completeness of the captured images.

Figure 4. YOLO v5 recognition module.

Principle of operation: After the camera captures image information of the garbage, it is transmitted to the YOLO v5 algorithm module for feature extraction and category matching. The algorithm library pre-stores typical feature data of recyclable garbage, kitchen waste, hazardous waste, and other garbage. By comparative analysis, the specific type of garbage is determined, and the recognition result is transmitted to the control system to provide instruction basis for the action of the separation device. For whole bags of garbage, the system first controls the bag-breaking mechanism to complete bag opening. After the garbage is scattered, recognition is performed to avoid errors in recognizing garbage inside the bag [4].

Separation device

Structural design: The separation device is installed below the feed inlet as shown in Figure 5. The core components are the telescopic push rod and the moving slide rail mechanism. The telescopic push rod uses an electric push rod, featuring adjustable stroke and stable thrust; the moving mechanism is driven by a stepper motor, allowing the push rod to move horizontally and vertically. A guide groove is set at the bottom of the device for precise alignment with the entrance of the storage device.

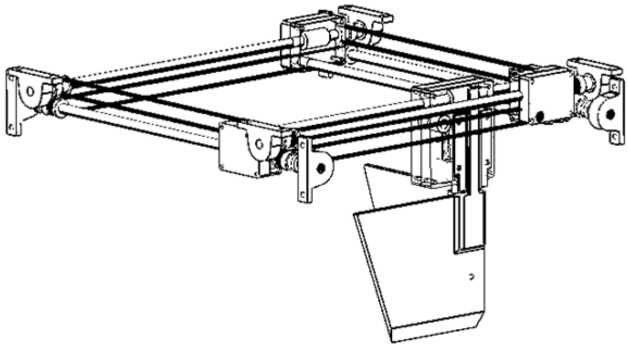

Figure 5. Separation device.

Functional principle: When the control system receives the garbage type signal from the recognition device, it drives the moving mechanism to move the telescopic push rod to the position of the corresponding garbage. Through the telescopic action of the push rod, the garbage is pushed into the guiding groove and then slides into the matching storage area. This device can achieve separation and processing of at least two types of garbage. By programmatically controlling the displacement and telescopic travel of the push rod, it can adapt to the disposal paths for four types of garbage, achieving precise separation of multiple kinds of garbage [5].

Storage device

Structural design: The storage device adopts a circular partition structure as shown in Figure 6. The whole unit is an enclosed box, internally divided into four separate areas by partitions, corresponding to the storage of recyclable waste, kitchen waste, hazardous waste, and other waste. Each area's entrance is equipped with a backflow prevention baffle to prevent waste from flowing back; the side of the box is designed with a removable door panel to facilitate waste collection and maintenance of the device.

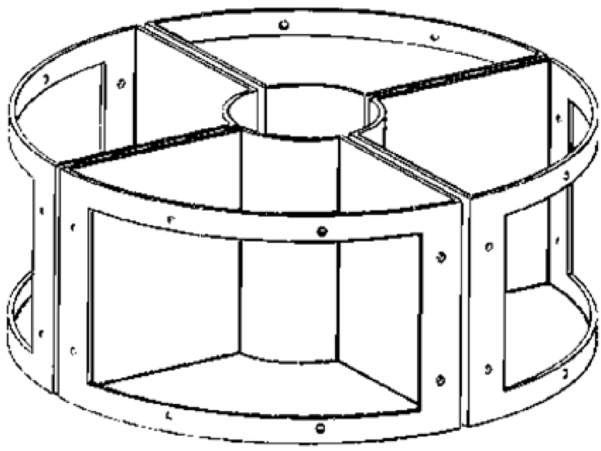

Figure 6. Storage device.

Functional principle: The storage device serves as the "final storage unit" for garbage sorting. Through partitioned design, it achieves physical separation of different types of waste, preventing cross-contamination. The capacity of each area is designed differently according to the amount of different types of waste generated. For example, the area for kitchen waste is larger than that for hazardous waste, enhancing the practicality of the device [6].

Information display device

Hardware selection: The display device uses a touch screen paired with a drive circuit board as shown in Figure 7. The display screen size is 7-10 inches, and the resolution meets the requirements for clear information display; the circuit board communicates with the control system to enable real-time data transmission and display. The touch screen ensures responsive feedback for operator convenience. Additionally, the board uses reliable communication protocols to prevent data loss.

