Garbage Classification and Management Control System Based on Convolutional Neural Networks

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Abstract. With the rapid development of technology and economy, research on the industrial control field is becoming more and more professional. In recent years, garbage collection and management have become more and more difficult. Thus, it is vital to make a control system to deal with this problem. In past studies, most research paid attention to developing waste disposal. This study analyze a kind of control system which used MATLAB and Simulink to manage garbage more easily than traditional control systems. The main aim of this research is to find out a control system that can help manage and recycle garbage in a better and greener way. By using CNN in Simulink, this control system can suit both constant garbage pouring speed and ramp garbage pouring speed. Compared with a light sensor, a pressure transducer has wider use. Although a light sensor can receive light to send signals, which is convenient, it still has lots of drawbacks and limitations. Because of the pressure transducer, this control system is sensitive to the garbage. This kind of sensor makes a big contribution to putting the control system into use. In the future, this control system can make a big contribution to managing garbage and protecting the environment.

Keywords: Intelligent management, Control system, Discrete-time integrator, Pressure trasducer.

1. Introduction

Nowadays, more and more garbage is produced in many areas. A typical city generates around 10,000 tons of garbage, with a 5% increase during holidays. According to this situation, the garbage control system is very significant. Deploying a smart waste management system prevents garbage overflow, while its optimal routing algorithms reduce fuel consumption by 20%, equivalent to a 20,000-ton reduction in annual emissions. This essay will introduce one control system for garbage. About 8–10 million metric tons of plastic are put into the ocean each year, and by 2050, fish will likely be outweighed by plastic, which is dangerous [1]. However, traditional garbage classification methods are both inefficient and susceptible to mistakes, relying on manual effort [2]. Thus, a new method is needed.

This kind of control system has plenty of advantages and disadvantages. Firstly, its scalability can bring many benefits. For example, modular design supports flexible expansions, such as laser sensors for high-precision scenarios or solar power for remote areas. Moreover, its data-driven decision making is also beneficial, as it analyzes historical fill rates to predict bin overflow via MATLAB, aiding municipal planning for bin density. The designed functions of MATLAB are used to handle data and perform other scientific tasks [3]. However, the control system still has some potential challenges and drawbacks. Its real-time limitation is a key problem, because the current 1-hour data sample intervals may miss sudden dumping events. The aim is to upgrade to 15 minutes in the future.

Obviously, further improving and optimizing the image recognition of the garbage system and classification methods is vital. When cluttered or occluded objects are present in images, image recognition often struggles with classification problems [4]. Based on deeper thinking, research on garbage image recognition and classification has become an important field. Intelligent waste control systems can be further optimized to improve garbage collection and recycling processes through the use of computer vision methods. Choosing suitable Convolutional Neural Network (CNN) architectures and efficient optimization methods can help enhance classification results. Garbage images can be largely identified and classified by using these methods, thus making intelligent waste management possible.

RNN has a strong ability to store information and obtain long-term reliable relationships among sequential data. However, it still has many drawbacks, such as periodicity. RNN is limited when it processes sequential data that is too long or too short. RNN is a class of DL models designed to process sequential data by incorporating feedback connections [5]. CNN performs well in image recognition and can automatically learn the feature representation of images. However, large CNN models require significant computational resources and training data [6]. Sparse connectivity and weight sharing are inherent characteristics of CNN networks [7]. CNN can also be utilized for its capability in differentiating sites of legitimate or phishing [8]. Thus, this research chooses to use CNN.

This study compares the linear garbage pouring speed, ramp garbage pouring speed, and sinusoidal garbage pouring speed to obtain data and graphs. The results show the importance of intelligent garbage management and enhance environmental sustainability. The results of this research will provide guidance and inspiration for garbage recycling and its control system, making a beneficial contribution to protecting the environment.

This research can also influence future development. The control system not only helps people to recycle garbage more effectively but also reduces the harmful effects brought by garbage.

