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NANJING FORESTRY UNIVERSITY

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题目	Smart garbage sorting project based on Raspberry Pi 4B				

Content Catalog

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Ⅰ. Project Introduction

With the acceleration of urbanization, waste management has become an urgent issue that major cities must address. Traditional manual sorting methods are not only inefficient, but also prone to misclassification, and it is difficult to achieve large-scale waste processing and resource recovery. Intelligent waste sorting systems have emerged to promote the popularization and implementation of waste sorting.

The intelligent waste sorting system of this project, based on deep learning, plans to adopt convolutional neural network algorithms and train the existing dataset with the YOLOv8 model. By integrating embedded technology with Raspberry Pi 4b, ultrasonic sensors, camera image recognition, LED indicators, and other technological means, real-time monitoring of trash bins and automatic identification and classification of waste types can be achieved. This addresses the issues of identification accuracy, real-time performance, and interactivity in traditional waste sorting, providing citizens with a convenient and intelligent waste-sorting experience. The specific functions are as follows.

1. Automatic Waste Sorting: The system automatically identifies and sorts waste types using integrated cameras and image-recognition technology. To improve the sorting accuracy, the system adopts a majority rule method based on five recognitions to ensure the high reliability of the final sorting results.
2. Trash Bin Overflow Detection: Ultrasonic sensors monitor the capacity of the trash bin in real-time. If the trash bin is full, the system provides a red warning through LED lights, alerting the staff to clean it out to prevent waste from overflowing and affecting the environment.
3. Real-time Feedback and Interactive Prompts: The system displays the results of waste sorting using LED indicators and provides different visual prompts based on the overflow status of the trash bins. When the trash bin is almost full, the indicator light flashes to remind users and managers. If there is a misclassification, the indicator light provides feedback prompts to help citizens correct their mistakes.

Intelligent waste-sorting systems have broad application potential in various practical scenarios. They are particularly suitable for public places, corporate parks, schools, hospitals, and other locations with high population densities. The system can efficiently identify waste types, enhance the accuracy of waste sorting, and reduce instances of misplacement and omissions. In addition, the overflow detection feature of the trash bins enables real-time monitoring of the status of each bin, effectively preventing overflow issues and avoiding environmental pollution. In addition, it can alert the staff when the bins are full, allowing for timely cleaning and ensuring that the bins continue to operate efficiently.

With the continuous development of intelligent technology, the level of intelligence of waste-sorting systems will continue to improve. Intelligent waste sorting systems not only help promote the implementation of waste sorting policies and reduce the final treatment burden of waste, but also greatly improve the efficiency of waste resource recycling, which is of great significance for promoting environmental protection and sustainable development.

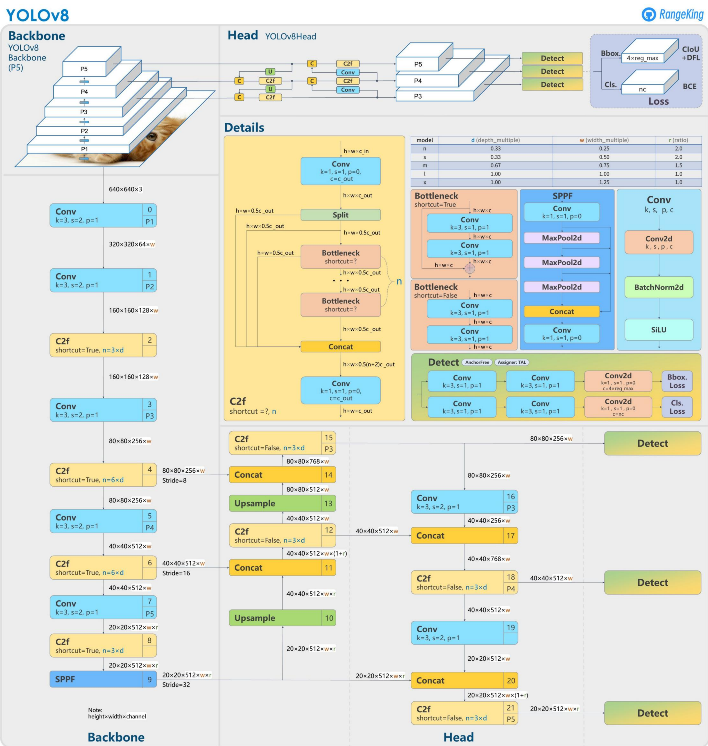
Ⅱ. Existing Technology

Deep learning, a type of machine learning that employs numerous concealed layers within a model, is currently the most widely utilized approach in the field. Deep learning, when used in conjunction with powerful AI technology and graphics processing units (GPUs), has made it possible to obtain exceptional results in image-classification tasks. Consequently, deep learning has been the driving force behind several recent breakthroughs in the fields of image identification, facial recognition, and the development of image classification algorithms that attain above-human-level performance and real-time image/object detection.

A.YOLO

YOLOv8, the latest version of the You Only Look Once (YOLO) family, is a state-of-the-art real-time object-detection model widely used for classification and recognition tasks. In the context of the smart waste classification system project, YOLOv8 was employed to classify different types of waste in real time using a camera feed. The model performs exceptionally well in object detection owing to its speed and accuracy, making it highly suitable for real-time applications, such as waste sorting.

The model builds on the strengths of its predecessors and offers improvements in both accuracy and efficiency. One of its key advantages is the reduction in inference time compared to previous versions, which makes it faster and more responsive to dynamic environments. This is crucial for applications where quick processing is essential, such as automated waste classification, where real-time feedback is necessary to guide users to dispose of their waste correctly. Another significant feature of YOLOv8 is its ability to detect smaller objects with greater precision, which is an essential capability for dealing with diverse waste items that may vary in size and shape. This is highly effective for the construction of our model.

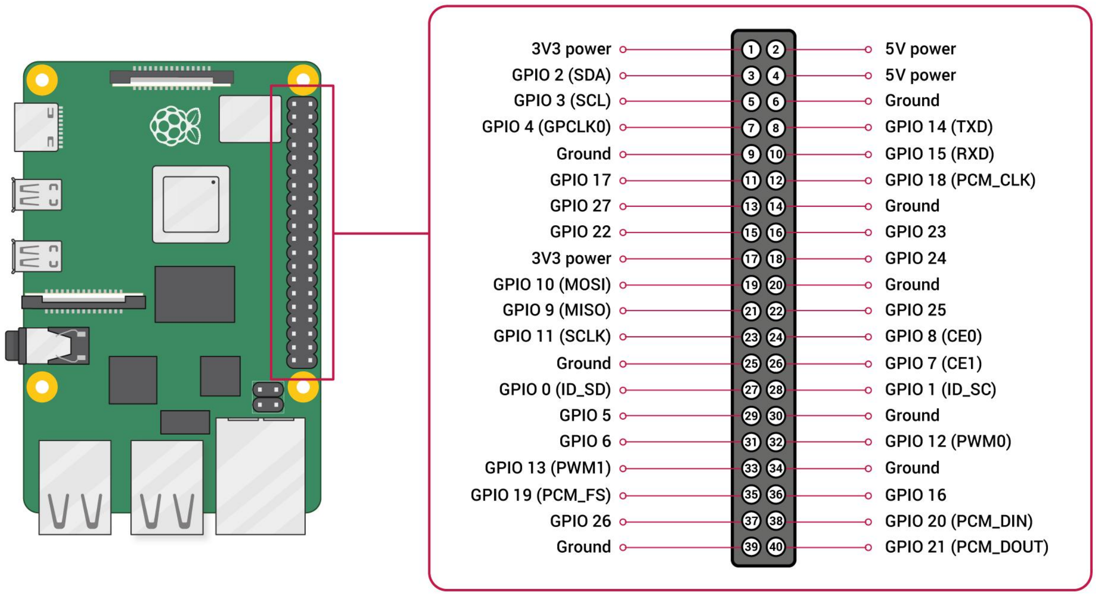


Another significant feature of YOLOv8 is its ability to detect smaller objects with greater precision, an essential capability when dealing with diverse waste items that may vary in size and shape. The model architecture has been optimized to handle various detection challenges, including handling overlapping objects and detecting waste in cluttered environments, which are common in practical applications.

