Design and Research of Intelligent Sorting Trash Bin Based on IoT

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Abstract. In view of the 'difficult' situation of trash front-end classification, this paper proposes a novel intelligent classification trash bin based on Internet of Things (IoT) technology. This trash bin uses both STM32C8T6 control module and K210 vision module to control the operation of the whole equipment. Firstly, the image of the trash bin is collected by the OV5642 camera. Secondly, the function of trash detection and classification can be realized by the K210 vision module. Finally, the recognition results are transmitted to the STM32C8T6 control module through the UART serial port in the form of data, which controls the motor module, ultrasonic module and buzzer module to achieve trash classification, compression crushing and other functions. The experimental results show that the average accuracy of trash recognition is more than 87%. Compared with the traditional smart trash bin, the hardware of our design is added with recyclable trash compression and kitchen waste crushing structure, and the software of our design is added with LCD display interface for providing a more reliable, efficient and low-cost solution for trash classification.

Keywords: Front-end processing · Intelligent sorting trash bin · K210 Visual module · STM32

1 Introduction

With population growth, urbanization, and changes in consumption patterns, China's trash production has continued to grow over the past few decades. China has become the world's largest generator of solid waste. If these wastes are not properly processed, it will have a negative impact on the environment [1]. In order to reduce the generation of trash and to improve the efficiency of trash recycling and processing, China has implemented a trash classification system nationwide since 2019 [2]. However, the trash classification system faces many challenges during the implementation process, such as insufficient public knowledge and awareness of trash classification, insufficient enforcement, and insufficient classification facilities.

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In order to solve various problems in the process of trash classification, re-searchers have developed smart trash bins that can autonomously identify and classify trash based on artificial intelligence technology [3–6] to reduce human burden and improve the accuracy and efficiency of trash classification. Kang zhuang et al. [7] used the Inception V3 model for trash identification and deployed it on Raspberry Pi 3B+. Shen Jian et al. [8] proposed an intelligent classification trash bin based on Jetson Nano. Zhou et al. [9] designed a smart trash bin based on the STM32F103ZET6 chip and the LD3320 speech recognition module, which facilitates trash classification and processing by manually speaking the name of the trash. Li et al. [10] proposed a smart trash bin based on Raspberry Pi and a 110-degree wide-angle camera, using the You Only Look Once vesion 5 (YOLO v5) model training data set to achieve a recognition ac-curacy of more than 90%.

The above-mentioned researches also have shortcomings in solving the problem of intelligent trash classification. Most of the results are not smart enough in functionality and cannot realize fully automatic trash identification and classification; some of the hardware is expensive and has no prospect of popularization and application. Therefore, it is very meaningful to design a trash classification system that is both fully automatic and low-cost. This article designs a smart trash bin based on STM32. The trash bin realizes automatic identification and classification of trash based on the STM32C8T6 microprocessor and the K210 module [11], achieving powerful performance while maintaining a low price. The smart trash bin model structure is as shown in Fig. 1.

The smart trash bin includes: 1. Trash storage port, 2. LCD display, 3. Steering gear, 4. Built-in trash bin, 5. Electric push rod, 6. Trash bin outer frame, 7. Trash temporary storage platform, 8. Camera. The outer frame of the model is constructed of aluminum profiles and edged with acrylic panels.

2 General Idea and Framework

The overall design idea is as follows: The smart trash bin use the K210 vision module for trash identification and classification, and uses STM32C8T6 to call ultrasonic waves, buzzers, and motors to achieve functions such as trash classification, full load detection, compression processing, and crushing processing. Meanwhile, it calls the LCD display module to display various parameters of the smart trash bin, which include whether the trash bin is full, the compression status of recyclable trash, and the completion of crushing kitchen waste. The frame of the smart trash bin is shown in Fig. 2. The device consists of five modules: STM32 control module, K210 vision module, ultrasonic and buzzer module, and motor module (mainly composed of three parts: trash classification module, compression module, and crushing module)), LCD display module. The STM32 control module can realize automatic detection and classification of trash by calling other modules and other functions.

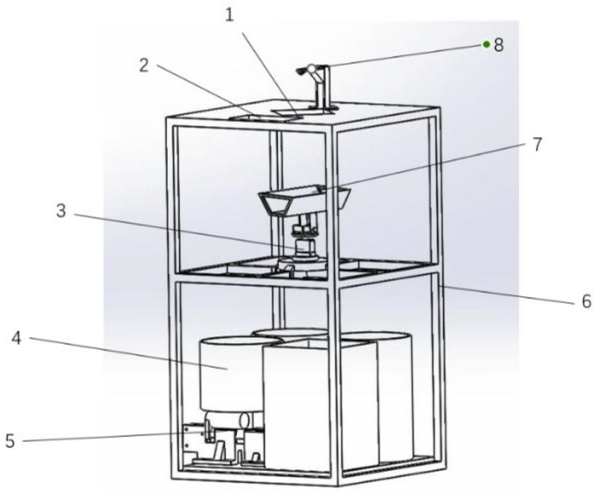

Fig. 1. Structure diagram of intelligent trash bin.