2. Methods

This research introduces a garbage management system based on CNN that uses real-time monitoring and optimization algorithms. The basic components of this system include real-time garbage levels, maximum garbage levels, a CNN controller, and a transfer function that monitors the actions of garbage trucks. To make the usage situation align with ideal results, the research uses Simulink and MATLAB to simulate the stacking speed and actions of garbage trucks. Fig. 1 represents the control system implementation of this method.

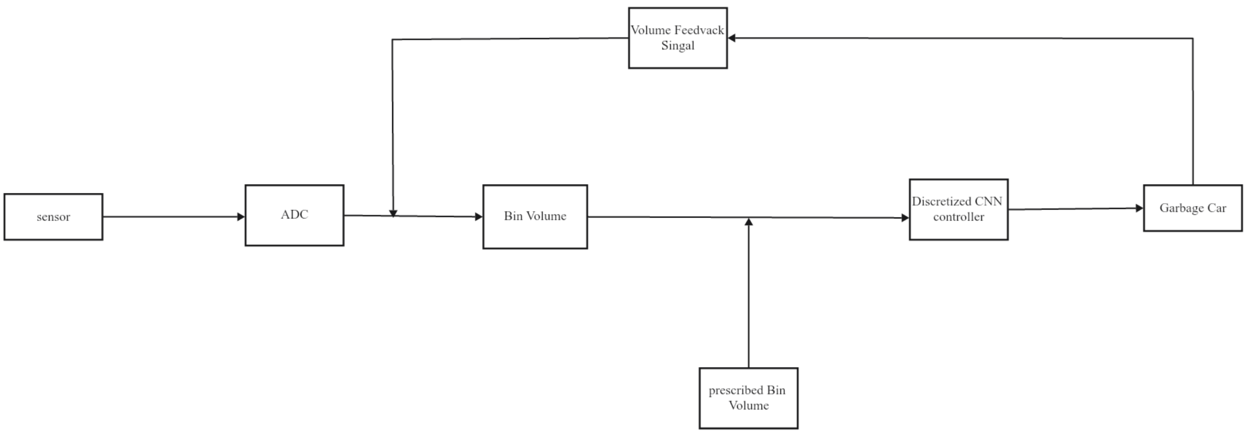

Fig. 1 Principles of image processing

Based on the control system implementation, the simulation block diagram can be created in Simulink. In the diagram, the discrete-time integrator simulates the speed and amount of the build-up of garbage. The transfer function simulates the garbage truck, and it represents how the garbage truck acts under certain conditions. Fig. 2 shows the block diagram in Simulink.

The research chooses a second-order transfer function to describe the moving characteristics of garbage trucks. This second-order transfer function simulates two kinds of time constants, both of which describe a period in actual conditions. One of them represents the time required to reach the trash can using garbage trucks, while the other represents the time to collect garbage. The research uses MATLAB to perform garbage truck modeling and build timescale estimation.

The code uses the “stepinfo” function and the “damp” function in MATLAB to obtain vital time-domain characteristics of the control system. The code also generates a figure to show the step response, which is used to check the quality of the control system. Fig. 3 shows the step response.