B. The application of ultrasonic sensors in Raspberry Pi

Various existing systems have utilized Raspberry Pi 4 B combined with ultrasonic sensors for a wide range of applications, including distance measurements and environmental monitoring. These systems highlight the versatility of Raspberry Pi in IoT-based projects, particularly in smart automation and sensor integration.

The Raspberry Pi 4 B is widely used in embedded systems because of its low cost, small size, and powerful processing capabilities. One of its main features is its general-purpose input/output (GPIO) pins, which provide an interface for connecting sensors and actuators. A common application is integrating the HC-SR04 ultrasonic sensor, which is used to measure the distance by emitting an ultrasonic pulse and calculating the time it takes for the pulse to return after reflecting off an object. This sensor is highly suitable for applications in which accurate distance measurement is required, such as object detection, level monitoring, and proximity sensing.

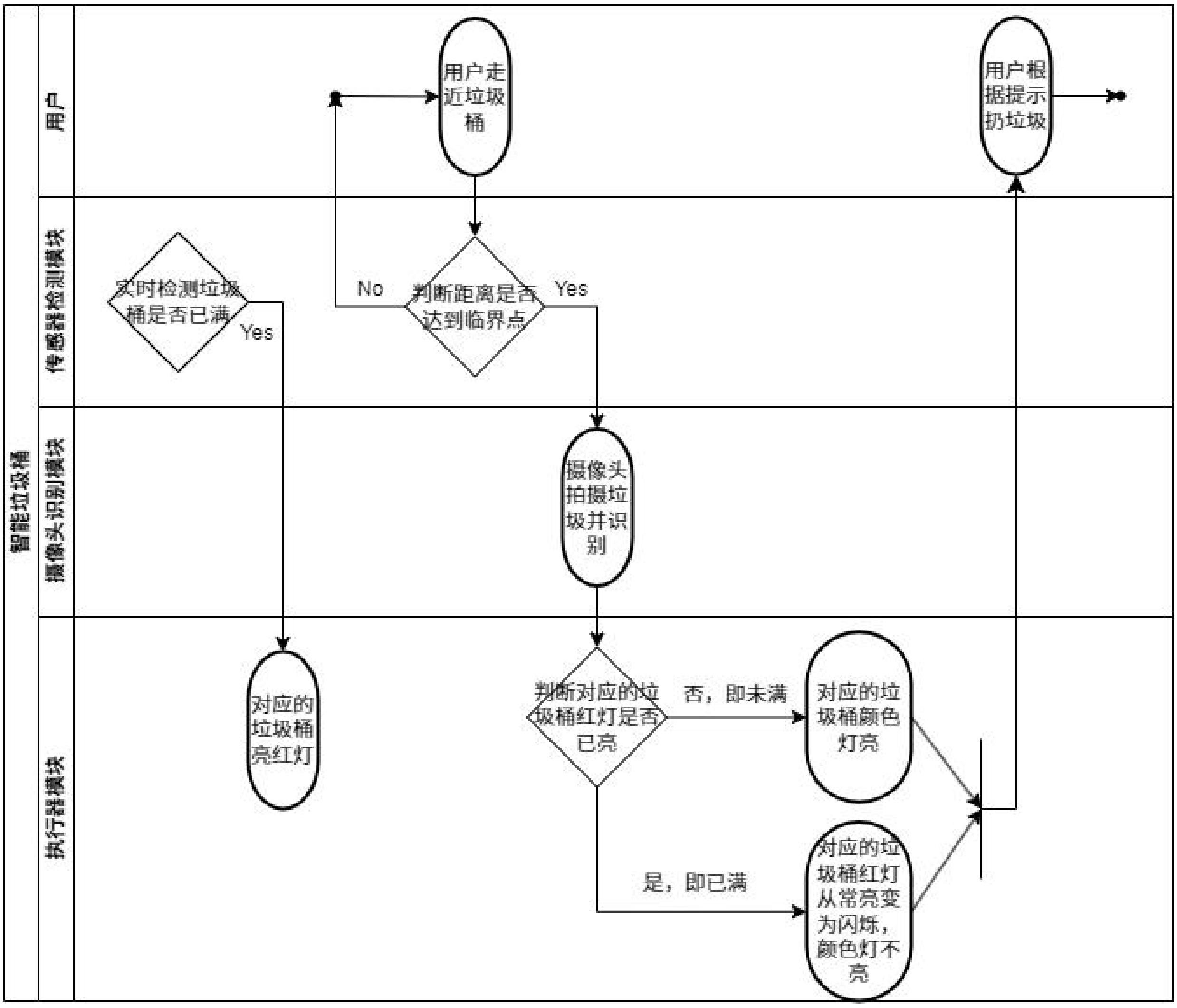


In the waste sorting management system, we combined Raspberry Pi with HC-SR04 to detect bin fullness. We placed an ultrasonic sensor inside the trash bin to measure the distance from the sensor to the top surface of the waste. By monitoring this distance, the system can determine when the bin is approaching full capacity and send notifications to the user via a mobile app or LED indicator.

III. Technical Solutions

1. Comprehensive

In order to make the process of implementing the entire function clearer and clearer, the following flowchart will be used to assist in explanation：



2. System Architecture and Functional Modules

The system achieves its functionality through the following three main modules. They are closely integrated and work in concert to achieve real-time monitoring, waste identification, and sorting, and provide feedback to users.

- **Image Classification and Trash Recognition Module**

The Image Classification and Trash Recognition Module is the core component of an intelligent waste-sorting system. This module utilizes the YOLOv8 (You Only Look Once) deep learning object detection model to recognize types of waste in real time and provide corresponding feedback. By connecting to a camera via Raspberry Pi, the system can capture real-time waste images and input them into the YOLOv8 model for processing. The classification results were fed back to users in a timely manner through LED indicators, ensuring that the waste was correctly sorted.

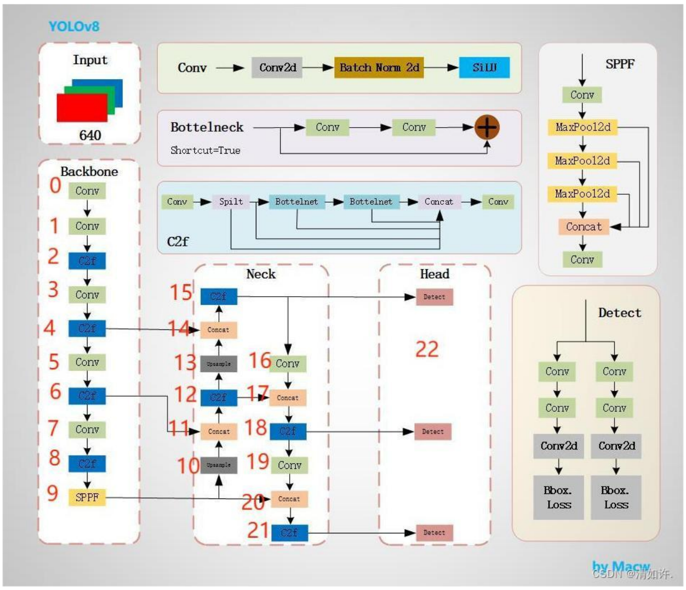
First, the system captures real-time images through a camera, which are then preprocessed. The preprocessing steps included resizing the images to the 640 × 640 pixels required by the YOLOv8 model and normalizing the pixel values to the range of [0, 1]. This process ensures that the input images meet the model requirements for precise inference. The YOLOv8 model has real-time object detection capabilities, is capable of identifying multiple objects in an image in a single forward pass, and simultaneously outputs the class, location, and confidence of each object. This feature makes waste sorting both fast and efficient.

