Research on Intelligent Trash Bin Design Based on Visual Recognition of Machine

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Abstract. Objective: To help the public solve the problem of garbage classification by means of science and technology, make automatic garbage classification through an intelligent trash bin, realize harmless garbage disposal and reduce pollution, thus facilitating environmental protection.
Methods: The type of garbage is determined by visual recognition of a machine to achieve the effect of garbage classification. In terms of visual recognition, feature points of garbage pictures are compared by the combination of hardware and software, the data is trained and optimized with deep learning technology and images are compared based on the VGG16 convolutional neural network model.
Result: A simple and small intelligent trash bin is obtained. Conclusion: Theoretical support is provided for the application of intelligent classification trash bins.

1. Introduction
The municipal waste in China has been increasing annually at a rate of 5% with population growth and urbanization, causing great pollution to the land, water and air. Its total amount exceeded that in the United States in 2018, making China the world’s largest garbage producer. Annual losses due to the municipal waste amount to RMB 25 billion ~ 30 billion in China. Such great economic losses are caused by the low utilization rate of municipal waste in China which is less than 5%. However, the utilization rate of municipal waste in developed countries is above 60%. In this context, China has begun to implement waste classification management regulations to improve the utilization rate of garbage by its classification. China started to promote garbage classification early in 2000 with Shanghai as the pilot city initially. However, the effect was quite unsatisfactory during the 20 years of promotion. Therefore, the Regulations of Shanghai Municipality on Management of Domestic Waste was adopted at the Second Session of the 15th Shanghai Municipal People’s Congress on January 31, 2019. The inclusion of garbage classification in the law has allowed us to see the effect gradually. Many difficulties have been encountered in the process of implementation, especially including the great inconvenience of garbage classification to people’s lives. A lot of manpower and material resources have been input during supervision on garge classification of the public. How to address the problem of garbage classification based on science and technology is a challenge to be tackled at the moment. To solve the problem of garbage classification faced by residents, an intelligent classification trash bin is designed, which identifies and classifies garbage automatically based on visual recognition, deep learning and VGG16 convolutional neural network algorithm.
2. Overall scheme design of intelligent classification trash bin based on visual recognition of machine

2.1 Garbage classification settings
The garbage classification in this study is based on the implementation regulations in Shanghai. Table 1 shows the details:

| Primary classification | Secondary classification                                      |
|------------------------|-------------------------------------------------------------|
| Dry garbage            | Napkins, toilet paper, shells, ceramics and big bones, etc. |
| Wet garbage            | Food and its products, fruit and vegetables, meat and eggs, aquatic products and canned food, etc. |
| Recyclable waste       | Waste plastics, waste paper, glass, metal and clothes, etc. |
| Hazardous waste        | Batteries and waste lamps, etc.                             |

2.2 General system design scheme of intelligent classification trash bin

2.2.1 System design requirements of intelligent classification trash bin
To ensure the normal operation of visual recognition, a stable light source is required for the camera system to take pictures of garbage and obtain recognizable images. When different types of garbage are recognized by the system, they are classified and put into the corresponding can through existing components. The system needs to operate stably when the intelligent classification trash bin is working. The last is the extensibility of the system which needs to adopt a modular design to lay a foundation for future upgrades and improvements.

2.2.2 System composition of intelligent classification trash bin
The entire system can be divided into four modules, namely control, garbage image acquisition, garbage image processing and automatic garbage classification modules, among which the control module controls the latter three modules.

(1) Garbage image acquisition module
   In the current design, the light source in the trash bin provides continuous illumination. When an object is thrown into the bin, the sensor sends an instruction back to the system which then takes pictures and transmits the data of the garbage image collected back to the server.

(2) Garbage image processing module
   After receiving an image, the system uses the VGG16 convolutional neural network model with a deep learning function to process it. The more data collected, the higher the accuracy.

(3) Automatic garbage classification module
   There is a high-torque steering gear in the trash bin. After receiving different instructions, the control module will allocate the gear for garbage classification and rotation to the corresponding recycling bin to complete automatic classification.