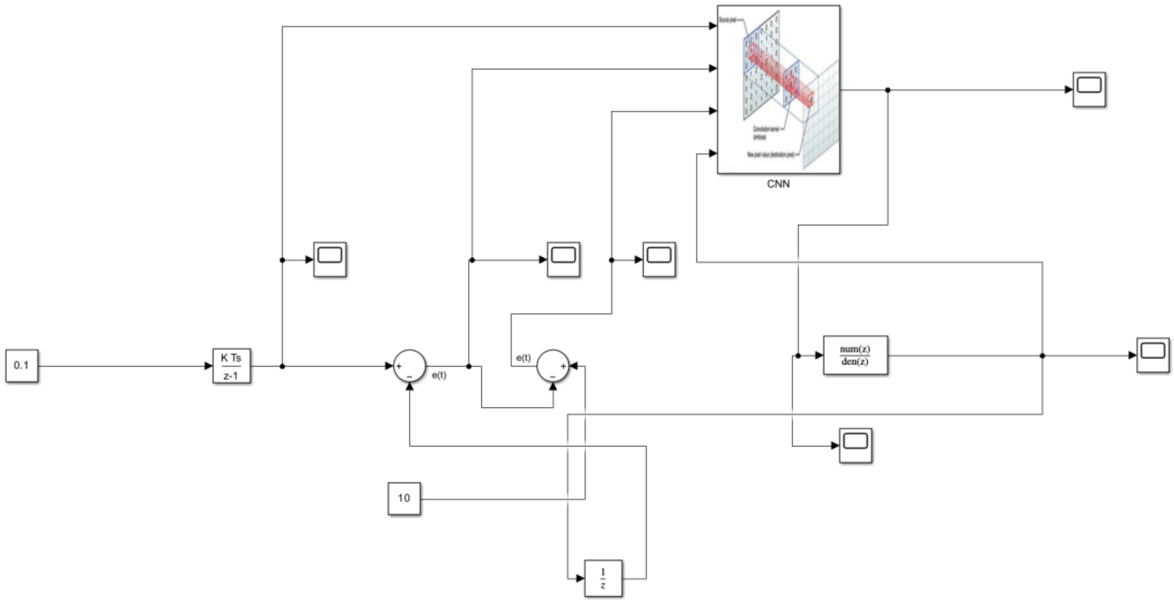

Fig. 2 Simulation block diagram

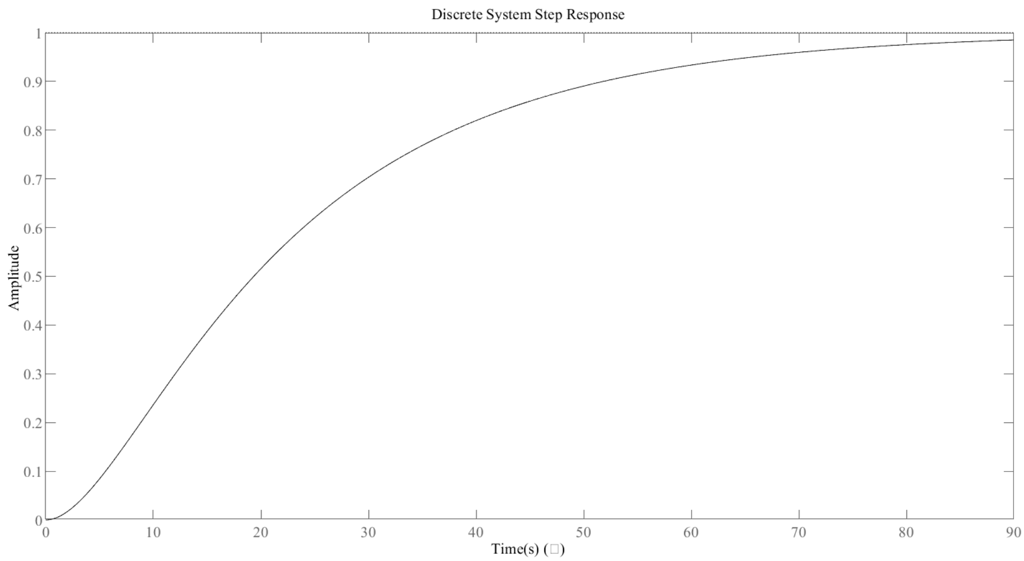

Fig. 3 Step response of the system

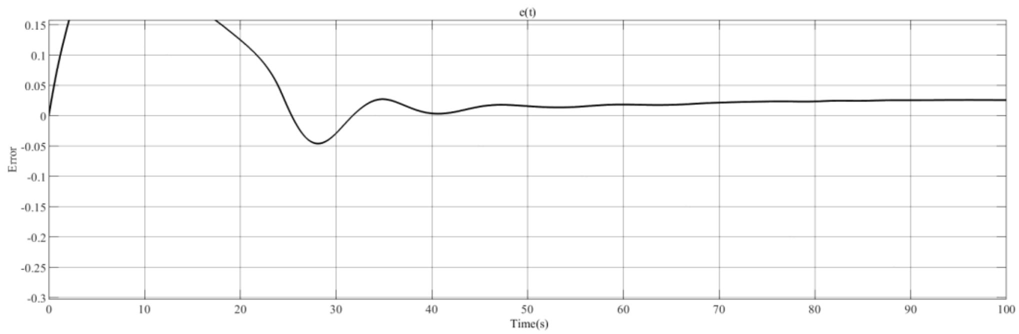

Fig. 4 Accumulated bin volume

However, garbage pouring speeds vary on different occasions. Thus, every type of garbage pouring speed situation requires individual control methods. The research sets characteristic CNN parameters to ensure that the system can work successfully and optimize the time constant of the CNN controller. The research uses Simulink and MATLAB to simulate different situations.

