Research on Intelligent Garbage Classification Device Based on the Fusion Technology of Differential Classification and Artificial Intelligence Recognition

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Abstract. To solve the problem of the "last mile" in garbage classification, this study designs an intelligent garbage classification device based on artificial intelligence, machine vision and automation technologies. By constructing a multi-modal garbage identification model (YOLOv5s) and integrating it with a differential sorting mechanism, the functions of garbage type identification, sorting and compression are achieved. The experimental results show that the device's recognition accuracy rate is ≥98%, the single-piece processing cycle is ≤300ms, the compression rate of recyclable waste is ≥70%, the operating cost is reduced by 60%, and the sorting rate of hazardous waste is increased to 99%. This device overcomes the bottlenecks of traditional classification efficiency and accuracy, providing core infrastructure support for the construction of "waste-free cities" and contributing to the achievement of the "dual carbon" goals.

Keywords: Intelligent garbage classification, differential sorting technology, AI visual recognition, YOLOv5s model, automated device.

1. Introduction

With the acceleration of urbanization, the output of domestic waste has increased sharply. Garbage classification has become the key to breaking the predicament of "garbage encircling cities". China's "Implementation Plan for the Domestic Waste Classification System" clearly requires that all prefecture-level cities across the country be covered by 2025 [1]. The "14th Five-Year Plan" for the development of a circular economy sets the goal of achieving a resource recycling industry output value of 5 trillion yuan and a waste resource utilization rate of over 60% by 2025. The "dual carbon" strategy further promotes the transformation of waste treatment towards green and low-carbon [2]. However, the current industry is confronted with pain points such as low classification efficiency (with a human error rate of 30% to 40% and a 50% increase in processing costs), the risk of hazardous waste pollution (over 2,000 tons of batteries are mistakenly thrown in each year), and insufficient resident participation (only 20% of households adhere to correct classification) [3]. The traditional manual sorting mode is no longer able to meet the demands of large-scale and intelligent processing.

Among the existing garbage classification technologies, manual sorting relies on experience, is slow and prone to fatigue. Traditional automated sorting mostly uses a single sensor (such as infrared, weight), and has limited ability to identify complex types of garbage [4]. In recent years, AI visual recognition technologies (such as CNN and YOLO series) have made progress in garbage detection, but there are problems such as large number of model parameters and low efficiency of embedded deployment. Differential sorting technology is widely applied in the logistics field, but the research on its integration with AI recognition for garbage classification is still in the exploratory stage, especially in the dynamic separation of multi-category garbage and the design of high-precision sorting mechanisms, where there are technical gaps.

This research aims to integrate differential sorting technology with AI recognition algorithms to design an intelligent garbage classification device and achieve three major breakthroughs: Build a lightweight identification model covering 4 major categories and over 30 subcategories, develop a high-precision sorting mechanism with a single-piece processing cycle of no more than 300ms, achieve a recyclable waste compression rate of no less than 70%, promote the transformation of the waste treatment industry towards intelligence and low carbon, and provide technical support for the national waste classification strategy [5].

2. Design planning and parameter indicators

2.1. Classification Standard System-Types of Garbage

Garbage is classified into four major categories: kitchen waste, other waste, hazardous waste and recyclable waste. The four types of garbage are specifically as follows:

(1) Kitchen waste: small potatoes or potato chunks, cut white radishes, carrots, etc.

(2) Other garbage: ceramic shards, pebbles, bricks, etc.

(3) Hazardous waste batteries (No. 1, No. 2, No. 5, No. 7), expired medicines or inner packaging, etc.

(4) Recyclable waste: plastic bottles or metal cans, paper cups, etc. of 100mL or less.

2.2. Distribution Method

Garbage should be thrown into the garbage classification device through the input inlet. Hands must not be inserted into the garbage classification device to avoid interfering with the garbage classification process.