(4) System control module
   The control module performs the functions of instruction collection, analysis and reallocation. The initial image acquisition, processing, analysis and classification processes are all determined by it. The specific system flowchart is shown in Figure 1:
2.2.3 System hardware design of intelligent classification trash bin
As the system of the intelligent classification trash bin is divided into four modules, in order to realize corresponding functions of the system, a mainboard for implementation of the overall design, a camera for capturing and collecting garbage image information, a light source for clarity of image capture and a steering engine for execution of the final garbage classification are supplied as hardware.

(1) Mainboard selection for intelligent classification trash bin
As the core of the control module, the mainboard performs the main functions of receiving, processing, recognizing and outputting image information. The system selects different instructions for execution according to the output information. In this study, a piece of small equipment is selected as the basis, which can be replaced after realization of basic functions. Raspberry Pi 3 Model B+ mainboard is used. The mainboard and its functions are shown in Figure 2:
The Raspberry Pi 3 Model B+ mainboard is used in this study, which is an embedded computer mainboard featured with small size, light weight and high performance. In particular, it supports 5G frequency bands, which lays a foundation for future upgrades. Moreover, it is provided with four USB ports, leaving room for future expansion.

(2) Camera selection for intelligent classification trash bin

The camera equipment is especially important as the intelligent classification trash bin performs the main function of analyzing and distinguishing garbage types based on visual recognition. In particular, the clarity of garbage pictures taken determines the accuracy of classification. In traditional virtual recognition, the camera equipment is composed of a camera and a lens and the object is captured and analyzed during shooting. However, the garbage remains stationary after thrown into the intelligent classification trash bin and therefore, only the clarity and stability of camera shooting are required. In terms of the camera component, a Raspberry Pi wide-angle camera of the same manufacturer as the mainboard is selected as the hardware support for visual recognition, which has up to 5 million pixels. The resolution rate of static pictures taken by it can reach 2,595*1,994, which fully meets the needs of this test. The physical object is shown in Figure 3:

(3) Light source selection for intelligent classification trash bin

There are high requirements for the light source as the space for recognition in the intelligent classification trash bin is confined. In order to achieve the accuracy of shooting, an analysis should be conducted on the uniformity, intensity and stability of the light source. Common light sources include LED lamps, halogen lamps, fluorescent lamps, electroluminescent tubes and optical fiber sources. LED lamps are finally selected as the light source in this study after analysis and comparison of the five light sources in terms of the uniformity, intensity, luminance, service life and stability.

(4) Steering gear selection for intelligent classification trash bin

As the driving element of the intelligent classification trash bin, the steering gear needs to transfer the garbage to the corresponding garbage can. Therefore, it should have an accurate rotation angle, high
torque, and most importantly, good heat dissipation in this test. The brand model of the steering gear is LD-27MG in the study.

3. Design of image acquisition device for intelligent classification trash bin

3.1 Design requirements for image acquisition device
The intelligent classification trash bin distinguishes the types of garbage through visual recognition and classifies them automatically based on the matching result. Therefore, it has higher requirements for image acquisition, and the space for image acquisition should be closed and stable.

(1) Closure: The space for image acquisition should be closed adequately so as to be stable. A stable light source and a unified background wall are required during acquisition, only with which can the image be recognized to the greatest extent.

(2) Stability: As trash bins are daily tools used all day long, the stability of data during operation is particularly important.