Firstly, the research analyzes the situation with a constant garbage pouring speed. Fig. 4 shows the accumulated bin volume. Fig. 5 shows the volume feedback. Fig. 6 shows the controlled bin volume.

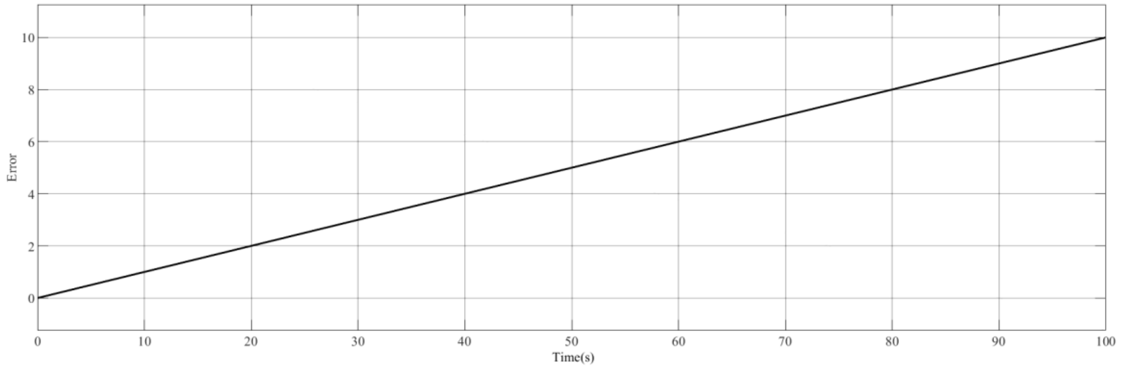

Fig. 5 Volume feedback (collected garbage)