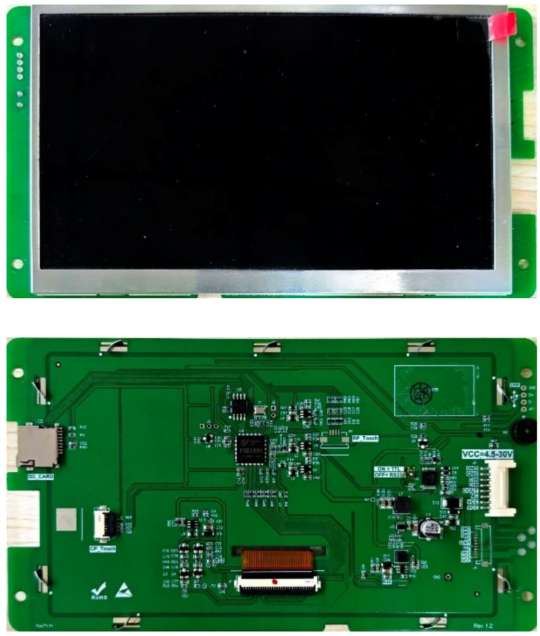

Figure 7. Display device.

Function principle: The display screen visualizes various information about garbage classification, including the order of garbage disposal, the identified names of the garbage, the quantity of each type of garbage disposed of, the remaining storage capacity of the trash bins, and prompts for the completion of classification tasks. At the same time, the display screen can integrate touch operation functions, supporting manual correction of garbage identification results, setting garbage classification modes, etc., enhancing the human-computer interaction of the device [7].

Ultrasonic distance measuring device

Hardware selection: The ultrasonic distance measuring device is used (Figure 8). The module consists of a transmitter and a receiver, with a measurement range of 2 cm to 450 cm and an accuracy of up to 3 mm, meeting detection requirements for the remaining capacity inside the trash bin. The module is installed at the top of each storage area, oriented vertically towards the bottom.

Figure 8. Ultrasonic distance measuring device.

Principle of operation: The ultrasonic transmitter emits ultrasonic signals toward the bottom of the storage device, and the receiver captures the reflected signals. By calculating the propagation time of the signals, the distance between the module and the surface of the garbage is determined, which is then used to calculate the remaining capacity of the storage area. When the remaining capacity falls below a set threshold, the system triggers a full-load alarm, prompts the user to remove the garbage through the display, and simultaneously sends a warning message to the backend management system (if connected to the Internet of Things) [8].

Garbage compression mechanism

Structural design: The garbage compression device for the recyclable waste area is designed as shown in Figure 9. The core component is a hydraulic or electric compression plate, paired with guide rails and a drive motor. The compression plate is installed at the top of the recyclable waste storage area and can move reciprocally in the vertical direction along the guide rails.

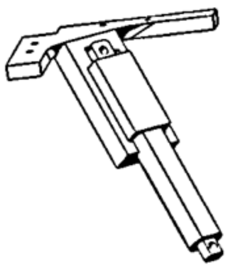

Figure 9. Garbage compression device.

Working principle: When recyclable waste (such as plastic bottles, cardboard boxes, etc.) accumulates to a certain height, the control system drives the compression plate to move downward, compressing the waste to reduce its volume and improve the storage efficiency of the recyclable waste area. After compression is completed, the compression plate resets and waits for the next compression command; if the recyclable waste area is detected to be fully loaded, the compression mechanism stops operating and triggers an alarm [9].

Control system design

Hardware architecture

The control system is centered on a microcontroller (such as STM32) or an embedded development board (such as Raspberry Pi), connecting the actuators and detection sensors of each module. This enables real-time data acquisition and automated response.

(1) Main control unit: Responsible for receiving signals from each module, running the control program, and sending action commands, serving as the “brain” of the entire device.

(2) Drive unit: Including motor drive modules, push-rod drive modules, and compression mechanism drive modules, converting the electrical signals from the main control unit into mechanical actions.

(3) Sensing unit: Comprising cameras, ultrasonic distance measurement modules, position sensors, etc., collecting information such as images, distances, and positions.

(4) Power supply unit: Powering by lithium batteries or an external power source, and equipped with a power management module for overcharge, over-discharge, and short-circuit protection.

Software process

(1) Initialization phase: After the system is powered on, each module completes self-check, the display screen shows the initialization interface, and the sensor detection begins working.