After analysis by the YOLOv8 model, waste was categorized into different types, such as recyclables, kitchen waste, hazardous waste, and other waste. The classification results are fed back to the users by controlling the status of the LED indicators through the GPIO interface of the Raspberry Pi. If the identification is correct, then the LED indicator flashes green.

The high accuracy and real-time detection capabilities of the YOLOv8 model render it particularly suitable for intelligent waste sorting systems. With the powerful computing capabilities of Raspberry Pi, YOLOv8 can run efficiently in resource-limited hardware environments, ensuring the system's real-time response and completion of waste sorting tasks. To further improve performance, the model can be optimized using smaller input image sizes (320 × 320) or by model quantization, reducing the occupation of computing resources and increasing the operational efficiency of low-power devices.

YOLOv8 Model Architecture：

In the process of image classification and trash recognition, the YOLOv8 model plays a central role, with its structure based on deep convolutional neural networks (CNNs), which can efficiently perform object detection tasks. The network architecture of YOLOv8 includes multiple convolutional and pooling layers, which ultimately output the class, location, and confidence of each object through multiple detection heads.



Explanation:

Input layer: Receive the preprocessed image data.
Convolutional Layers: Extract image features through multiple convolutional layers.
Pooling Layers: Downsample the feature maps obtained from the convolution to reduce the computational load.
Fully Connected Layer: Flattens the feature maps and makes final predictions through fully connected layers.
Output Layer: Predicts the class, location, and confidence of each object.

- **Sensor Detection Module**

The Sensor Detection Module is another important component of the intelligent waste sorting system, primarily responsible for monitoring the waste capacity inside the trash bin in real time using an ultrasonic sensor to determine if it has reached an overflow state. The implementation of this module relies on the ultrasonic distance measurement sensor (HC-SR04), which measures the distance inside the trash bin by emitting and receiving ultrasonic waves, thereby estimating the remaining capacity of the trash bin. Based on the detected distance information, the system can determine whether the trash bin is full and provide feedback through an LED indicator.

(1) Ultrasonic Sensor Principle

The ultrasonic sensor HC-SR04 is a common distance measurement sensor that calculates the distance by emitting ultrasonic waves and receiving reflected waves. The working principle is as follows:

- Emitting Ultrasonic Waves: The sensor first emits a set of high-frequency ultrasonic signals.
- Receiving Echoes: When ultrasonic waves encounter an object (such as a pile of waste), they reflect back, and the sensor receives the reflected waves.

- Calculate Distance: The sensor measures the time it takes for the ultrasonic waves to travel to an object and back. It uses the formula: $Distance = \frac{Time \times Speed\ of\ Sound}{2}$ to calculate the distance between the object and the sensor.

By measuring the distance inside the trash bin, the system can obtain information regarding the current height of the waste in the bin and determine whether the trash bin has reached an overflow state.

(2) Module Operation Method

Distance Measurement: The system regularly measures the distance inside the trash bin using an ultrasonic sensor. A sensor was installed at the top of the trash bin.

Data Processing: Raspberry Pi receives the time data returned by the ultrasonic sensor through the GPIO interface and calculates the current height of the waste inside the trash bin.

Overflow Judgment: The system compares the measured height with the preset maximum height (i.e., overflow height of the trash bin). If the current measurement is less than the preset maximum height, it indicates that the trash bin has not overflowed. If the measurement is greater than or equal to the overflow height, it indicates that the trash bin is full.

Feedback Mechanism: If the trash bin is full, the system controls the LED indicator to stay red through the GPIO interface, alerting users that the trash bin is full, and simultaneously uploads the information to the staff for timely cleaning.

(3) Design Considerations and Optimizations

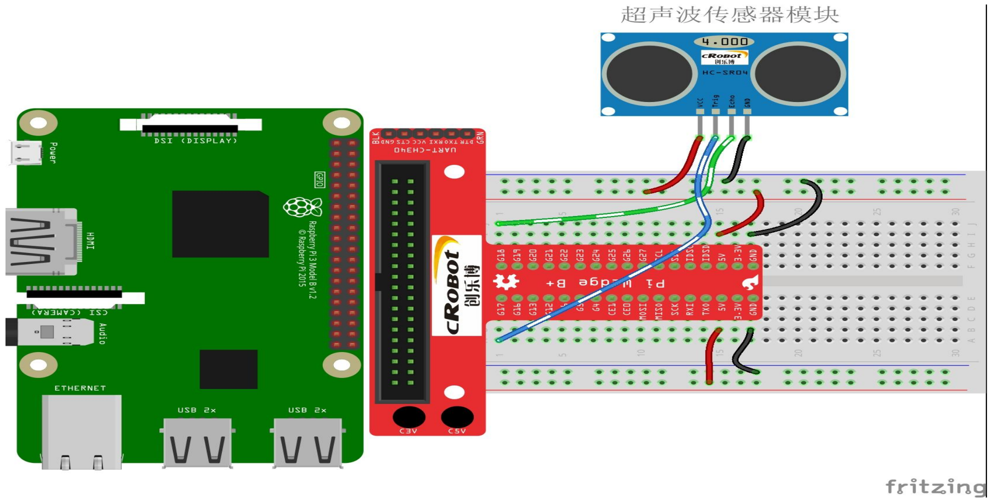
Several aspects need to be considered when designing the trash overflow detection module.

- *Sensor Placement:* The installation location of the ultrasonic sensors is crucial. Considering the shape of the accumulated trash, a sensor was installed at the center of the top of the trash bin.
- *Measurement Accuracy:* The measurement accuracy of an ultrasonic sensor is influenced by various factors, such as the shape of the trash, smoothness of its surface, and reflective characteristics of ultrasonic waves. Therefore, calibration and filtering are necessary to ensure the accuracy of the measurement results.
- *Response Time:* The system must ensure the real-time nature of the detection process. When trash accumulates to a certain level, the system must be able to provide feedback quickly to prevent overflow.
- *Environmental Interference:* There may be some noise interference in the environment that affects the accuracy of the ultrasonic sensor. The system can be designed using noise filtering algorithms, or the sensor can be chosen with an appropriate frequency range during the design to minimize such interference.

(4) Circuit Connection and Hardware Architecture

The hardware architecture of the trash overflow detection module includes an ultrasonic sensor, Raspberry Pi, LED indicator, and power supply module. The ultrasonic sensor was connected to the Raspberry Pi via the GPIO interface, with the Raspberry Pi responsible for controlling the sensor and receiving the returned data. Additionally, the Raspberry Pi controls the state of the LED indicator, which is used to provide feedback to users regarding the status of the trash bin.

Hardware Architecture Diagram：



The TRIGGER pin of the ultrasonic sensor is connected to GPIO pin 7, and the ECHO pin is connected to GPIO pin 8.

- **Actuator Module**

a. Function Description

The actuator module provides feedback to users regarding the results of waste sorting using LED indicators. The system uses four colors of LED lights to represent the four types of waste and indicates whether the trash bin is full with a red LED light. The specific feedback is as follows.