3 Hardware Structure

3.1 STM32 Control Module

The STM32 control module uses a 32-bit microcontroller STM32F103C8T6 developed based on the ARM Cortex-M core. The working frequency of these STM32 series 32-bit microcontrollers can reach up to 72MHz, and the internal use is 64K or 128K bytes flash program memory, with 20K bytes of SRAM data memory and built-in CRC cyclic redundancy check and 96-bit encoding (24-bit hexadecimal number) of the chip's unique serial number. Its main system consists of 4 control units [DCode bus (D-bus), system bus (S-bus), general DMA1, general DMA2] and 4 controlled units (internal SRAM, internal Flash, FSMC, AHB to APB bridge AHB2APBx), which are connected to each other through a multi-level AHB bus.

3.2 K210 Vision Module

This design uses the Maixpy development board equipped with the K210 chip, which is equipped with the RT-Thread operating system and uses the RISC-V 64-bit Dual Cores. Each core has a built-in independent floating point unit (FPU) with super computing power and a dedicated neural network processing unit (NPU) performing real-time video processing. At the base rate of 400MHz, the INT16 test has a performance of 300GMAC/s, and the entire machine consumes less than 1W.

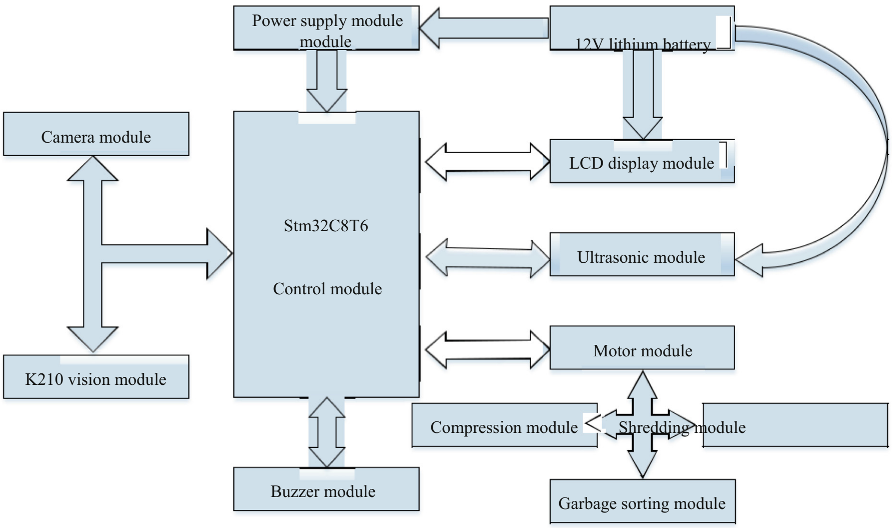

Fig. 2. Intelligent trash bin framework.

3.3 Camera Module

The camera sensor module uses OV5640 with 5 million pixels, supporting higher resolutions. Meanwhile, the OV5640 photosensitive array reaches 2624x1964 resolution (physical size), supporting up to 2592x1944@15fps (QSXGA) or 90fps VGA (640480) image capture, with high acquisition rate and higher image pro-cessing performance, which can provide highly identifiable input values to the K210 vision module.

3.4 Ultrasonic and Buzzer Module

For full-load detection, it is essential to implement high-precision distance detection. We use the HC-SR04 ultrasonic module, which has the characteristics of high frequency, short wavelength, small diffraction phenomenon, good directionality, and becoming ray thus directional propagation. The detection distance ranges from 2cm to 450cm, and the accuracy can also reach 3mm. We use an active buzzer for the full load alarm, which contains an oscillation source inside and it will sound as soon as the power is turned on for easy operation.

3.5 Classification Platform Module

As shown in Fig. 3, the classification platform is composed of a placement plat-form 1, a connector 2, and a steering gear 3. The steering gear is a 20KG dual-axis steering gear of the RDS3218 model, while the connecting parts between the steering gears are printed using 3D printing technology. The placement platform is made of laser-cut acrylic sheets and is placed directly above the classified trash bin after assembly.

