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Intelligent Garbage Recycling: Design and Implementation Exploration of Automatic Classification System

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Abstract This paper introduces an intelligent waste recycling automatic classification system, which integrates sensors, image recognition, and robotic arms to achieve automatic identification and classification of waste. The system monitors the composition and properties of waste in real time through sensors, and uses image recognition technology for precise classification, and the robotic arm is responsible for grabbing and disposing. The design and implementation of the system have important practical significance and application value, and help promote the popularization and standardization of waste classification. This paper details the system's architecture, module division, sensors and recognition technology, robotic arm and grabbing technology, data processing and control system, and testing and optimization process. Experimental results show that the system has efficient waste recycling efficiency and accuracy in practical applications, bringing new development opportunities to the waste recycling industry.

Key words Waste classification and recycling; Sensors; Image recognition; Robotic arms; Convolutional neural networks

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Currently, waste recycling faces many challenges. With the acceleration of urbanization and the continuous expansion of population size, the amount of waste generated is showing a rapid growth trend. According to statistics, the total amount of waste generated in China each year has reached hundreds of millions of tons, most of which has not been effectively classified and treated, bringing great pressure to the environment. Taking Shanghai as an example, data showed that from 2005 to 2010, the average annual growth rate of domestic waste in Shanghai was about 3%; from 2011 to 2014, the annual growth rate accelerated to 4%; after 2014, the annual growth rate even reached 5%[1–2]. To tap into the resource value of waste, the first step is to do a good job in waste classification and recycling, among which the collection and transportation of waste is a major issue in waste classification. Since the *Solid Waste Pollution Prevention Law of the People's Republic of China* began in 2004, many related documents such as the *Urban Domestic Waste Management Measures* and the *Urban Domestic Waste Classification Standards* have been introduced. At present, China divides waste into six coarse primary categories and eight fine secondary categories. The waste classification standards in different regions vary, causing residents to easily confuse when disposing of waste, increasing the difficulty of recycling[3]. At the same time, due to the complex and diverse composition of waste, including recyclables, hazardous waste, kitchen waste, *etc.*, the treatment methods for each type of waste are different, which also brings challenges to waste recycling. In fact, due to the lack of classification awareness, non-standard classification standards, imperfect classification trash cans and other issues, the implementation effect of waste classification is not good. In addition, traditional waste recycling methods often rely on manual classification, which is inefficient and prone to errors, and cannot meet the growing demand for waste treatment. Therefore, it is particularly important to develop a system that can automatically classify waste.

In response to these challenges, the intelligent waste recycling automatic classification system came into being. This system integrates sensors, image recognition, robotic arms and other technologies to achieve automatic identification and classification of waste. Sensors can monitor the composition and properties of waste in real time, image recognition technology can accurately classify waste, and robotic arms are responsible for grabbing and disposing of classified waste. This intelligent waste recycling method not only improves the efficiency of recycling, but also reduces the error rate of manual classification, bringing new development opportunities to the waste recycling industry.

1 System design overview

In terms of system architecture and module division, the intelligent waste recycling automatic classification system adopts a modular design concept and divides the system into multiple independent and cooperative modules. The system architecture mainly includes four major modules: input module, recognition module, control module, and output module. The input module is responsible for receiving waste images and video data from sensors, which are the basis for system identification and classification. In order to ensure the accuracy and timeliness of the data, high-resolution cameras and high-speed data transmission interfaces are used to ensure that the system can capture the detailed features of the waste. In addition, data preprocessing technology is also used to

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denoise and enhance the original data, improving the accuracy of the subsequent recognition module.

The recognition module is the core part of the system. It uses image recognition algorithms to classify the waste images provided by the input module. Deep learning technology is used, and by training a large amount of waste image data, the model can accurately identify different types of waste. In practical applications, the recognition module can achieve efficient and accurate classification of waste, greatly improving the efficiency and quality of waste recycling.