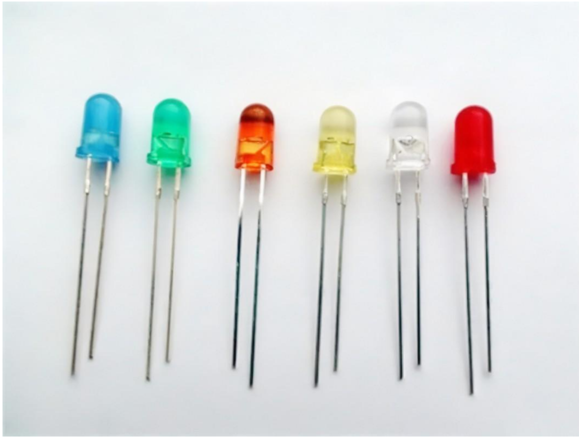
Green LED light: indicates that the waste has been correctly sorted as recyclable.

Yellow LED light: This indicates that the waste has been correctly sorted as kitchen waste.

Blue LED light: indicates that the waste has been correctly sorted as hazardous waste.

White LED light: This indicates that the waste has been correctly sorted as other waste.

Red LED light: There are four, each indicating that the corresponding trash bin is full.



b. Module Structure and Working Principle

The core of the actuator module is the LED indicator. The four colored LED lights were used to provide feedback on the sorting of the four types of waste, while the red LED light was used to indicate the overflow status of the trash bin.

Operating Status:

1) Correct Waste Identification: When system correctly identifies the type of waste through the YOLOv8 model, the corresponding LED light (green, yellow, blue, or white) will light up, signaling to the user the category of the waste and then dispose of it in the appropriate trash bin.
2) Trash Bin Full: When the ultrasonic sensor detects that the trash bin is full, the corresponding red LED light will stay on, alerting staff to empty the trash bin in a timely manner. Simultaneously, the red light changes from a constant to a flashing state to further alert users that the trash bin is full and cannot accept more waste. For the sake of the local environment, users are advised to visit another waste disposal site.
3) Hardware Design: Each colored LED indicator was connected to the system via the GPIO pins of the Raspberry Pi. When the waste sorting result corresponds to a certain category, the system controls the appropriate LED light to be turned on through the GPIO pins.

IV.Specific Implementation

1. Dataset Acquisition and Model Training

In the Windows system environment, garbage classification datasets were collected online, and the datasets were cleaned and labeled. Subsequently, the YOLOv8 model was used for training to obtain the best weight file (best.pt), and the classification effect was demonstrated using test images.

Operation Process:

✧ The data classification (as shown in Figure 1).

- ✧ Train with YOLOv8n and save the results as best.pt (Figure 2).
- ✧ Convert the model to the onnx format for easy deployment on Raspberry Pi.

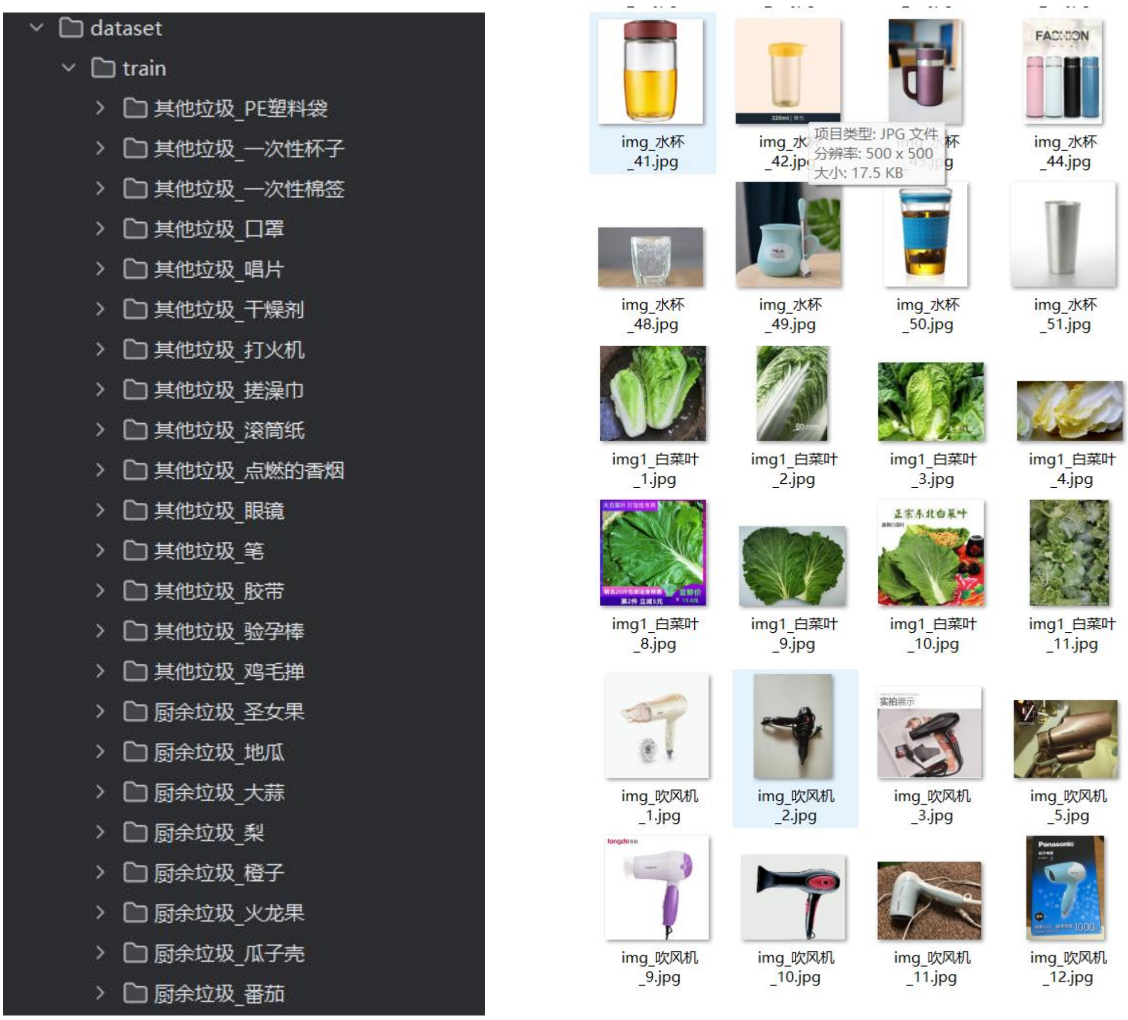


Figure 1

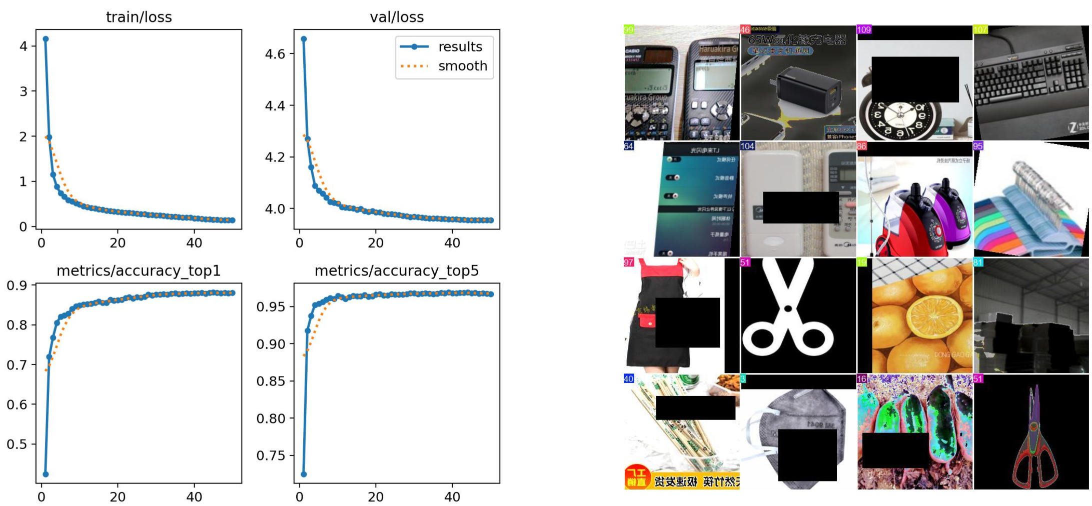


Figure 2

2. Hardware Selection and Circuit Connect

The following hardware was purchased according to the system requirements: ultrasonic distance measurement sensor HC-SR04, LED lights (green, blue, yellow, white, and red), DuPont wires, GPIO expansion board, and breadboard.