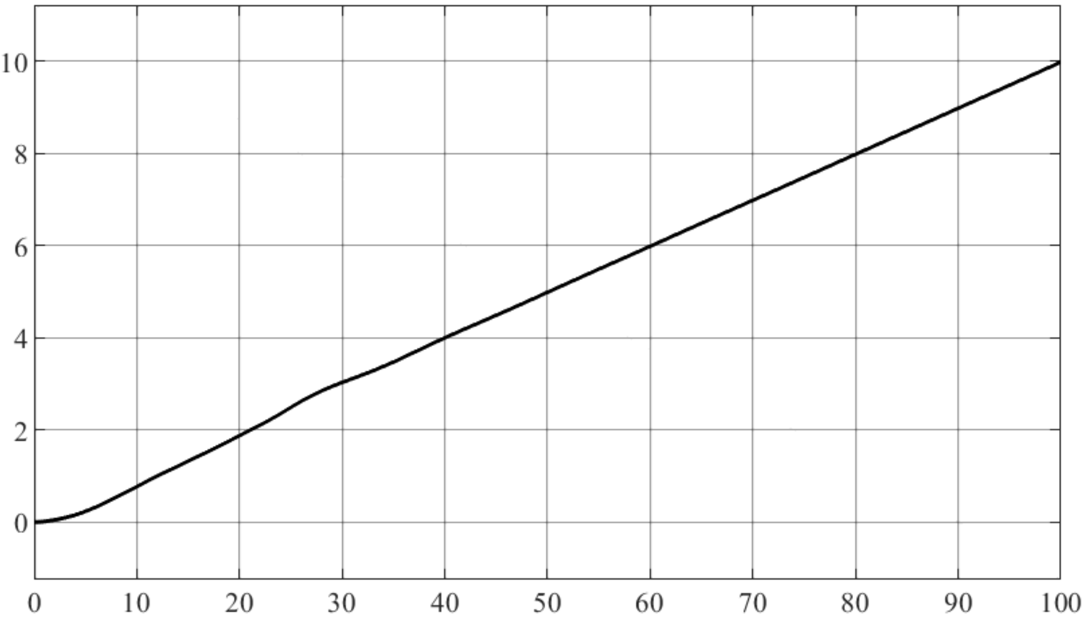

Fig. 6 Controlled bin volume

Then the research also analyzes the situation with ramp garbage pouring speed. Fig. 7 shows the accumulated bin volume. Fig. 8 shows the volume feedback. Fig. 9 shows the controlled bin volume.

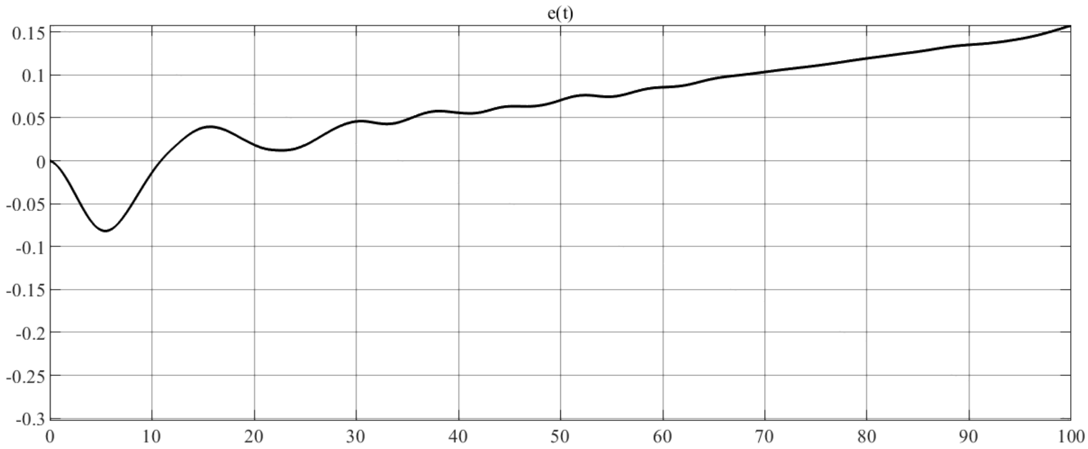

Fig. 7 Accumulated bin volume

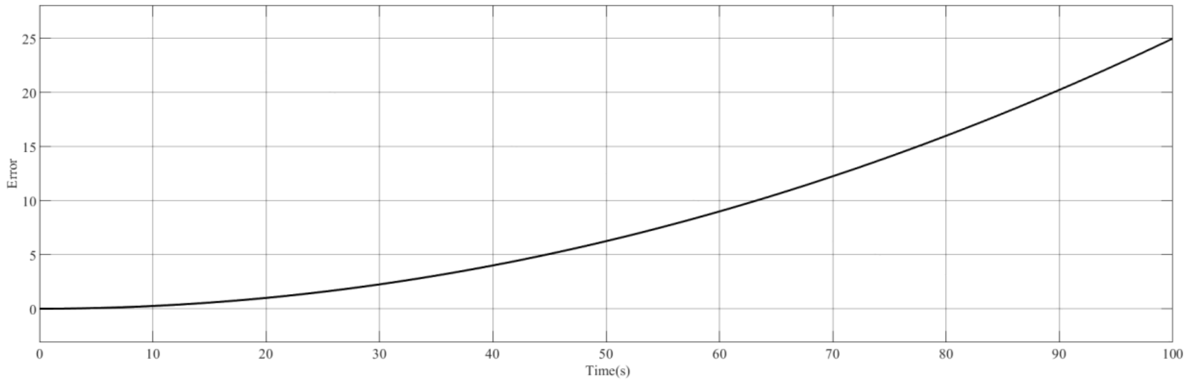

Fig. 8 Volume feedback (collected garbage)