3.2 Shooting process design
Visual recognition requires photo comparison and algorithms for type judgment. Therefore, a lot of photos should be taken for the garbage, which can not only improve the accuracy of comparison, but also supplement the contrast database. The shooting process is designed into two parts: first, import, including the import of the shooting drive which is started when the garbage enters the shooting area, and the control of the import time; second, shooting, which is a cyclic process. The photo to be taken is first named, which is named as the shooting time in this study. Then, photos are taken and stored. The system indicates "shooting" when photos are taken and "shooting completed" at the end of shooting. Figure 4 shows the specific process:

3.3 Design of image acquisition process
The position of the garbage within the scope of control and the possibility of clear shooting should be ensured for image acquisition. It is required to collect garbage features during shooting. Settings in the placement area should ensure the compliance of the shooting scope with image acquisition requirements. Only with clear images can the garbage type be judged accurately. The process of throwing garbage is random. When the garbage enters the trash bin, its location and direction are both random. Therefore, it is necessary to capture features of the garbage from different angles and in different directions during
data collection. Each piece of garbage is photographed at different angles and positions, and 15 pictures with the most prominent features are taken as reference for comparison. A black background for acquisition is provided in the trash bin to ensure uniformity. The image acquisition process is divided into three stages: first, preparation, including hardware startup and software execution; second, acquisition, i.e. garbage shooting and acquisition of feature points; third, completion, i.e. completion of image acquisition and information summary. Figure 5 shows the specific process:

![Image acquisition flowchart](image)

Figure 5 Image acquisition flowchart

4. Garbage classification model based on deep learning

4.1 Garbage recognition model

It is necessary to use Python and deep learning framework Keras in combination for programming in visual recognition, which can realize fast scanning and recognition of image feature points. Preparations below should be made before a recognition model is created:

(1) Data cleaning

Data cleaning is also a phase of data purification, in which the quality of image data is improved and the optimal features are reflected with minimum photos. Sometimes the garbage is folded many times and put into the limited space for image acquisition, resulting in poor data quality. In such case, extra data may be cleaned up.
(2) Data classification
Daily garbage is divided into four categories and several sub-categories. Different garbage photos should be stored in corresponding folders to ensure data accuracy.

(3) Secondary collection of feature points
There are data and feature points entered in advance in the database, through the comparison of which the type of garbage is identified. New feature points, if any in the comparison data, will also be included, which is a secondary collection of feature points. The more times it is used, the more data is accumulated, and the higher the accuracy of recognition will be.

4.2 Visual recognition modeling and training
The visual recognition system under deep learning is mainly composed of two parts - data reading and processing and data training. In terms of data reading, the accuracy of recognition is improved with cross-validation and data enhancement techniques. In terms of training, the VGG16 convolutional neural network is mainly used for deep learning. The effect of accurate recognition can only be achieved by the improvement of data processing and comparison capacities in combination with deep learning technology.

(1) Cross-validation
The cross-validation method is mainly applicable for optimizing and purifying the existing data in the case of insufficient data, which applies to this study. There are tens of millions of types of garbage in daily life. It is impossible to collect all the data in the process of data acquisition. Therefore, data information and quality are improved with cross-validation in the study. In cross-validation, there are three functions, namely data training, data validation and recognition, and data testing. The training function is the prototype of the recognition model which requires comparison to draw conclusions. The testing function is based on the selection of the optimal model, and is also a criterion for judging the performance of the model. In cross-validation, the data is divided into subsets. There are three subsets in total in the whole validation process, including training set, validation set and test set which account for 60%, 20% and 20% respectively in this study. The division diagram is shown in Figure 6:

![Data sample](image)

Figure 6 Data distribution in cross-validation

(2) Optimization of comparison data
The data has been preliminarily collected and optimized with the calculation based on cross-validation. However, the current data size cannot support highly competitive visual recognition. Therefore, it is necessary to retrain the data and optimize the comparison data through data enhancement. The data is again arranged and optimized based on Keras, the quality of which will be greatly improved after optimization in such aspects as the improvement of recognition of the same object after rotation, lateral translation, vertical translation and horizontal flip. A data warehouse including four categories and fifty-six sub-categories of data optimized based on Keras is obtained, which is the original warehouse for comparison of the intelligent classification trash bin. It will continue to be optimized and improved after inclusion of new feature points.