Connection Method:

- ✧ The ultrasonic sensor was connected to the Raspberry Pi via a GPIO 7 (Trigger) and GPIO 8 (Echo).
- ✧ The LED indicators are connected to the corresponding GPIO pins (for a specific allocation, see Figure 3).
- ✧ A brief diagram of the hardware layout is shown in Figure 4.

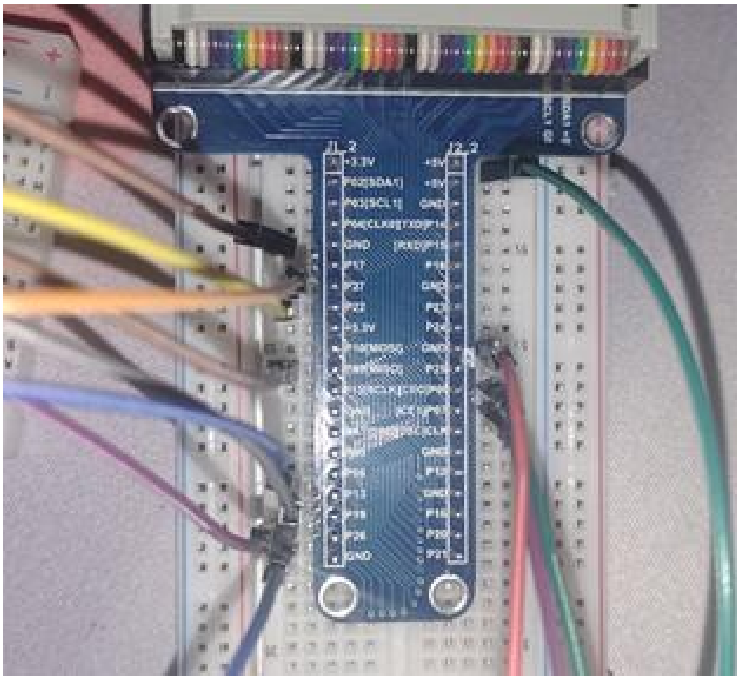


Figure 3

Figure 4

3. Ultrasonic Distance Measurement Program Development

In the Raspberry Pi environment, the necessary software packages are installed (as shown in Figure 5, listing only the main packages) and a program is written to detect whether a user is approaching the trash bin using an ultrasonic sensor.

Main Logic:

- ✧ GPIO 7 outputs a high-level signal that triggers the ultrasonic sensor to emit a signal.
- ✧ The echo is received through GPIO 8, and the time difference between transmission and reception is calculated to deduce the distance.
- ✧ The detection range was set to 20–100 cm, and it was checked if it was sustained for more than 3 s.
- ✧ If it is sustained for more than 3 s, it is considered that the user is approaching and intends to identify the waste.
- ✧ Figure 6 shows the timing diagram of the ultrasonic signal that we monitored.

Package name	version
RPi.GPIO	0.7.1
torch	2.5.1
Numpy	1.23.5
ultralytics	2.0.12
pandas	1.5.3
opencv-python	4.6.2.31
ultralytics-thop	2.0.12

Figure 5

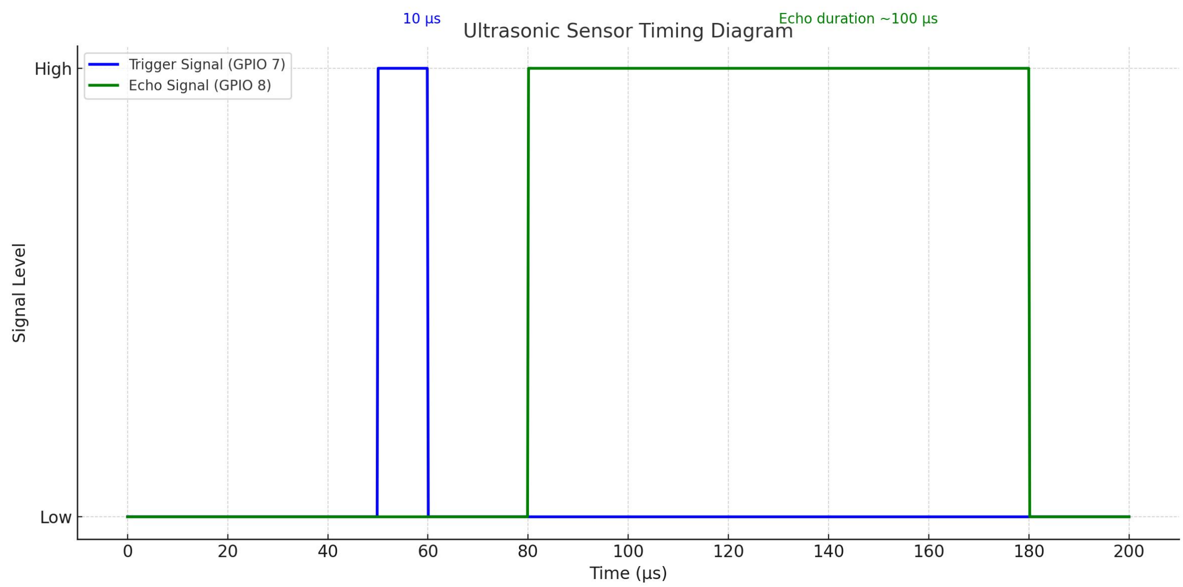


Figure 6

Detection Logic Optimization:

To avoid false positives, a time-weighted calculation method for continuous multiple detections can be set, such as detecting five times per second and calculating the moving average.

4. Camera Recognition and Waste Sorting

When someone was detected nearby, the program activated the camera to capture an image and perform waste sorting. The classification algorithm used YOLOv8, and the mode (most frequent outcome) of the five classification results was taken as the final output to minimize the error from a single classification instance.

LED Indicator Feedback Logic:

- ✧ If the trash bin is not full, the corresponding colored LED flashes three times and then stays on for five seconds.
- ✧ If the trash bin is full, the red light stays on continuously, and the LED corresponding to the identification result flashes thrice.
- ✧ Figure 7 shows the logic diagram for waste sorting and LED control.

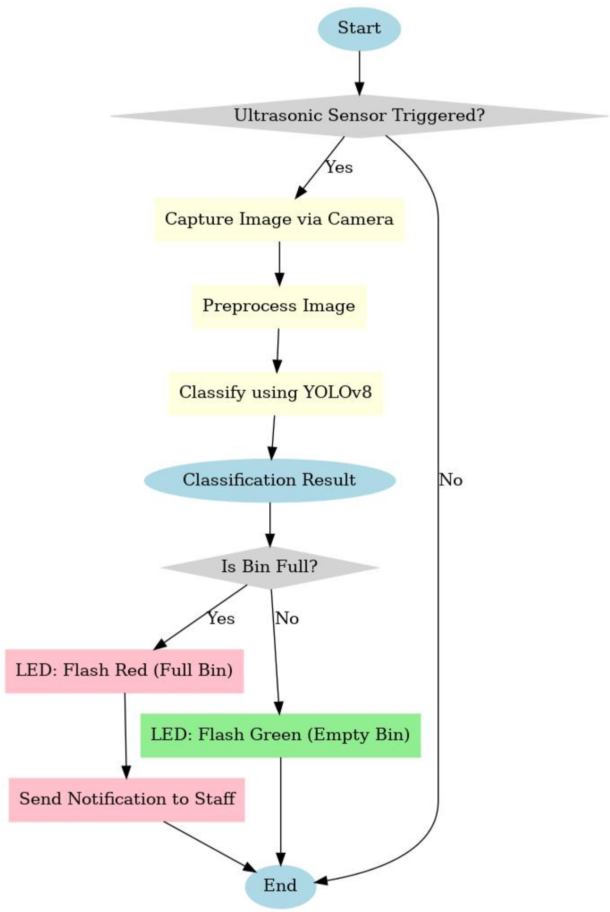


Figure 7

5. Trash Bin Overflow Detection

By installing an ultrasonic sensor at the top of the trash bin, it detects whether the waste has accumulated within the measurement range of the sensor. If the detected distance is less than the set threshold (10 cm), the system determines that the trash bin is full and triggers the red light to remain on.