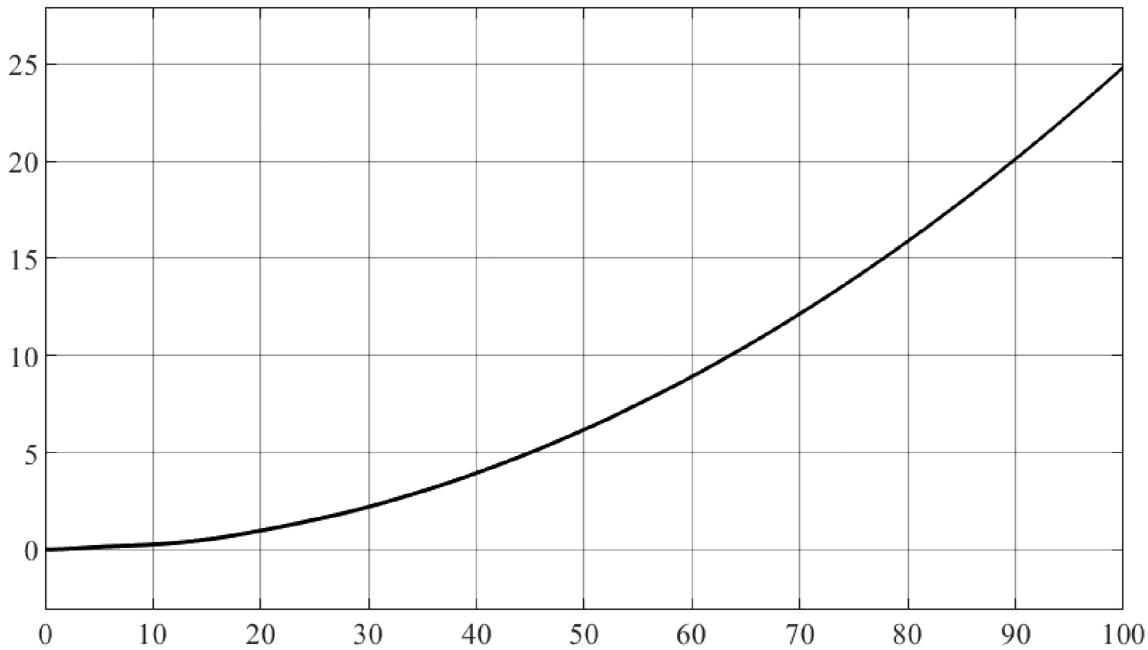

Fig. 9 Controlled bin volume

Finally, the research also analyzes the situation with sinusoidal garbage pouring speed. Fig. 10 shows the accumulated bin volume. Fig. 11 shows the volume feedback. Fig. 12 shows the controlled bin volume.