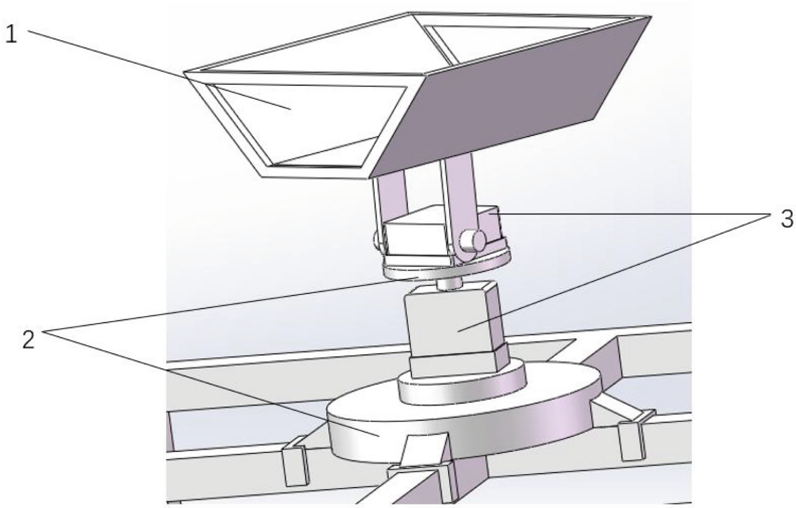

Fig. 3. Classification platform structure diagram.

3.6 Compression Module

As shown in Fig. 4, the compression module is composed of a rear-end fixed seat, an electric push rod, a guiding platform, a connecting piece of the push rod pressing plate, and a pressing plate. During the experiment, the rear-end fixed seat, the guiding platform, and the connecting piece were all independently designed with three-dimensional drawings through SolidWorks and printed with a 3D printer. The pressing plate was processed by sheet metal and all assembled together to form a compression module. The pressing plate and the trash bin form a certain wedge-shaped angle to compress the sorted recyclable garbage to achieve the purpose of improving the utilization rate of the space in the trash bin.

3.7 Shredding Module

As shown in Fig. 5, the crushing module is composed of a crushing blade 1, a crushing device bushing 2, and a motor module 3. The crushing blade is formed by laser cutting parts and sheet metal processing. The blade is installed on the rotating shaft. The rotating shaft and the bushing parts of the crushing device are made by turning aluminum bars. The assembled parts are installed on the stepping motor to form a crushing module. The sorted kitchen waste is subjected to a pulverized micro-treatment, which achieves the purpose of improving the utilization rate of the space in the trash bin.

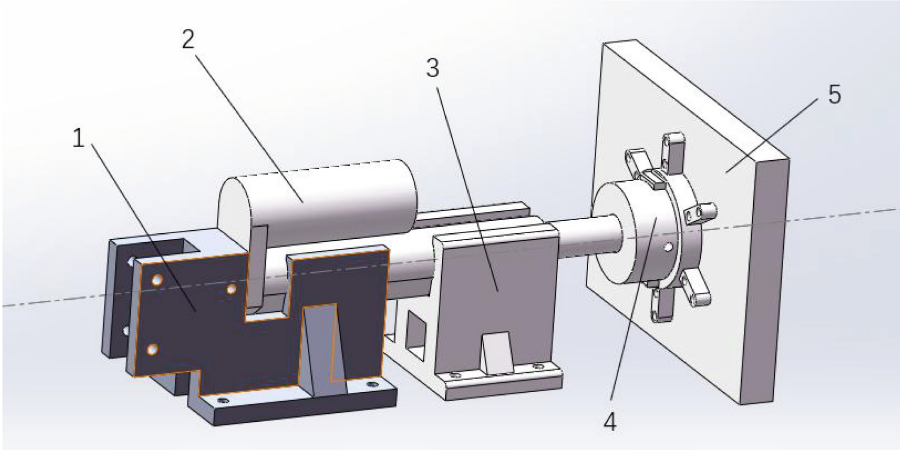

Fig. 4. Compression structure diagram.

3.8 Display Module

This module adopts the X5 series of Taojingchi (Shenzhen Taojingchi Electronics Co., Ltd.) serial screen, which is a kind of LCD screen with display function that can communicate through the serial port. It is generally composed of hardware equipment and operating software of the serial screen: the hardware part includes processors, LCD screens, touch panels, FLASH storage, RS232 or 485 serial port chips, audio and video decoding chips, SD card slots and other different units. The user needs to first use the USART HMI software of the serial screen to create the "project file" of its corresponding interface effect, and then download the prepared "project file" to the processor of the serial screen and FLASH to run through the PC and the serial port SD card of the serial screen.

4 Software System Design

The software structure of the smart trash bin is mainly composed of K210 and garbage classification algorithm design on STM32C8T6, camera control, ultra-sonic module and buzzer module control, steering gear control, and LCD display.