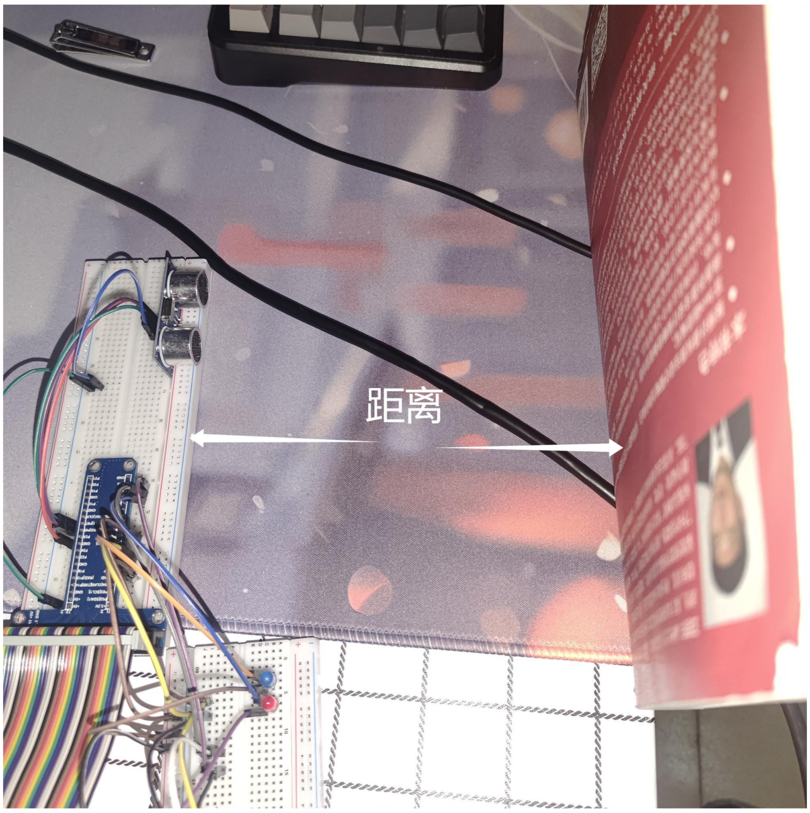
Overflow Feedback:

- ✧ Local red lights alert users.
- ✧ A reminder message was sent over the network to the cleaning staff.

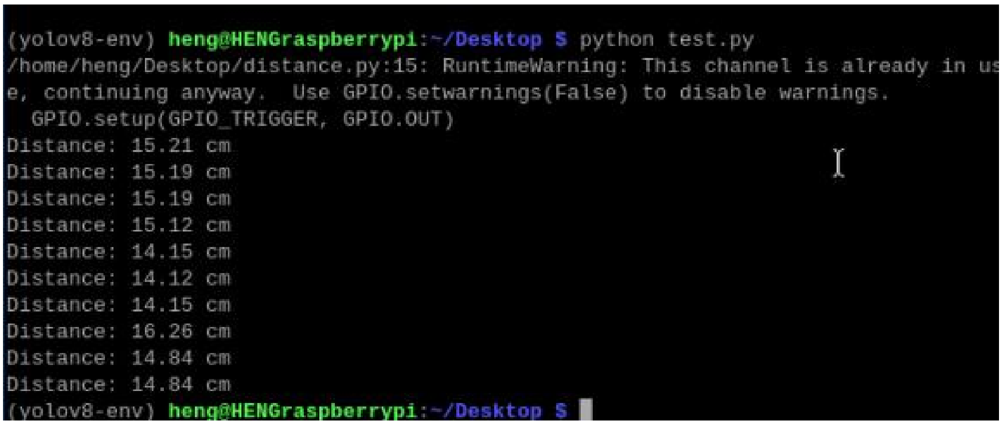
V.Test cases and running results

1. Test the Ultrasonic Distance Measurement Module:

Place a book upright directly in front of the sensor.



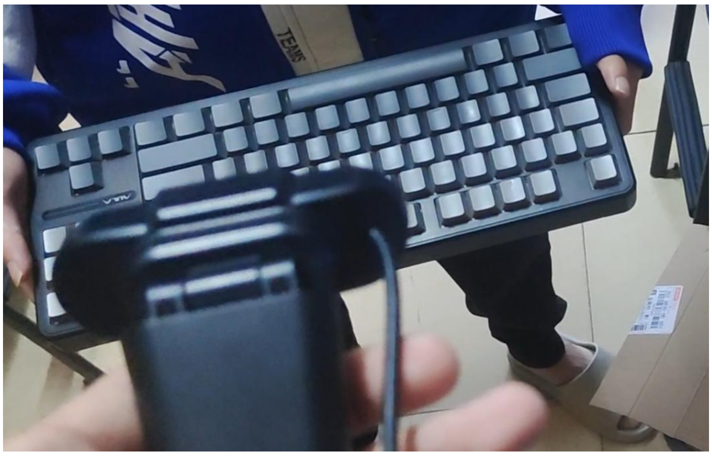
Running result：



2. Intelligent Waste Sorting Effect Inspection:

Recognize a keyboard, an apple, and a pen respectively, check the recognition results, and verify whether the LED lights can display correctly.

- Keyboard：



Running result：

- ✧ The green light (for the recyclable waste) is on.

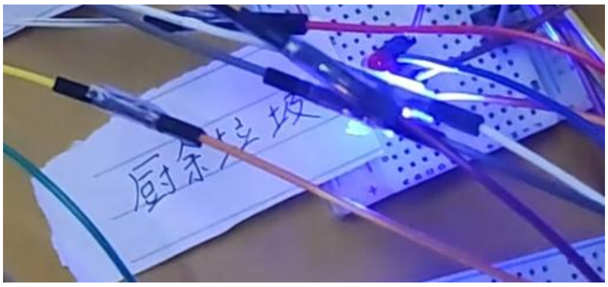
- ✧ The code execution interface displays "可回收物_键盘".

```
True
start garbage_classify
Waiting for 3 seconds before starting detection...
Predicted: 可回收物_键盘, Major Category: 可回收物, Confidence: 0.9967
Waiting for 1 seconds before next detection...
Predicted: 可回收物_键盘, Major Category: 可回收物, Confidence: 0.9985
Waiting for 1 seconds before next detection...
Predicted: 可回收物_键盘, Major Category: 可回收物, Confidence: 0.9880
Waiting for 1 seconds before next detection...
Predicted: 可回收物_键盘, Major Category: 可回收物, Confidence: 0.9765
Waiting for 1 seconds before next detection...
Predicted: 可回收物_键盘, Major Category: 可回收物, Confidence: 0.9996
normal
可回收物
```