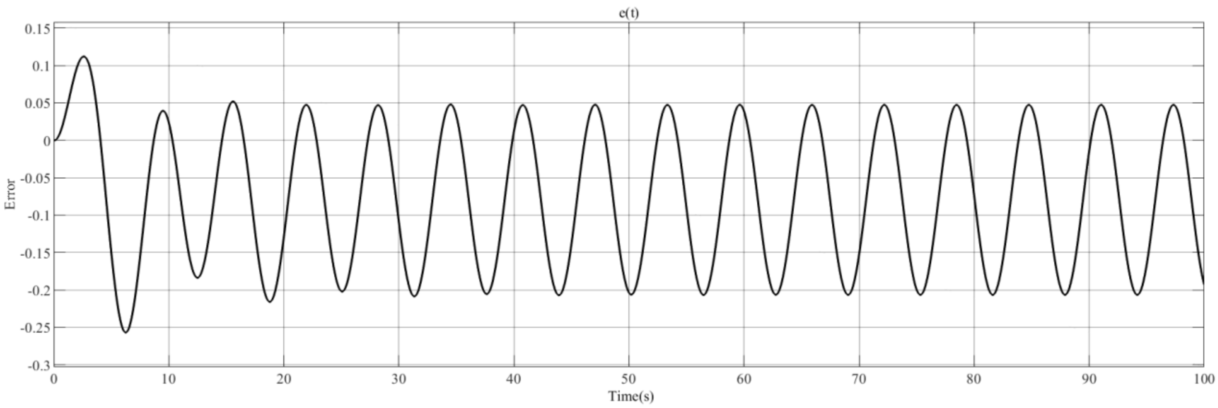

Fig. 10 Accumulated bin volume

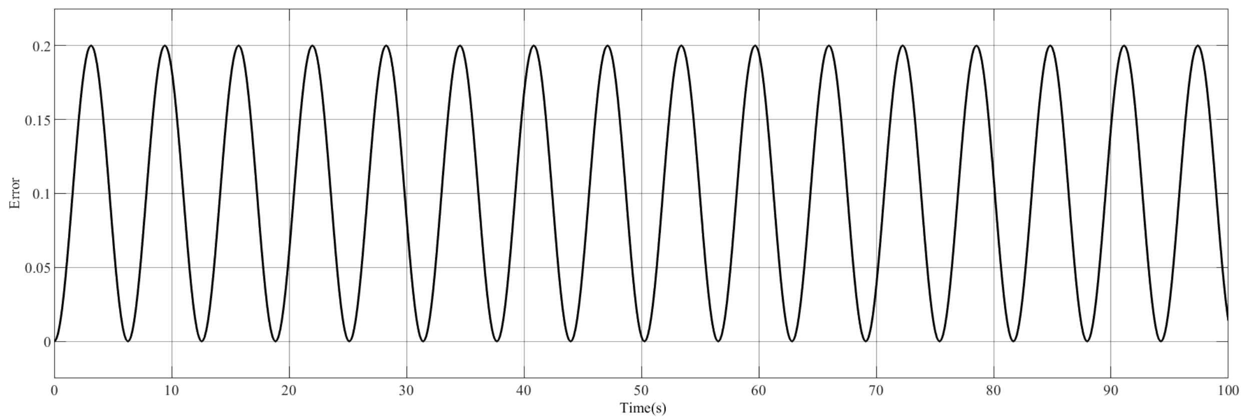

Fig. 11 Volume feedback (collected garbage)

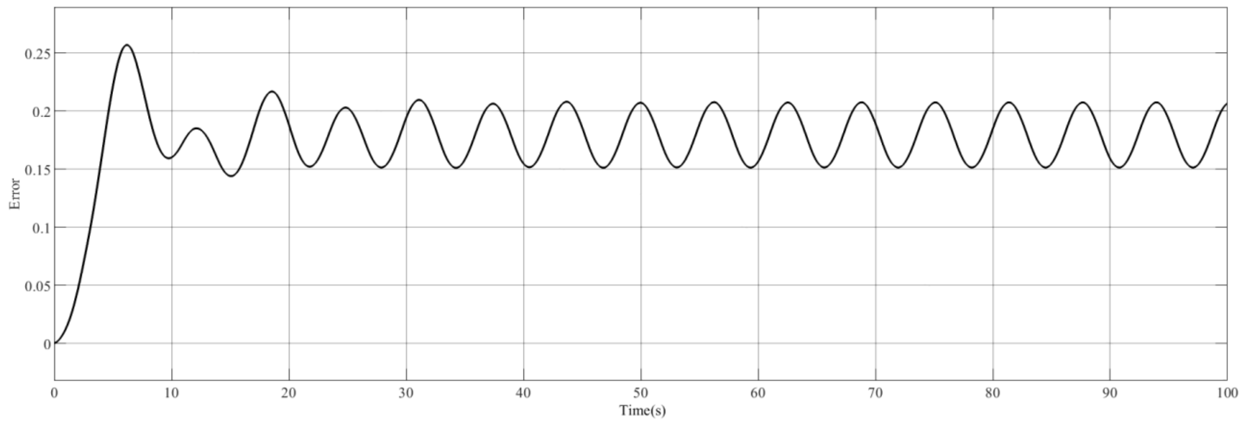

Fig. 12 Controlled bin volume

3. Results

Figures 4, 5, and 6 show the simulation results for constant speed. By observing these figures, the accumulated bin volume increases at first, then decreases after reaching the peak, and finally tends to stabilize. The controlled bin volume shows a similar trend to the volume feedback. Both increase continuously during the whole period.