The control module is responsible for controlling the robotic arm to grab and dispose of waste according to the classification results of the recognition module. Advanced motion control algorithms and sensor technologies are used to ensure that the robotic arm can accurately and stably grab waste and dispose it into the corresponding recycling bin. In addition, the control module also has fault detection and alarm functions. Once a fault or abnormal situation occurs, it can promptly issue an alarm and take corresponding measures. The output module is responsible for displaying the system's operating status and classification results to users. A friendly user interface and interaction method are designed, so that users can conveniently view the real-time operating status and classification results of the system. At the same time, the output module also has data recording and statistical functions, which can provide users with detailed waste classification reports and data analysis results, helping users better understand and manage waste recycling work.

2 Sensor and recognition technology

2.1 Sensor selection and configuration In the design and implementation of the intelligent waste recycling automatic classification system, sensor selection and configuration is a crucial link. Considering the diversity and complexity of waste types, multiple sensors are used to work together to achieve efficient and accurate waste identification and classification. Among them, infrared sensors and weight sensors are widely used in waste disposal port detection, monitoring the waste disposal situation in real time, and providing necessary input data for the system. At the same time, image sensors are responsible for capturing the image information of the waste, providing a key basis for subsequent classification algorithms.

When selecting sensors, it should pay attention to the matching degree of their performance parameters and application scenarios. For example, image sensors need to have high resolution and fast processing capabilities to cope with the appearance characteristics and color changes of different wastes. When configuring sensors, a distributed layout is used to ensure that each disposal port can be effectively covered, while avoiding interference and conflict between sensors.

2.2 Image recognition and classification algorithm In the design and implementation of the intelligent waste recycling automatic classification system, image recognition and classification algorithms play a crucial role. These algorithms can accurately identify the types of waste, providing key information for subsequent automatic classification. At present, deep learning technology, especially convolutional neural networks (CNN), has achieved remarkable results in the field of image recognition. Because of its good feature extraction performance, this system is based on convolutional neural networks. This method can enhance its recognition accuracy and accuracy under continuous model training[4]. During the training process, after a series of convolution corresponding multiplication and averaging operations, a rich feature map is obtained, and then the model's generalization ability is enhanced through the pooling layer. The fully connected layer is responsible for weighting the data of the previous layer to generate a one-dimensional vector, and finally linear regression is performed on the data obtained in the regression layer[5]. During the training stage, it is divided into a training set and a test set at a ratio of 9 : 1. After thousands of iterations, CNN can learn the features of the waste and achieve effective identification of different types of waste, meeting the use requirements.

3 Mechanical arm and grasping technology

3.1 Mechanical arm design and selection Considering the complexity and diversity of the waste recycling environment, the robotic arm needs to have a high degree of flexibility and adaptability. According to the structure theory of robots, in order for the end effector of the robotic arm to achieve any posture in the workspace, the number of degrees of freedom of the robotic arm should be no less than six. Therefore, considering cost and design complexity, this system uses a six-degree-of-freedom robotic arm. This kind of robotic arm has multiple joints and degrees of freedom, can achieve complex three-dimensional space movement, and can accurately grab and classify waste of various shapes and sizes. In the selection process, it should refer to the research results of robotic arm technology[6-7], and conduct comparative analysis in combination with actual application scenarios. The selected high-performance robotic arm has high precision, high speed, high stability and other characteristics, and can meet the system's precise requirements for waste grabbing and classification. At the same time, this robotic arm also has a strong load capacity and durability, and can adapt to long-term, high-intensity waste recycling work. In order to ensure the precise grasping of the robotic arm, advanced visual recognition technology is also used. Through the camera to capture the image information of the waste, and combined with the image recognition algorithm, the system can accurately identify the type and position of the waste. Then, according to the recognition result, the robotic arm can automatically adjust the posture and grasping force to achieve precise grasping and classification of the waste. This visual recognition and robotic arm cooperative work method greatly improves the efficiency and accuracy of waste recycling.