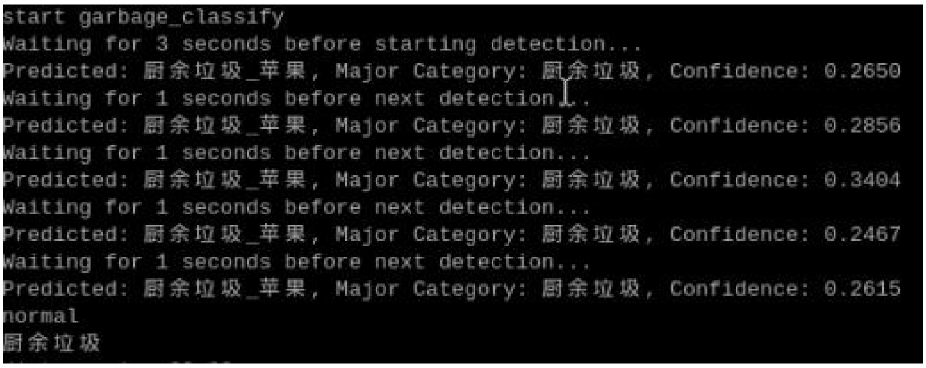
◆ Apple

Running result:

✧ The yellow light (for the kitchen waste) is on.



✧ The code execution interface displays "厨余垃圾_苹果".

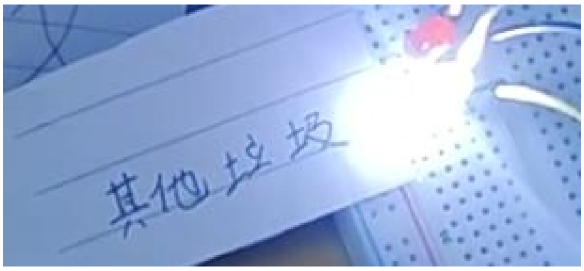


```
start garbage_classify
Waiting for 3 seconds before starting detection...
Predicted: 厨余垃圾_苹果, Major Category: 厨余垃圾, Confidence: 0.2650
Waiting for 1 seconds before next detection...
Predicted: 厨余垃圾_苹果, Major Category: 厨余垃圾, Confidence: 0.2856
Waiting for 1 seconds before next detection...
Predicted: 厨余垃圾_苹果, Major Category: 厨余垃圾, Confidence: 0.3404
Waiting for 1 seconds before next detection...
Predicted: 厨余垃圾_苹果, Major Category: 厨余垃圾, Confidence: 0.2467
Waiting for 1 seconds before next detection...
Predicted: 厨余垃圾_苹果, Major Category: 厨余垃圾, Confidence: 0.2615
normal
厨余垃圾
```

◆ Pen

Running result：

✧ The white light (for the other waste) is on.



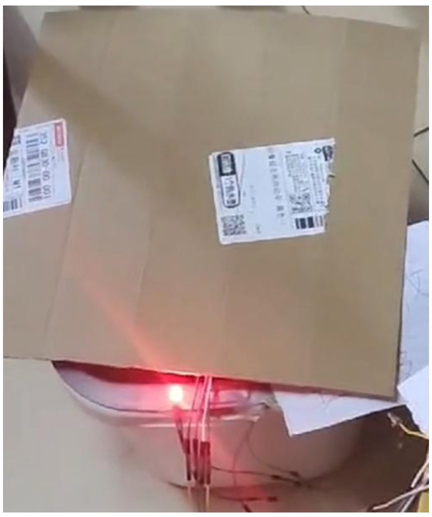
✧ The code execution interface displays "其他垃圾_笔".

```
True
start garbage_classify
Waiting for 3 seconds before starting detection...
Predicted: 其他垃圾_笔, Major Category: 其他垃圾, Confidence: 0.3477
Waiting for 1 seconds before next detection...
Predicted: 可回收物_订书机, Major Category: 可回收物, Confidence: 0.3385
Waiting for 1 seconds before next detection...
Predicted: 其他垃圾_笔, Major Category: 其他垃圾, Confidence: 0.3234
Waiting for 1 seconds before next detection...
Predicted: 可回收物_订书机, Major Category: 可回收物, Confidence: 0.5967
Waiting for 1 seconds before next detection...
Predicted: 其他垃圾_笔, Major Category: 其他垃圾, Confidence: 0.2260
normal
其他垃圾
```

PS： A single identification has a high probability of causing errors that can affect the operation of subsequent actuator modules. Therefore, to improve the accuracy of the camera's identification, we conducted five identifications and took the result with the highest frequency of occurrence as the final outcome.

3. Trash Bin Overflow Detection:

Fill the trash bin and close the lid.



We found that the red light of this trash bin will stay on.

VI.References

Referenced papers:
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VII.Summary

1. What have you mainly learned:

In this "Intelligent Waste Sorting System" project, our team members collaborated closely, continuously consulted literature, and even sought advice from online communities and AI, correcting our previous misconceptions and deeply learning a variety of knowledge related to embedded development, deep learning, hardware control, and system integration. Our greatest achievement was learning how to identify and solve problems and then translate them into specific codes. Additionally, teamwork has greatly facilitated project development, breaking through the bottleneck of individual thinking that was not rigorous or expansive enough.

In the image classification part, we gained an in-depth understanding of the working principles of the YOLOv8 model and mastered how to use this model for real-time image processing, classification, and detection, particularly how to optimize deep learning models for efficient operation on embedded devices. When using the ultrasonic sensor for distance measurement and trash bin overflow detection, we first gained a deeper understanding of the structure and logic of the HC-SR04 sensor used in this study. Second, connecting the ultrasonic sensor to the GPIO interface was a significant challenge for us because of our lack of knowledge of circuitry. We consulted with classmates from the telecommunications field and spent an additional half a week learning about the relationship between interfaces and the implementation of the interface and program code. On this basis, we once again recognize the importance of teamwork, as each person has different knowledge, which allows for a more comprehensive application of knowledge to the project.During the code-writing process, we consolidated the core concepts of embedded development, as well as knowledge of duty cycle settings, PWM signals, GPIO interfaces, etc., and implemented the execution functions of the actuators by controlling different LED lights to light up or flash.

In summary, our team members in this project have become familiar with the control and connection of hardware, improved our programming skills, and most importantly, learned to associate the two, achieving control and coordination of hardware through programming.

2. What other issues have not been achieved

Although we have successfully implemented most of the system's functions, compared to the actual application requirements, there are still some unresolved areas that need improvement.

a. Improvement of Classification Accuracy

Although the current system can perform the basic classification of four types of waste, the recognition accuracy of the YOLOv8 model needs to be further improved under conditions where some items have similar shapes and there are significant changes in lighting. In particular, for waste categories that are highly similar, the system occasionally misclassifies them. Although we have reduced the errors by taking the mode from multiple identifications, for some complex items, complete accuracy is still difficult to achieve.

b. Environmental Adaptability

As the system relies on a camera for waste recognition, changes in lighting, angle, and background can affect the recognition effect. In situations with poor lighting or suboptimal camera angles, the quality of image capture decreases, which may affect recognition accuracy. Although we have enhanced the model's robustness through image enhancement techniques, the system's adaptability to complex environments still requires improvement.

c. System Response Time

Although Raspberry Pi 4 B provides a certain level of real-time performance when processing the YOLOv8 model, the response time is still somewhat slow owing to the high computational load, especially in complex scenarios. When multiple objects appear in the field of view simultaneously, the system's response time is delayed. To address this, we have considered improving the system efficiency through model compression and acceleration, but further optimization is still needed.

d. Limitations of Notification and Feedback Mechanisms

The current notification feedback mechanism provides feedback only through LED lights, which cannot offer a richer interactive experience for users. Although we inform users of the success of waste sorting through multiple flashes and red light alerts, to enhance user experience, future considerations could include the addition of display screens or other more efficient notification methods.