2.3. Parameters of the device

(1) Size of the placement port: 150×150 (mm)

(2) Device external dimensions: (Length × Width × height) 400×400×600 (mm)

(3) Trash can size and volume: Φ100mm×100mm (height)

The overall shape of the device is shown in Figure 1 below.

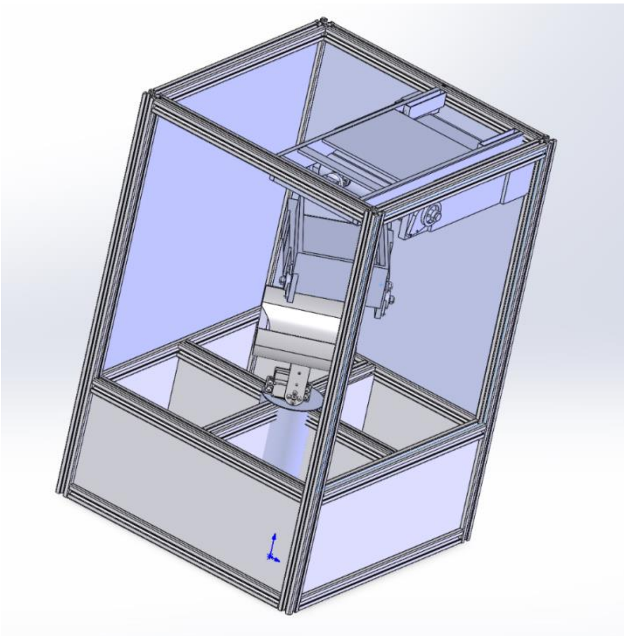

Figure 1. Overall design of the device

3. Core Technologies and Implementation plans

3.1. Device Selection and Electronic Control Design

After receiving the garbage information, the single-chip microcomputer controls the rotation of the steering gear pan-tilt and the dumping action. For recyclable garbage, the single-chip microcomputer will also control the electric cylinder to compress the recyclable garbage. The trash can determines whether it is fully loaded by detecting the distance through a laser sensor. When multiple pieces of garbage are put in, the garbage is separated by controlling the speed of the conveyor belt to achieve classification. The device selection is as follows.

(1) Maixcam: Run the YOLOv5s model and send the identified types of garbage to STM32.

(2) STM32F103: As the main control chip, it controls the LCD screen to play animations, display junk information, show full load information, control the movement of the steering gear pan-tilt, control the movement of the compression mechanism, receive the switch signal input from the photoelectric switch, and receive the input signal from the laser sensor to determine full load.

(3) DC12v DC motor: Controls the movement of the conveyor belt.

(4) 6mm camera: Maixcam captures images.

(5) High and low power voltage reduction modules: Reduce and stabilize the power supply voltage to ensure the normal operation of the devices.

(6) 20kg servo: pan-tilt selection, dumping action, opening and closing action of the baffle after garbage compression.

(7) vl23l0x: Determine whether it is fully loaded by detecting the distance.

(8) Photoelectric switch: It determines whether the trash can is in working condition by detecting whether a human body approaches.

(9) 24v electric cylinder push rod: Compresses recyclable garbage.

(10) 24vLED beads: Supplementary lighting to enhance the accuracy of garbage identification.

(11) 7-inch LCD screen: Connected to a single-chip microcomputer, it displays promotional animations, garbage classification information, full-load information, etc.

(12) 24v lithium battery: Powered by the device.

3.2. Operational Logic of Garbage Classification Institutions

Garbage separation is carried out by using a differential bed conveyor belt. When garbage is conveyed from the low-speed conveyor belt to the high-speed conveyor belt, the first piece of garbage will be kept at a certain distance from the second one. Such a design can effectively avoid cross-interference among garbage and provide convenience for subsequent classification work. Subsequently, a two-axis pan-tilt will be used for garbage classification, accurately placing the identified garbage into the corresponding trash bins.