(2) Garbage input phase: After the garbage enters the temporary storage device, the bag-breaking mechanism (if any) operates, and the garbage scatters into the recognition area.

(3) Recognition phase: The camera collects images, the YOLO v5 algorithm completes the garbage type recognition, and the results are transmitted to the main control unit.

(4) Separation phase: The main control unit drives the separation device to push the garbage to the corresponding storage area based on the recognition results.

(5) Information update phase: The display screen updates the garbage classification information in real time, and the ultrasonic module detects the remaining storage capacity.

(6) Auxiliary action phase: If the recyclable garbage area needs compression, the main control unit drives the compression mechanism. If a full load is detected, an alarm is triggered [10].

Performance parameters and technical specifications

(1) Classification accuracy: Equipping with YOLO v5 algorithm, garbage recognition accuracy ≥90% (for common types of garbage).

(2) Classification efficiency: Single garbage classification task takes ≤5 seconds, can process multiple items continuously.

(3) Storage capacity: Total storage capacity ≥20L, capacity of four categories of garbage areas can be allocated as needed.

(4) Full-load detection accuracy: Ultrasonic distance measurement error ≤5mm, full-load warning response time ≤1 second.

(5) Compression efficiency: Recyclable garbage volume reduction after compression ≥50%.

(6) Power supply: Supporting DC 12V external power or lithium battery supply, lithium battery endurance ≥8 hours (per single charge).

(7) Operating environment: Suitable for temperatures 0-40 °C, humidity ≤85%, meeting conventional indoor and outdoor usage requirements [11].

Installation and maintenance

Installation requirements

(1) Site requirements: Placing on flat surface, avoiding tilting that could cause garbage to fall abnormally; keeping a distance of ≥10cm between the device and the wall to facilitate heat dissipation and wiring.

(2) Wiring requirements: Ensuring voltage matching when connecting to an external power supply, and making sure the wiring is secure without looseness; the IoT module (optional) needs to be connected to the network to ensure normal data transmission.

(3) Debugging requirements: After installation, perform debugging for garbage recognition and separation, calibrate the stroke and displacement accuracy of the push rod to ensure accurate sorting actions.

Daily maintenance

(1) Cleaning the interiors of the temporary storage device, separation device, and storage device regularly to prevent odors and jamming caused by residual garbage; and wiping the camera lens regularly to maintain image capture clarity.

(2) Hardware maintenance: Checking the lubrication of the telescopic push rod and moving mechanisms, and adding lubricant in a timely manner. Checking whether the ultrasonic module's probe is blocked to ensure accurate distance measurement.

(3) Maintenance: Updating the YOLO v5 garbage feature database regularly to enhance recognition accuracy; backing up the control program to avoid equipment failure resulting from program loss.

Innovative points and application prospects

Design innovation point

(1) Multi-module collaboration: Organizing functions such as temporary storage, recognition, separation, and storing into an integrated system to achieve full-process automation of waste sorting, reducing manual intervention.

(2) Intelligent recognition technology: Using the YOLO v5 algorithm to improve the accuracy and speeding of waste recognition, adapting to complex waste category scenarios.

(3) Functional expandability: Integrating features such as full-load detection and wasting compression to enhance the device's practicality and resource utilization.

(4) Information visualization: Displaying classification information in real-time on a screen to enhance user engagement and supervision in waste sorting.

Application prospects

This physical model of smart sorting trash can can be widely used in households, office buildings, shopping malls, communities, and other scenarios, addressing the pain points of traditional waste sorting. In household scenarios, it can improve the convenience of residents' waste sorting; in public scenarios, it can reduce the cost of manual sorting and improve the efficiency and accuracy of waste sorting. With the integration of Internet of Things technology, it can also achieve networked management of multiple trash cans, providing data support for big data analysis of urban waste management and promoting the construction of a smart sanitation system [12].

Conclusion

This physical model of smart sorting trash can integrates mechanical structure with intelligent control technology, achieving automatic identification, separation, storage of waste, and information visualization. It also features practical functions such as full-load detection and recyclable waste compression, meeting the needs of refined waste classification. The design of the device balances practicality, intelligence, and scalability, making it highly valuable in the field of waste sorting. Subsequent improvements could further optimize the algorithm model to enhance the recognition accuracy of complex waste types, while also lightweighting the device structure to reduce production costs and promote large-scale application of the product.

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Conflicts of Interest

The authors declare no conflict of interest.

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