3. Problems encountered during the course design process and solutions:

During the implementation of the project, the team members encountered several technical challenges, and there were some key issues and their solutions.

a. Model Deployment Issues

When the camera is used to recognize and classify images, a computational performance bottleneck is encountered, leading to poor real-time performance. To address this issue, the team decided to quantize the model to reduce its file size and adjust the input image dimensions to alleviate the computational load. We compressed the frames of the images captured by the camera, reducing the resolution to 320 × 320 pixels. Through these optimization measures, the model was able to run more efficiently on Raspberry Pi.

b. Ultrasonic Sensor Data Error

On the day before the project's completion, there was a significant error in the measured distance data during the testing of the ultrasonic sensor. After continuous testing, we found that the main reason was the interference signals in the environment or unstable signal reflection. To solve this problem, we adjusted the sensor's transmission frequency and improved its accuracy by taking the average of multiple measurements. At the same time, we also optimized the sensor's operating distance range to reduce the interference of outliers.

c. Hardware Connection Issues

During the hardware connection phase and subsequent development, some components (such as LED lights and ultrasonic sensors) frequently exhibit poor contact issues. We had to constantly check the circuit design to ensure that all the connections were secure. Eventually, we adopted more robust DuPont wires and connection methods to reduce the system instability caused by hardware failures. Although some issues still occur, we have gained the ability to resolve such problems.

4. Compare the improvement before and after the course design:

Throughout the entire project, team members have not only made significant improvements in their respective technical skills but have also received excellent training in project management, communication, and problem-solving. By collaborating with team members, everyone has not only strengthened their understanding and application of technology, but has also learned how to work in a division of labor and communicate effectively to solve problems. We established project plans and made adjustments, avoiding many potential issues in the project through regular discussions and testing, and making timely adjustments and optimizations, effectively managing time and resources, and improving work efficiency, which has cultivated good habits for our future work.

5. How to learn in the future:

In the future, team members will plan to continue deepening their studies in the following areas:

a. Deep Learning and Model Optimization

Focusing on the recognition accuracy and response speed of YOLOv8, the team plans to further research lighter object detection algorithms in deep learning, such as YOLOv5 and MobileNet, to enhance the application of models in embedded systems. Simultaneously, they also delve into learning how to use hardware acceleration technologies, such as GPUs or TPUs, to speed up the inference process.

b. Internet of Things and Smart Hardware

In the field of the Internet of Things, the team will learn more about sensors, embedded development boards (such as Arduino and ESP32), and cloud computing platforms to improve the project's remote monitoring capabilities and the intelligent level of the system. For example, waste sorting information can be uploaded to the cloud in real time for analysis and management using wireless communication protocols (such as MQTT or LoRa).

c. System Integration and Optimization

The team will also learn how to optimize the system as a whole, reducing latency and improving accuracy to further enhance user experience. In addition, considering the diversity of actual application scenarios, the team will explore how to combine different sensors (such as infrared sensors and temperature and humidity sensors) to improve the system's intelligence level and adaptability.

d. Human-Computer Interaction

To improve the user experience of the system, the team plans to explore speech recognition technology by combining voice feedback and visual cues to create more intuitive and diverse interaction methods to help users sort waste more conveniently and accurately.

Overall, this project is certainly behind the latest generation of technology, but we firmly believe in the principle of "if you can't clean your own room, how can you govern a country?" We believe that projects can be improved through continuous improvements and updates. With the continuous development of technology and our own skills, we will continue to refine this project, striving to make it more flexible, convenient, and interactive in the future to solve practical problems and enhance the intelligence level of the system.

VIII.Project Division of Labor

1. Lu Boheng

- Data Collection: Responsible for finding and collecting datasets suitable for waste classification. This includes searching for public datasets, screening and organizing data, and performing the necessary preprocessing to ensure that the dataset is suitable for training.
- Waste Classification Model Training and Deployment: Trains waste data using the YOLOv8 deep learning model, adjusts model parameters, optimizes the training process, and continuously refines to improve classification accuracy. The trained YOLOv8 model (. pt file) in the ONNX format to ensure smooth operation in the Raspberry Pi environment.

- Waste recognition code writing: Waste recognition code that interfaces with the model, uses Raspberry Pi to access the camera, captures real-time images, and inputs them into the model for waste classification recognition.
- Component Selection and Purchase: Responsible for purchasing various hardware components needed for the project, including cameras, sensors, LED lights, and GPIO expansion boards, and selecting the most suitable components based on project requirements.
- Sensor Wiring: Responsible for completing the wiring of the ultrasonic sensor and other hardware devices, ensuring smooth communication and normal operation between hardware components.
- Project Report Writing: Responsible for initial drafting of the project report.

2. Shao Yicheng

- Ultrasonic Distance Measurement Module Development: Responsible for developing and debugging the ultrasonic distance measurement module, ensuring that the Raspberry Pi can control the ultrasonic sensor to measure the distance through GPIO pins.
- Distance measurement algorithm optimization: Write and optimize the ultrasonic distance measurement code to ensure stable operation when detecting the distance, especially when determining if the trash bin is full, to accurately obtain data.
- Trash Bin Overflow Detection: Responsible for monitoring the fill level of the trash bin using the ultrasonic sensor and calculating whether the bin is full.
- Sensor debugging and testing: Debugging and testing of the ultrasonic sensor to ensure that the system correctly identifies the overflow state of the trash bin and feeds accurate data back into the system.
- Data collection and algorithm adjustment: Collect sensor data and further optimize the criteria for judging trash bin overflow using algorithms to ensure the system's accuracy and stability.
- Software Documentation Writing: Optimizes the content of software documentation.

3. Sun Jie

- Person Detection Module Development: Responsible for developing and implementing a person detection feature before waste classification, ensuring that waste classification recognition only starts when a person is nearby.
- Person Detection Algorithm Optimization: Optimizes the person detection algorithm and adjusts detection thresholds and response times to avoid false identification and delayed responses. Ensuring that the system starts waste classification promptly when a person approaches.
- Interface Design and Testing: Designs and tests the interface between person detection and waste classification modules to ensure accurate and conflict-free information transfer.
- Testing and Optimization: Conduct real-time testing of the system to check the response speed and accuracy when a person approaches, and continuously optimize the algorithm to improve detection precision.

- Software Documentation Writing: Drafts software documentation.

4. Li Qianqian

- LED Control Logic Design: The LED control code is designed and implemented to ensure that different colored LED lights (such as green flashing for three seconds and then staying on) are controlled based on the waste classification results and trash bin overflow status.
- Feedback Mechanism Implementation: Provides user feedback through controlled flashing and continuous lighting of LED lights when waste is correctly classified. If the trash bin is full, the red LED light remains to warn the users to clean up.
- Red Light Flashing Function Design: When waste classification is incorrect, the red light changes from continuous to flashing to prompt users to reclassify, ensuring timely and correct feedback to prevent incorrect waste disposal.
- GPIO Interface Programming: Responsible for interfacing with Raspberry Pi's GPIO to ensure that actuators work as intended according to the set logic.
- System debugging and optimization: Debug LED control code and main function code to ensure coordination with other modules, ensuring that the system responds efficiently and stably in practical applications.
- Project Report Writing and Flowchart Drawing: Responsible for writing the project report, later review and content optimization, and drawing flowcharts in later stages.

5. Peng Yuxuan

- Flowchart Drawing: Responsible for drawing various flowcharts in the early stages of the project, such as waste classification and trash bin overflow detection processes, to help team members better understand the working principles of the system.
- Document Typesetting and Review: Responsible for typesetting, formatting, and reviewing documents to ensure they meet standards and are highly readable.
- Literature Review: Conduct research and review relevant literature and references.