Working principle:

a) When several pieces of garbage are thrown down simultaneously, they will scatter and fall onto the conveyor belt, and the conveyor belt will roughly separate the multiple pieces of garbage.

b) There is a beam grating sensor at the end of the conveyor belt, which can detect whether there is any garbage falling into the tipping bucket on the conveyor belt. If garbage is detected falling into the tipping bucket, the conveyor belt will stop moving and wait for the garbage classification in the tipping bucket to be completed. If not, let the conveyor belt continue to move;

c) There is a camera above the tipping bucket, which can identify whether there is garbage in the tipping bucket. If there is, the garbage classification will continue. If not, return to step b) and let the conveyor belt continue to move;

d) When all the garbage classification is completed, the squeezing device in the recyclable box starts to work and squeeze the recyclable garbage.

e) This classification has been completed.

The operation flowchart is shown in Figure 2 below.

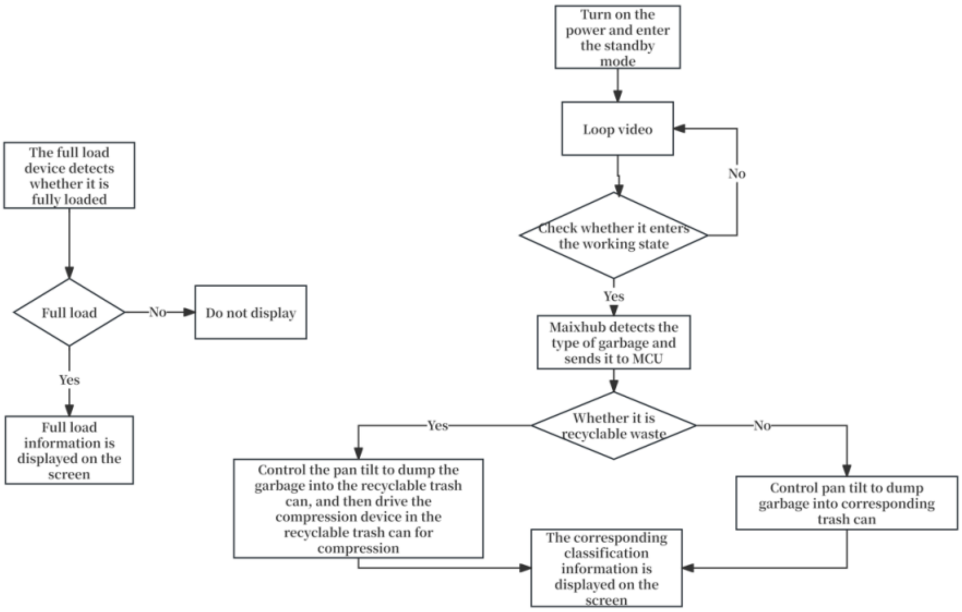

Figure 2. Flowchart of the operation of the garbage classification agency

3.3. Structural Design of compression Machinery for recyclable Waste

The push rod compression scheme is as follows: Install a motor push rod in the trash can beside the recyclable trash can. When it detects that recyclable garbage has entered the corresponding trash can, the push rod will extend and compress the garbage (set the extension length of the push rod to match the width of the trash can). When the compression reaches a certain extent, the push rod will automatically retract, completing the compression.

3.4. Sunken pan-tilt design

To save space height and increase the service life of the tipping bucket actuator, the rotary actuator is embedded in the chassis, as shown in Figure 3 below.