4.1 Trash Classification Algorithm Design

Image Preprocessing. In the process of image transmission and storage, due to various factors, such as sensor noise, signal interference, compression algorithm, the image may be affected by noise and damage, resulting in image quality degradation, which will directly affect the efficiency and accuracy of feature recognition [12]. In order to solve this problem, a series of image preprocessing techniques, such as denoising, image enhancement, sharpening, can be applied to eliminate or reduce the noise and damage to the image, for improving the success rate of feature recognition. By preprocessing the

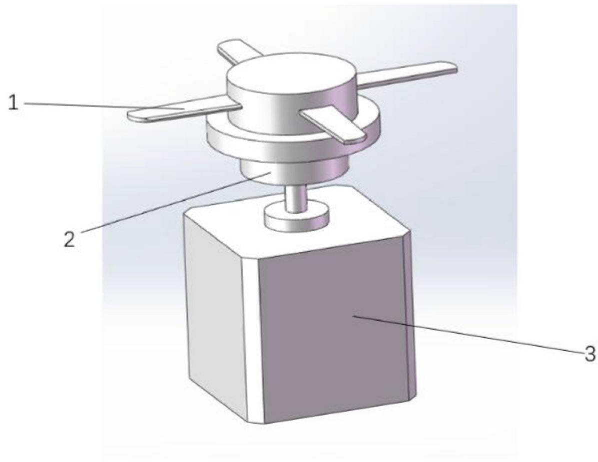

Fig. 5. Crushing structure diagram.

image, the influence of noise and damage can be effectively reduced, the success rate of feature recognition can be improved, and more accurate and reliable results can be obtained.

The light background is one of the important influencing factors in the image acquisition process, which can have a significant impact on the image data, in-cluding over-exposure, shadow effects, color distortion, which will seriously mask the characteristics of the object. To solve the problems caused by the light back-ground, it is necessary to use reasonable image preprocessing technology to reduce the influence of the light

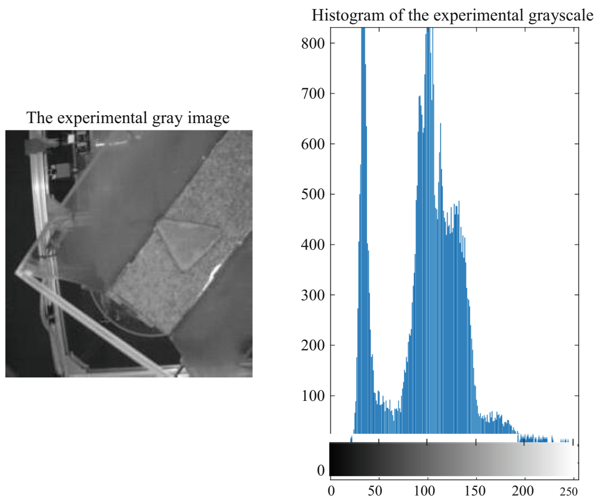

Fig. 6. Item grayscale.

background and improve the reliability and accuracy of object features. The experimental grayscale image of the object is shown in Fig. 6. It can be seen that the grayscale pixels of the object are concentrated in the range of 0–100.

This paper performs two operations on the image: reducing grayscale pixels and enhancing grayscale pixels. It can be observed from Fig. 7 that, in the image with reduced grayscale pixels, the distinction between the object and the background decreases, and the grayscale pixels are mainly concentrated in the range close to 0; while in the image with increased pixel pixels, the distinction between the object and the background contrast is enhanced, and grayscale pixels are mainly concentrated in the range of 100 to 200. Experimental results show that reducing grayscale pixels can make the difference between the object and the background smaller, which may make the object more difficult to identify or distinguish. Enhanced grayscale pixels can enhance the contrast between the object and the background, helping to improve the visibility and recognition of the object.

This paper performs a histogram equalization process on the enhanced grayscale image, and the experimental results are shown in Fig. 8. It can be observed that the contrast of the object is further enhanced, and the grayscale pixel distribution range of the image is expanded from 100 to 200 to 0 to 255. This means that the gray value range in the image is fully utilized, making the details in the image clearer. The three-dimensional feature map after histogram equalization processing of the garbage data set is shown in Fig. 9. It can be seen that different categories of trash bin be clearly distinguished.

Dataset The data set is independently completed by researchers through real-life photography. There are a total of 6,000 pictures of 12 items. Combined with the designed garbage classification hardware system, all garbage is divided into four categories, namely hazardous garbage, recyclable garbage, kitchen waste, and other garbage. The specific classification is shown in Table 1. Among them, the training samples account for 80%, and that is 4800; the number of verification samples accounts for 15%, and that is 900; the test samples account for 5%, and that is 300.

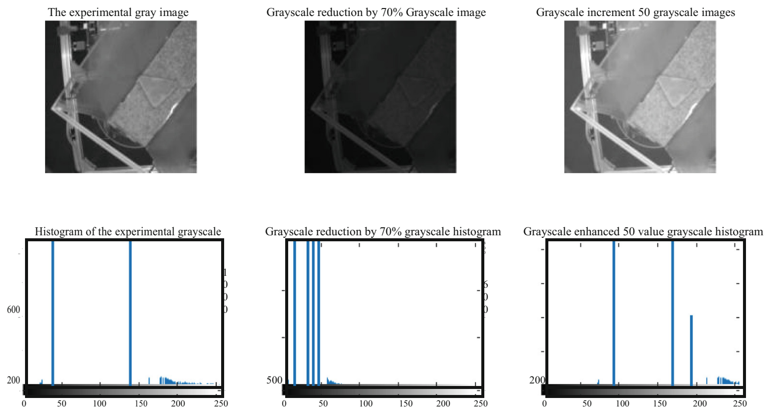

Fig. 7. Grey Processing.