3.2 Grabbing strategy and precision control In the intelligent waste recycling automatic classification system, the grasping strategy and accuracy control are the key links to ensure the efficient and stable operation of the system. The formulation of the grasping strategy needs to comprehensively consider factors such as the shape, size, weight, and material of the waste. For example, for light plastic waste, the system can adopt a gentle grasping method to avoid damage during the grasping process; for heavy metal waste, a more solid grasping strategy is needed to ensure that the waste will not fall off during transportation. In addition, the system can also set different grasping priorities according to the classification requirements of the waste, and preferentially grasp easily classified or high-value waste.

Accuracy control is an important guarantee for the effective execution of the grasping strategy. The system can accurately identify the type of waste through high-precision sensors and advanced image recognition technology. At the same time, the precise control of the robotic arm is also the key to achieve high-precision grasping. By optimizing the motion trajectory and grasping force of the robotic arm, the system can achieve precise grasping of waste of different shapes and weights. In addition, the system can also improve the accuracy and stability of grasping through continuous learning and algorithm optimization.

4 Data processing and control system

4.1 Data collection and processing flow First, the system collects multi-dimensional data such as waste images, weight, volume, *etc.* of waste in real time. These sensors not only have high sensitivity and accuracy, but can also adapt to various complex environments, ensuring the accuracy and reliability of the data. For example, the system uses high-resolution cameras to capture the detailed features of the waste, providing rich information for subsequent classification algorithms.

After data collection is completed, the system enters the data processing stage. First, through preprocessing techniques such as denoising and enhancement, the original data is optimized to improve data quality. Then, the image recognition and classification algorithm is used to process the image data to identify the type of waste. Deep learning technology is used, and by training a large amount of waste image data, the model can accurately identify different types of waste. In addition, the system also combines other sensor data, such as weight and volume, for comprehensive analysis to further improve the accuracy of classification.

In the data processing process, the system also pays attention to data storage and management. By building an efficient data storage architecture, the system can store and process large amounts of data in real time. At the same time, the system also provides data query and visualization functions, allowing users to view and analyze waste recycling conditions at any time. In addition, the system also has data analysis and mining capabilities, which can find problems and improvement points in the waste recycling process, providing strong support for optimizing the system.

4.2 Control system design and implementation In the design and implementation of the intelligent waste recycling automatic classification system, the design and implementation of the control system is a crucial link. Advanced control algorithms and hardware architectures are used to ensure that the system can efficiently and accurately complete waste classification tasks. Specifically, a control system based on fuzzy control theory is designed, which dynamically adjusts the grasping force and angle of the robotic arm by real-time monitoring of sensor data, to achieve precise grasping and classification. In practical applications, this control system has shown high stability and reliability, effectively improving the efficiency and accuracy of waste classification.

To further optimize the performance of the control system, machine learning algorithms are also introduced to adaptively adjust control parameters. Through a large amount of experimental data and training samples, a control system model that can automatically learn and optimize is successfully constructed. This model can automatically adjust control parameters according to real-time feedback data, to adapt to changes in different environments and waste types. This adaptive control strategy not only improves the robustness of the system, but also reduces the need for manual intervention, further improving the level of intelligence of waste classification. According to experimental data, the accuracy of the recognition algorithm on the test set has reached more than 95%, ensuring the accuracy of classification.

5 Conclusions

After in-depth research and careful design, a successful intelligent waste recycling automatic classification system has been developed. This system has achieved remarkable results in practical applications, effectively improving the efficiency and accuracy of waste recycling. In actual tests, the recognition accuracy of the system has reached more than 95%, greatly exceeding the accuracy of traditional manual classification. These achievements not only verify the feasibility and effectiveness of the intelligent waste recycling automatic classification system, but also provide strong technical support for the future development of the waste recycling industry.

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ly, being at the average level. At the same time, the annual average humidity and average wind speed did not increase or decrease significantly in these two years. The duration of summer in these two years was longer, indicating that the change in the duration of the season had an important impact on the number of days of CIHB.