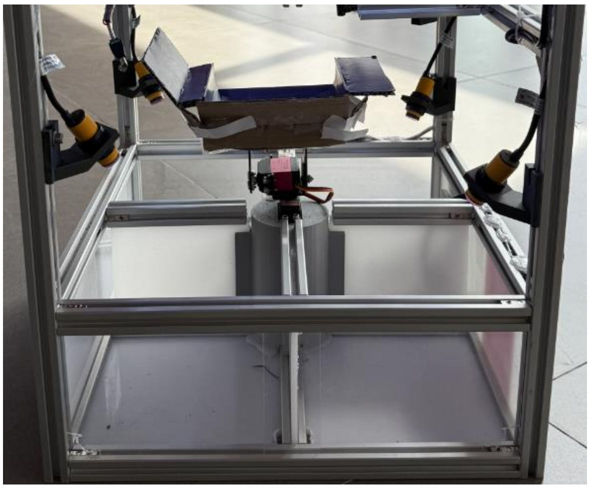

Figure 3. Sunken pan-tilt design

3.5. Mobile Camera Design

To adjust the height of the camera in real time according to the size of the garbage, a mobile stand is used to fix the camera, as shown in Figure 4.

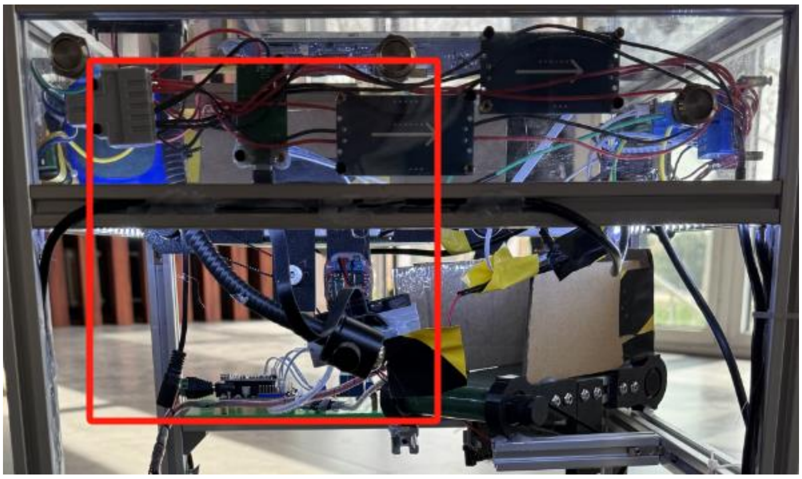

Figure 4. Design of Mobile Camera

3.6. AI Visual Recognition Technology

A lightweight model was constructed based on YOLOv5s. Through channel pruning and 8-bit quantization, the number of parameters was compressed to 3.5M and the inference speed reached 50FPS (Kendryte K210 chip). Set up self-service lights such as supplementary lights, supporting real-time adjustment of light intensity from 50 to 1000lux, and improving recognition accuracy by 30%.

YOLOv5s is an efficient object detection model that adopts a convolutional neural network (CNN) architecture and is capable of quickly identifying various types of targets in real-time scenes [6-8]. The YOLOv5 model divides the image into multiple grid cells, and each cell predicts a bounding box and a target category [9]. This end-to-end training method enables YOLOv5 to not only have high precision when processing images, but also meet the requirements of real-time processing in terms of speed [10].

In order to carry out garbage classification and recognition, the YOLOv5s model is first trained on the PC side using the PyTorch framework. PyTorch is a flexible and efficient deep learning framework with excellent dynamic computational graph characteristics, facilitating the development and debugging of models. During the training process, garbage classification images with labeled data are used to train a target detection model capable of recognizing different types of garbage.

After the model training is completed, in order to transplant it to the embedded device (Maixcam) for real-time inference, the trained YOLOv5s model is converted from the PyTorch format (.pt) to the format supported by the MaixHub platform. This conversion uses the toolchain provided by MaixHub and is accomplished by exporting the PyTorch model to the.kModel format. The.kmodel format is an optimized model format for the MaixHub platform, applicable to Kendryte K210 chips, and capable of running efficiently on resource-constrained embedded devices.