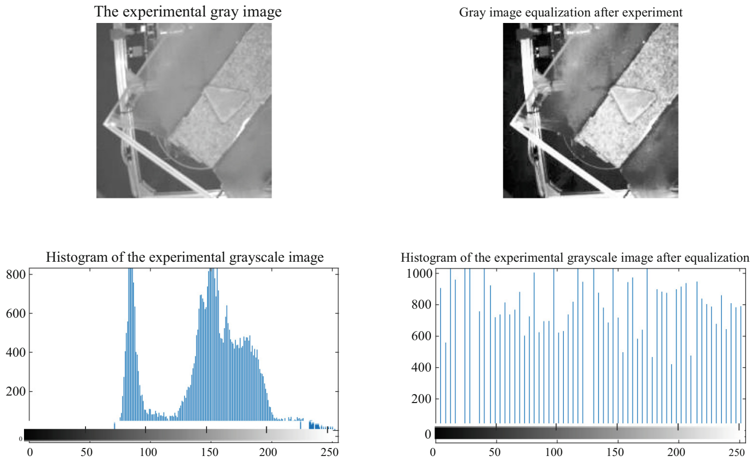

Fig. 8. Histogram equalization processing.

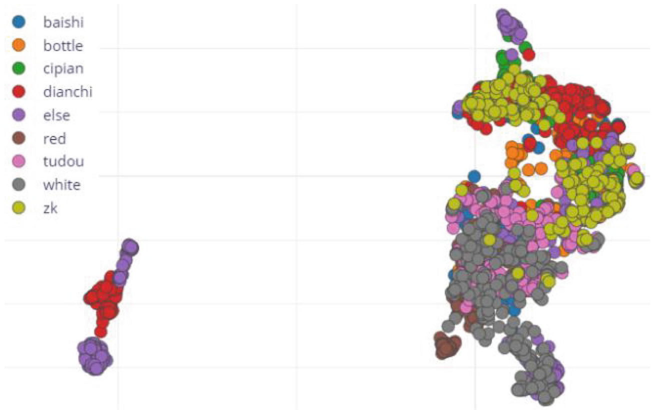

Fig. 9. 3D feature map.

Table 1. Trash dataset.

Hazardous trash		Recyclable trash		Kitchen trash		Other trash	
Battery	500	Can	500	Potato	500	Porcelain	500
Expired drugs	500	Small water bottle	500	White radish	500	Cobblestone	500
Thermometer	500	Carton	500	Carrot	500	Cigarette butt	500

Trash Classification Algorithm Design Due to the particularity of the K210 vision module used, we use the YOLOv2 target detection algorithm. YOLOv2 is a target detection algorithm based on deep learning. Its network structure mainly consists of two parts: feature extraction network and detection network.

Feature Extraction Network. YOLOv2 uses the Darknet-19 network [13] as the feature extraction network, as shown in Fig. 10. It consists of 19 convolutional layers and 5 pooling layers, similar to the VGG (Visual Geometry Group) net-work structure, but lighter than VGG. The input of this network is a 416×416 image, and the output is a 13×13×1024 feature map. After processing by the feature extraction network, YOLOv2 can convert the input image into a series of useful features for subsequent processing by the target detection network.

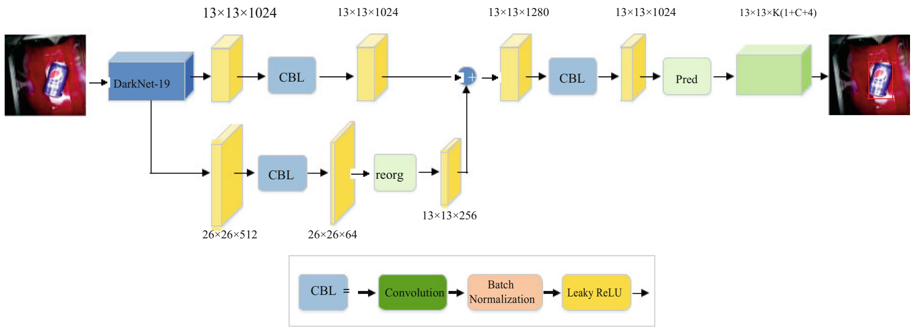

Fig. 10. Deep Learning Framework.

Detection Network The detection network in YOLOv2 includes three detection layers of different scales. Firstly, these three detection layers are respectively connected to the 13×13, 26×26, and 52×52 feature maps of the feature extraction network, and predict the positions and categories of all objects whose center points fall within each grid cell. Secondly, each detection layer consists of a convolutional layer and a fully connected layer to process the feature maps passed in from the feature extraction network and predict the output detection results. Finally, YOLOv2 uses the non-maximum suppression (NMS) algorithm to post-process the detection results, to remove overlapping candidate frames, and to output the final target detection results. The following is a detailed analysis of the working principle of YOLOv2.