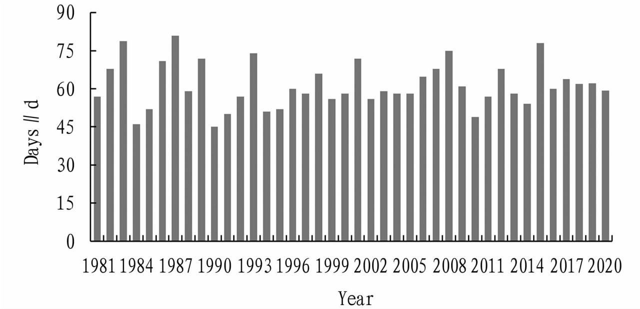

Fig. 10 Number of days of CIHB at grade 7

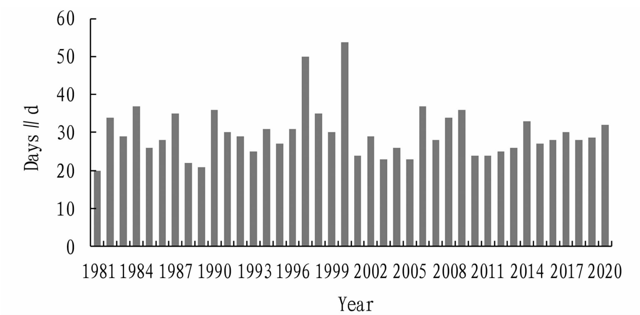

Fig. 11 Number of days of CIHB at grade 8

2.2.7 Grade 9. The number of days of grade 9 (very hot) was larger in 1994, 2002, 2013, 2017 and 2018, and at the same time, annual average temperature was higher in these years. In 1982, 1987, 2008 – 2009 and 2014 – 2015, the number of days of grade 9 was significantly smaller, but annual average temperature was lower than that of neighboring years. It shows that the change of annual mean temperature can well correspond to the change in the number of days of grade 9.

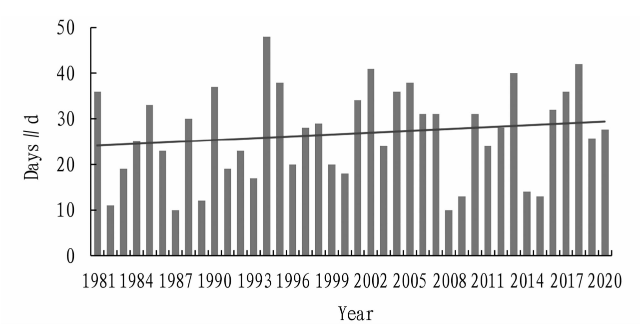

Fig. 12 Number of days of CIHB at grade 9

3 Conclusions

Based on the daily meteorological data of Bengbu City from 1981 to 2020, the changing characteristics of three elements needed for the calculation of CIHB were discussed, and daily CIHB was classified and discussed.

(1) From 1981 to 2020, annual average temperature showed a significant rising trend. Annual mean wind speed and relative humidity showed a decreasing trend before 2011 but an increasing trend after 2011.

The duration of the four seasons in Bengbu City mainly increased in spring, decreased in winter, decreased first and then rose in summer, and increased first and then reduced in autumn.

(2) When CIHB was at grades 1 and 9 (the most uncomfortable), the three factors had different effects on them. For cold weather, besides the influence of temperature, the influence of relative humidity and wind speed on CIHB can not be ignored. In hot weather, the influence of temperature was dominant, and the change of annual mean temperature could well correspond to the change in the number of very hot days.

(3) Under the background of climate warming, the number of cold days tended to decrease generally, but it was larger in the years with fewer very cold days.

(4) In the context of climate warming, there was no obvious change in the number of days of the overall comfort of human body.

(5) The number of hot days was closely related to the duration of summer, and the number of days of grade 8 increased significantly in the years with an increase in the duration of summer.

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