(3) VGG16 convolutional neural network
Convolutional neural network is an algorithm for collection, extraction and comparison of characteristic values. The first-generation convolutional neural network LeNET had 5 convolutional layers and was originally used to recognize handwritten digits. With the development, the convolutional neural network has changed from the original CNN to the current VGG. The intelligent classification
trash bin just uses the VGG16 convolutional neural network in which "16" represents that it has 16 layers, of which 3 are connection layers and 13 are convolutional layers. There are nearly 140 million parameters in the VGG16 convolutional neural network. 1,000 categories of images can be stored after configuration and training, which can support the visual recognition of the intelligent classification trash bin. The neural network architecture is shown in Figure 7, in which the gray shows convolutional layers, green shows connection layers and red shows sampling layers, and the blue at the front end shows the classifier.

(4) Model training
The model should be trained before use of the convolutional neural network. There are many directions in model construction. To match this study, the performance of the model is calculated by the accuracy of garbage recognition. The neural network outputs a real value which represents the confidence of the corresponding category recorded after garbage classification. Therefore, the logarithmic loss function is used to perform the underlying operation in this study. The formula is shown below:

\[
\text{log - loss} = - \frac{1}{N} \sum_{i=1}^{N} y_i \log p_i + (1 - y_i) \log (1 - p_i) \quad \text{(Formula 1)}
\]

Where, \(y_i\) refers to the true category 0 or 1 to which the \(i\)th sample belongs; \(p_i\) represents the probability that the \(i\)th sample belongs to category 1; and \(N\) refers to the total number of test samples. The model is subject to iterative training for 200 rounds, and the recognition accuracy is recorded after completion of each round.

(5) Test results
Iterative training is performed on the model, and statistics is made for the accuracy in each round, which is shown in Figure 8. According to the Figure 8, the accuracy rate tends to stabilize and is at a relatively high level after 125 iterations, which basically meets the requirements of this study. The accuracy of the model will increase progressively as the number of use increases in the future.
Figure 8 Results after 200 rounds of iterative training of the model

Thirteen types of garbage are set in this study, including No. 1 banana peels with a recognition accuracy rate of 88.54% in model training, No. 2 used batteries with 99.14%, No. 3 waste fabric with 65.56%, No. 4 waste glass with 99%, No. 5 waste glass with 99.5%, No. 6 waste medicine with 99.9%, No. 7 scrap metal with 78.8%, No. 8 orange peels with 95%, No. 9 plastic bags with 76.74%, No. 10 plastic boxes with 98.3%, No. 11 plastic bottles with 99.98%, No. 12 toilet paper with 97.46% and No. 13 cigarette butts with 99.83%.

5. Shape design

(1) Trash bin size and material
The first-generation product is mainly home-based. The intelligent classification trash bin designed in this study based on the dimension of trash cans available in the market has a diameter of 35 cm and a height of 30 cm and is provided with four quadrant classification cans with a radius of 15 cm and a height of 30 cm. Its main raw material is polypropylene, which has low costs and a short production cycle.

(2) Effect picture of intelligent classification trash bin
The exploded view of the trash bin is shown in Figure 9. It is designed into gray considering the resistance to dirt.

Figure 9 Exploded view of intelligent classification trash bin

(3) Physical display
Figure 10 shows the front and back of the intelligent classification trash bin.
Figure 10 Physical display of intelligent classification trash bin

Figure 11 shows its internal structure, including 11a showing its recognition area, b showing the processor and its connection and c showing the camera and its connection.

The intelligent trash bin is finally encapsulated, the effect of which is shown in Figure 12 including 12a presenting the working state of the bin and b showing its state when the work is stopped.
6. Conclusion
The best solution to the problem of urban garbage disposal is garbage classification. However, the implementation of garbage classification has brought a great burden to the government and the public. To solve the existing problem, an intelligent classification trash bin is designed based on deep learning technology in combination with the visual recognition function, which has achieved good results in the design and testing phases. The current contrast database does not have rich data. The accuracy of recognition will continue to increase after the data in the contrast database becomes increasingly rich as time goes by.

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