When inputting a picture, YOLOv2 divides the input picture into S×S grid units. If the center of the target object falls into a certain mesh, this mesh is responsible for detecting the object. Each grid unit predicts B border positions, including 5 normalized prediction parameters: the offset of the center point of the target border position relative to the upper left corner of the grid, and the width and height of the border relative to the width and height of the entire image ratio, and give the corresponding confidence [14].The expression is as follows

$$Confidence = \Pr(Object) \times IOU_{pred}^{truth} \tag{1}$$

where Pr(*Object*) is the probability of the pure target in the grid, if it exists, the target takes 1, otherwise it takes 0. *IOU* (intersection over union) is the coincidence degree of the target frame predicted by the network with the target frame marked in the original input image, which can be expressed as

$$IOU_{pred}^{truth} = \frac{box_{pred} \cap box_{truth}}{box_{pred} \cup box_{truth}} \tag{2}$$

where box_{pred} is the marked target bounding box and box_{truth} is the predicted target bounding box.

The class-specific confidence score for each candidate box is:

$$Conf_i = \Pr(Class_i|Object) \times \Pr(Object) \times IOU_{pred}^{truth} \tag{3}$$

Where $\Pr(Class_i|Object)$ is the conditional probability of the target category. For each candidate box, predict the probability of the target and the position of the bounding box, then the predicted value of each candidate box output is:

$$[x, y, w, h, Confidence, Conf_i] \tag{4}$$

where $(x, y)$is the offset of the center point of the target frame position relative to the upper left corner of the grid, $(w, h)$is the ratio of the width and height of the frame to the width and height of the entire image, $Confidence$ is the confidence, and $Conf_i$ is the probability of the target category. For each image input, the final network output is a vector [15], which can be expressed as

$$S \times S \times B \times [x, y, w, h, Confidence, Conf_i] \tag{5}$$

In general, the network structure of YOLOv2 is an end-to-end fully convolutional neural network [16], which can efficiently detect objects in the input image and achieve relatively high detection accuracy.

Model Usage. The first step: training the model and propagate forward through the network: inputting the pre-processed image into the YOLOv2 network, and extracting the feature information of the image through a series of operations such as convolution layer, pooling layer and fully connected layer. Candidate box generation: Converting predictions to a sequence of bounding boxes, including coordinates and target probabilities for each box. Sorted by probability from large to small, retaining the box with the highest probability, and suppressing other boxes that intersect with it to reduce repeated detection. Object category recognition: Inputting the bounding box and the image into the classification network together, and outputting the probability distribution of the objects in each box through the classification network. Threshold processing: retaining the candidate boxes whose probability values are greater than the preset threshold, and removing the candidate boxes whose probability values are too low. Bounding box decoding: According to the coordinates of the candidate box and the information of the image, the actual position of the bounding box is decoded. Non-maximum value suppression (NMS): Through the non-maximum value suppression algorithm, bounding boxes with excessive overlap are removed, and the trained model is finally output. The training process is shown in Fig. 11.

The second step: import the trained model file into the K210 vision module, and call the built-in neural network processor KPU of the K210 vision module, by loading and running the program file and model file written in Maixpy IDE [17] to achieve the target detection. The classification process is shown in Fig. 12.

4.2 Camera Control

The camera is connected with K210 through DVP parallel interface. In the experiment, by writing a program on Maixpy IDE, the camera recognizes the image and transmits the image to the interface specified by the K210 vision module recognition program. The recognition program performs frame-by-frame target detection on the images sent back by the camera module in the interface. When the target is recognized, the data is sent to the STM32C8T6 main control chip to control the corresponding steering gear and display module. The capture process is shown in Fig. 13.

4.3 Ultrasonic Module and Buzzer Module Control

As shown in Fig. 14, the trash bin uses an ultrasonic module and a buzzer module to realize full load detection and early warning functions. The ultrasonic module uses HC-SR04 ultrasonic to calculate the distance to obstacles by obtaining the time between ultrasonic transmission and reception. The buzzer module uses an active buzzer, which is connected to the STM32C8T6 main control module through the IO port. In our design,

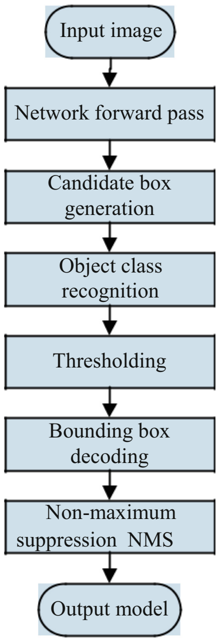

Fig. 11. Training model process.

the ultrasonic module is placed above the smart trash bin, and it is used to calculate the height of the garbage in the smart trash bin and feed back the storage height of the garbage in the bucket to the STM32C8T6 main control module to realize full load detection. When the STM32C8T6 module sends data to the buzzer module through the IO port when the distance transmitted by the ultrasonic module is lower than the set full-load threshold, it will issue a full-load alarm.