On the target device, load and run the model through the tool (MaixPy) supported by the MaixHub platform. After the camera captures the real-time image data, the image will undergo preprocessing (such as scaling, normalization, etc.) and then be input into the YOLOv5s model. The model analyzes the images, predicts the types of garbage and outputs the corresponding classification results. The entire process not only has real-time performance, but also can effectively classify and identify the types of garbage in the image, thereby providing intelligent support for garbage classification. By integrating the YOLOv5s model with the MaixHub platform, the system can operate efficiently on Maixcam with low power consumption and latency, and achieve precise garbage classification and identification in resource-constrained environments. It has now been upgraded to a linux local deployment, not relying on an online platform, with more available data sets and significantly improved model accuracy. As shown in Figures 5 and 6.

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100 epochs completed in 0.952 hours.
Optimizer stripped from runs\train\exp\weights\last.pt, 14.4MB
Optimizer stripped from runs\train\exp\weights\best.pt, 14.4MB

Validating runs\train\exp\weights\best.pt...
Fusing layers...
Model summary: 157 layers, 7020913 parameters, 0 gradients, 15.8 GFLOPs
        Class    Images  Instances       P        R      mAP50   mAP50-95: 100%|██████████| 38/38 [00:05<00:00,  7.48it/s]
          all       600        600   0.999        1      0.995      0.759
      kitchen       600        164   0.999        1      0.995      0.803
        other       600        158   0.999        1      0.995      0.733
      harmful       600        142   0.998        1      0.995      0.728
      recycle       600        136   0.999        1      0.995       0.77
Results saved to runs\train\exp
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Figure 5. mAP values of model iteration

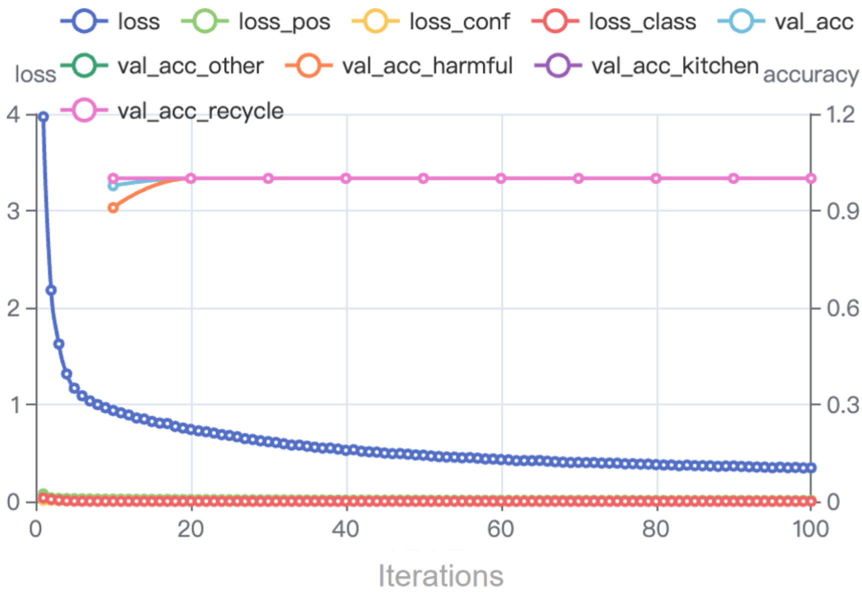

Figure 6. Shows the curve of the model's accuracy rate

3.7. Intelligent Control System

(1) Multi-sensor fusion: Laser ranging (VL53L0X) detects full load, and photoelectric switch (E18-D80NK) triggers the sorting process.

(2) Task scheduling algorithm: The EDF (Earliest Deadline First) strategy ensures parallel processing of multiple tasks, with a system response delay of ≤30ms.

3.8. Material Selection

The shell is made of 3mm acrylic sheet to provide an environment conducive to visual recognition. The frame is assembled with aluminium profiles and round head screws to ensure the stability of the overall frame and the necessary toughness, rigidity, etc. The circuit board part is cut and installed with 5mm acrylic sheets, ensuring good processability and installation stability. The internal special-shaped structural components are 3D printed with composite materials, ensuring the strength of the materials. For some non-standard load-bearing components, metal sintering was adopted to obtain excellent structural performance. By combining the installation of a rotating mechanism at the bottom with the conveyor belt structure at the top, the function of separating and classifying various types of garbage can be achieved.

3.9. Display Module

The display module adopts a QCX high-definition display screen. By self-compiling the PYQT program, it can play promotional videos on garbage classification, display the results of garbage classification in real time, and provide alarm reminders when the garbage is fully loaded.

3.10. Design of Full-Load Detection Module

The full-load detection module adopts a photoelectric distance sensor (E18-D80NK). Based on the changes in the sensor sensitivity electrical signal determined during debugging, it can detect whether the garbage is fully loaded and whether the height of the garbage has generally reached the preset height. If it has reached the preset height, a full-load alarm will be triggered, as illustrated in Figure 7.

Figure 7. Full-load detection display

4. Core innovation points

4.1. Sunken pan-tilt design

The sunken pan-tilt is a type of pan-tilt equipment that is installed at a position lower than the surrounding plane and also serves as a stage for garbage disposal. The purpose of this pan-tilt design is, first, to reduce the occupation of surrounding space when not in use, and to avoid the protruding parts affecting the surrounding environment or causing collision risks. When in use, it can also normally perform the functions of the pan-tilt, enabling operations such as Angle adjustment and rotation of the devices installed on it (such as cameras, etc.) to meet the requirements of different shooting angles. It is internally connected with a servo motor. The output end direction of the servo motor is connected to a dual-axis motor through a connecting rod, and the output end of the dual-axis motor is rotatably connected to a tipping bucket, as shown in Figure 8.

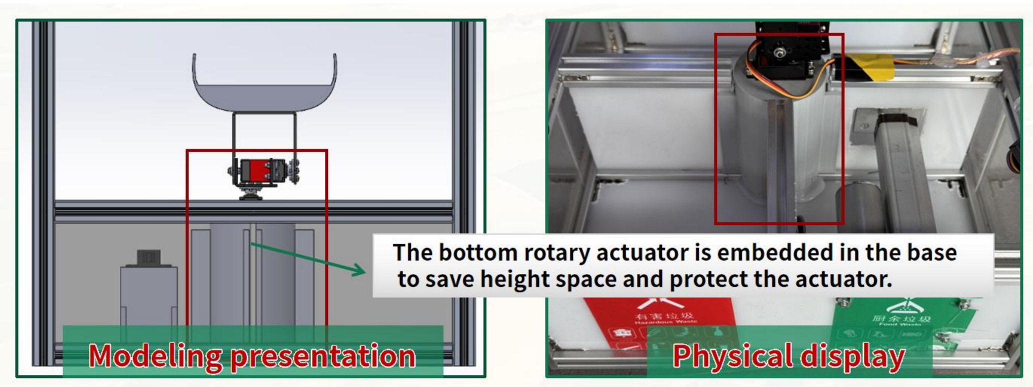

Figure 8. Sunken pan-tilt

4.2. Conveyor Belt

The conveyor belt uses continuously moving circular belt strips, etc., and employs two-stage transmission to convey items. It can efficiently and stably transfer items from one place to another, improving production and logistics efficiency, as shown in Figure 9.