4.4 Servo Control

In our study, the steering gear is mainly used to handle the parts that require mechanized control to realize functions such as garbage placement, recyclable garbage compression, and kitchen waste crushing. The overall process is completed through the PID control algorithm. The specific implementation is to write the PWM wave function of the steering gear in the STM32C8T6 main control chip, process the different class parameters returned by K210, compress the recyclable garbage, and crush the kitchen waste. When a PWM signal is generated from the GPIO port of the STM32C8T6 main control chip, it is connected to the steering gear, which drives the mechanical structure to release garbage, compress garbage, and crush garbage to realize the automatic classification, compression, and crushing functions of garbage. The steering gear control process is shown in Fig. 15.

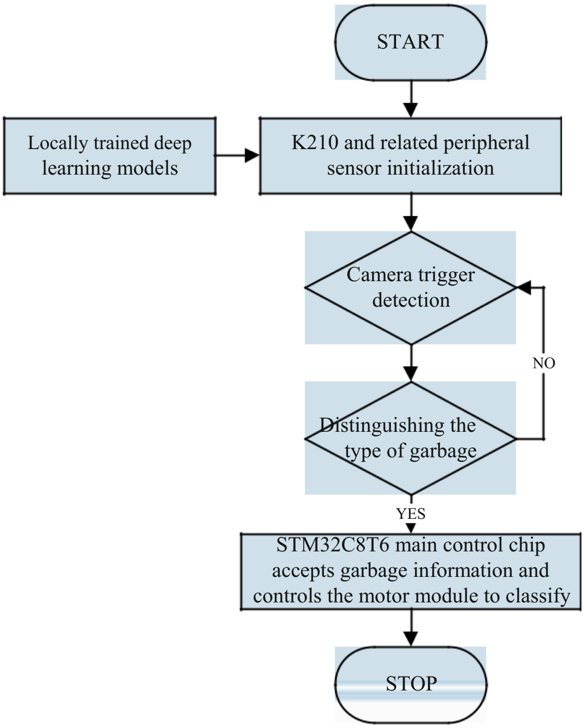

Fig. 12. Trash sorting process.

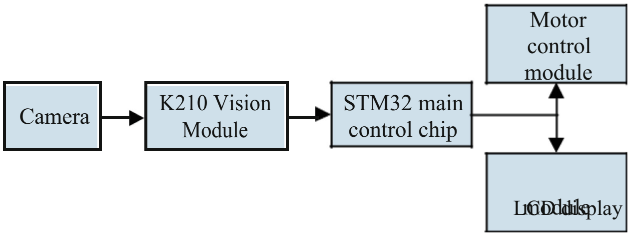

Fig. 13. Camera capture process.

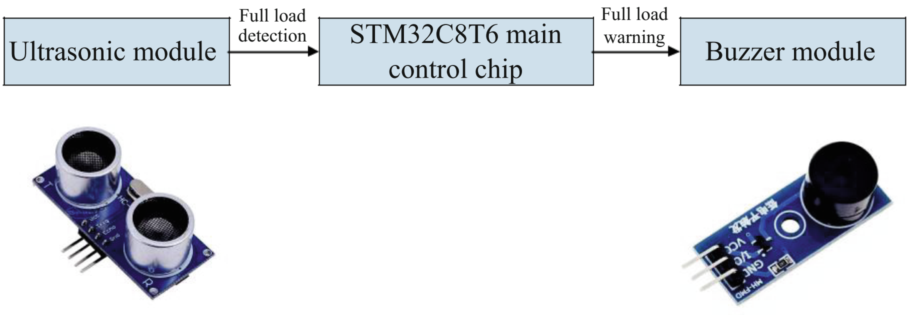

Fig. 14. Full load detection and early warning.

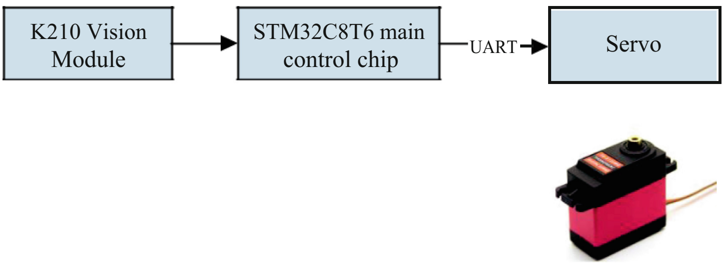

Fig. 15. Servo control flow.