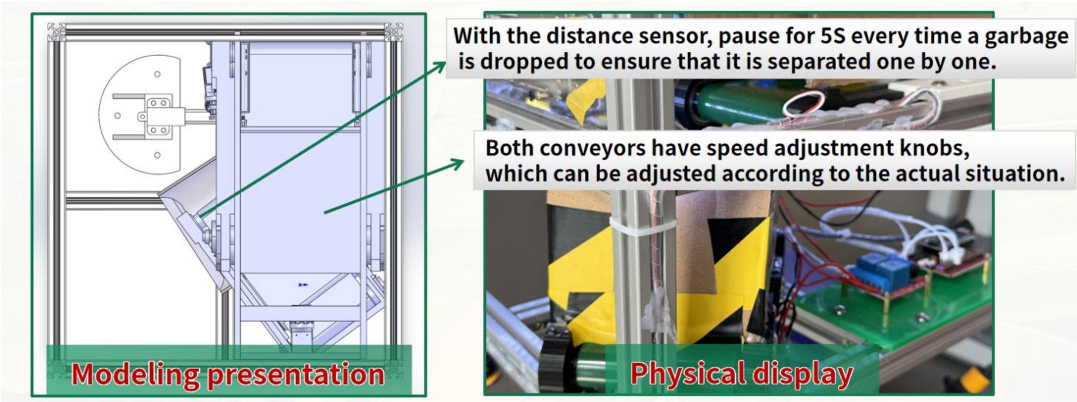

Figure 9. Two-stage differential conveyor belt

4.3. Quick-release baffle (stuck in the profile)

The quick-release baffle is a baffle structure with a special design. The "quick-release type" highlights the convenience of its installation and disassembly. It can be installed or removed from the corresponding position in a relatively short time without the need for complex tools or cumbersome operation procedures. The "baffle" explains its basic function and form, and is usually used for protection, separation, etc.

4.4. Adjustable camera at any Angle

It can flexibly change the shooting Angle in multiple dimensions. According to actual needs, it can be adjusted to various different angles such as horizontal, vertical and inclined, thereby obtaining pictures from different directions and perspectives. This kind of camera can scan the garbage more comprehensively and achieve more efficient recognition. For details, please refer to the introduction in the previous picture.

4.5. Dynamic Visual Compensation System

A 24-LED array (color rendering index ≥90) combined with an optical image stabilization module (compensation frequency 100Hz) is suitable for complex lighting environments, as shown in Figure 10.

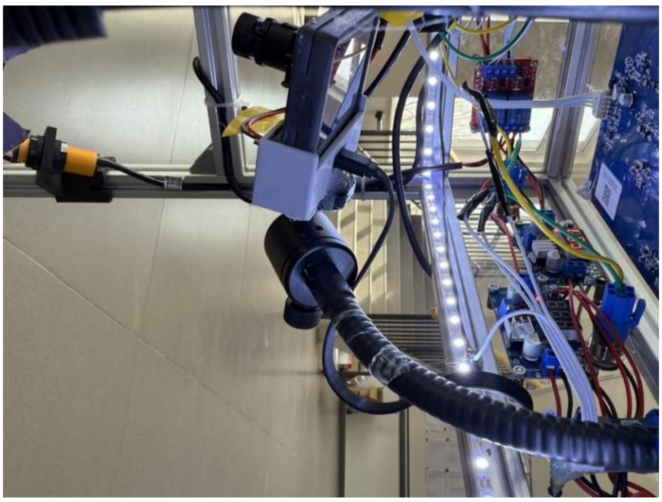

Figure 10. Illustration of supplementary lighting beads

5. Conclusion

This research integrates artificial intelligence, machine vision and automation technologies to design an intelligent garbage classification device. Build a multimodal garbage identification model, develop high-precision sorting and compression mechanisms, achieve an identification accuracy rate of ≥98%, a single-piece processing cycle of ≤300ms, a recyclable garbage compression rate of ≥70%, reduce operating costs by 60%, and a hazardous waste sorting rate of 99%. The hardware of the device is made of materials such as acrylic and aluminum profiles, combined with multi-sensor intelligent control, to meet the real-time sorting requirements. Innovative designs such as sunken pan-tilt and differential conveyor belts are adopted to enhance space utilization and sorting efficiency. In the future, the generalization ability of the model will be optimized and special waste treatment scenarios will be expanded.

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