4.5 LCD Display

The LCD display screen is used in this platform to display various parameters of the intelligent garbage classification system, including the order of delivery, the type of delivery, the quantity of four types of garbage, and whether the delivery is successful. After the K210 vision module, motor module, and ultrasonic module process the garbage in real time, the data is transmitted to the LCD display module through the STM32C8T6 module. The LCD module will display the garbage type, the amount of garbage, whether it is full, compression processing, crushing processing, etc. The operating environment of the system is shown in Table 2, and the interface designed in this paper is shown in Fig. 16.

Fig. 16. Servo control flow.

Table 2. Operating environment.

Hardware Environment		Software Environment	
	Intel(R) Core(TM)		Windows10 Home
Processor	i5-10200H	Operating System	Edition
	CPU @2.40GHz		
Memory	8GB	Development Tools	USART HMI IDE

5 System Test

5.1 Specific Debugging

During debugging, import the iterative weight model and Python program from the garbage classification algorithm design into an SD card, place it into the testing Sipeed Maix Bit K210 development board, and put the C language program into the STM32C8T6 development board. The 12 kinds of garbage are put on the classification platform in turn, the camera module collects and acquires the garbage images, puts the collected image data into the K210 vision module, and the K210 vision module sends the processed data to the STM32C8T6 main control chip through the serial port, STM32C8T6 The main control chip conducts data analysis, controls the steering gear to perform garbage delivery, recyclable garbage compression, and kitchen waste crushing, and sends the information to the LCD display module through the serial port.

5.2 Trash Identification Results

Through specific debugging, the various garbage recognition results are shown in Table 3. It can be observed that the recognition accuracy of the system for all kinds of garbage is above 87%, and the recognition time is less than 50ms. Com-pared with he raspberry pie and jetson nano modules in the literature [7, 18], this module has a shorter recognition time while maintaining a high recognition rate, and the detailed time is shown in Table 4. The trash bin can accurately identify the types of garbage, and the mechanical structure operates normally, which can well meet the working requirements of the smart trash bin and efficiently complete the automatic classification of garbage types.

Table 3. Table captions should be placed above the tables.

Test items	Recognition average time(ms)	Accuracy(%)	Identify Classification Results	Servo
Battery	29	93.4	hazardous trash	action
Expired drugs	37	90.2	hazardous trash	action
Thermometer	34	91.1	hazardous trash	action
Cans	29	92	recyclable trash	action
Water bottle	32	91.3	recyclable trash	action
Carton	30	92.5	recyclable trash	action
Porcelain	31	89.9	other trash	action
Cobblestone	33	88.4	other trash	action
Cigarette butt	41	90.3	other trash	action
Potato	37	87.2	kitchen trash	action
White radish	32	91.2	kitchen trash	action
Carrot	33	89.5	kitchen trash	action

Table 4. Recognition time.

Module name	Single frame recognition average speed(ms)
Maixbit	37
Jetson nano	550
Raspberry pie	910

5.3 Innovation Advantages

Compared with the traditional smart garbage can in literature [7, 8, 11], this pa-per adds recyclable garbage compression and kitchen waste crushing mechanical structure in the hardware structure, which can accommodate more recyclable garbage and kitchen waste. To a certain extent, the volume of the trash bin remains unchanged but its capacity increases. In terms of software structure, an LCD interface that can display the status of the trash bin in real time is added, which can display the current capacity of the smart trash bin, whether it is full, and the degree of compression and crushing in real time.

In terms of cost, compared with the mainstream Raspberry Pi, OpenMV, and Jetson Nano modules on the market, the prices of the modules used in this product are only half of them. The prices of the above modules are shown in Table 5. The prices of Raspberry Pi 4th generation 4G single board and Xingtong OpenMV H7 have reached more than 400, and the price of JETSON NANO B01 4GB single board is as high as 1199. The MAIX Bit board used in this paper only costs 148 and can achieve much faster recognition speed than them.

Table 5. Price of each module.

Module name	Price(¥)
MAIX Bit single board	148
Raspberry Pi 4th Generation 4G Single Board	462
OpenMV4 H7	429
JETSON NANO B01 4GB single board	1199

6 Conclusion

For the front-end garbage sorting, this project designs an intelligent sorting trash bin based on the STM32 microcontroller. The intelligent sorting trash bin can classify garbage with an accuracy rate of over 87%, and can display various parameters of the trash bin through the LCD display. In addition, the smart trash bin is also equipped with early warning, compression and crushing functions, which can realize the alarm of full load garbage, compress recyclable garbage and crush kitchen waste. The designed intelligent sorting trash bin satisfies people's intelligent treatment of front-end garbage sorting to a certain extent, and can effectively improve users' environmental protection awareness and quality of life.

In the future research, the function of human-computer interaction and more types of garbage will be added. It is planned to realize the function of human-computer interaction by adding a voice broadcast module and a wireless network module on the trash bin, and further improve the intelligence level of the intelligent garbage classification system. The types of data sets will be added to achieve accurate identification of more types of garbage, highlighting the humanized characteristics of the intelligent garbage classification system.

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