It is obvious that this control system can efficiently control the movement of garbage trucks. Even if the amount of garbage increases continuously, the feedback signal only fluctuates slightly. This illustrates that the control system has good quality.

Moreover, although the garbage pouring speed increases, the control system can still adjust appropriately and ensure that the garbage truck can successfully complete its work on time. The ramp garbage pouring speed maintains accuracy. By observing Figures 7, 8, and 9, it is clear that the accumulated bin volume fluctuates at first but then continues rising. The trends of volume feedback and controlled bin volume are similar, both climbing steadily.

Although this situation is not very common, this test still demonstrates that the control system can handle fluctuations when encountering sinusoidal garbage pouring speed. Even if the rate changes significantly, the control system can still remain stable. Fig. 13 shows the predicted results between the first round and the second round, while Fig. 14 shows the actual results between the first round and the second round.

By observing these figures, the accumulated bin volume increases at first, then decreases after reaching the peak, and finally maintains a certain fluctuation. The controlled bin volume shows a similar tendency, while the volume feedback maintains this fluctuation throughout the whole period.

To reduce error, the research compares predicted results with the actual results. According to the code, the figures should behave as expected. In this code, the research uses the CNN method to simulate. The input is as follows:

$$V = conv2(W, X, "valid") + b \tag{1}$$

where W represents matrix size, X represents convolution kernel size, and b represents bias. And the output is as follows:

$$Y = \varphi(V) \tag{2}$$

The overall error is

$$E = \frac{1}{2} \| d - y^L \|_2^2 \tag{3}$$

Where d represents the vector of expected output, y^L represents network output. Then the gradient formula can be deduced, which can be described as follows:

$$\frac{\partial E}{\partial w} \frac{\partial Ee}{\partial w_{ij}} = \frac{\partial E}{\partial v_{ij}} \frac{\partial v_{ij}}{\partial w_{ij}} = \delta_{ij} \frac{\partial v_{ij}}{\partial w_{ij}} \tag{4}$$

It is obvious as follows:

$$\delta^{l-1} = conv2(rot180(W^l), \delta^l, 'full')\varphi'(v^{l-1}) \tag{5}$$

According to convolution formula, it can be achived as follows:

$$y_{11}^l = w_{11}^l x_{11}^{l-1} + w_{12}^l x_{12}^{l-1} + w_{21}^l x_{21}^{l-1} + w_{22}^1 x_{22}^{l-1} \tag{6}$$

As a result:

$$\frac{\partial E}{\partial w'_{12}} = \delta_{11}^l x_{12}^{l-1} + \delta_{12}^l x_{13}^{l-1} + \delta_{21}^l x_{22}^{l-1} + \delta_{22}^l x_{23}^{l-1} \tag{7}$$

The partial derivative matrix is shown as follows:

$$\frac{\partial E}{\partial w^l} = conv2(\delta^l, x^{l-1}, 'valid') \tag{8}$$

Finally, it can be shown as follows:

$$\frac{\partial E}{\partial b^l} = \frac{\partial E}{\partial v_{11}^l} \frac{\partial v_{11}^l}{\partial b^l} + \frac{\partial E}{\partial v_{12}^l} \frac{\partial v_{12}^l}{\partial b^l} + \frac{\partial E}{\partial v_{12}^l} \frac{\partial v_{21}^l}{\partial b^l} + \frac{\partial E}{\partial v_{22}^l} \frac{\partial v_{22}^l}{\partial b^l} = \delta_{11}^l + \delta_{12}^l + \delta_{21}^l + \delta_{22}^l = \sum_i \sum_j \delta_{ij}^l \tag{9}$$

However, there are still some differences compared with the actual results. To obtain the actual response, the research first loads the data. Then it separates the input and output, followed by standardizing the input. After that, the research splits the data into two parts: a training set and a testing set. Randomized input is also set to ensure that the results can be reproduced. Moreover, the data is converted to the 4D model required by CNN. For 1D data, the width is set as 1, while the length is set as the characteristic number. Then the code builds the CNN model and sets training options, such as *MaxEpochs*. Training the network and testing the results follow. Finally, the code generates figures to show the actual results and predicted results.

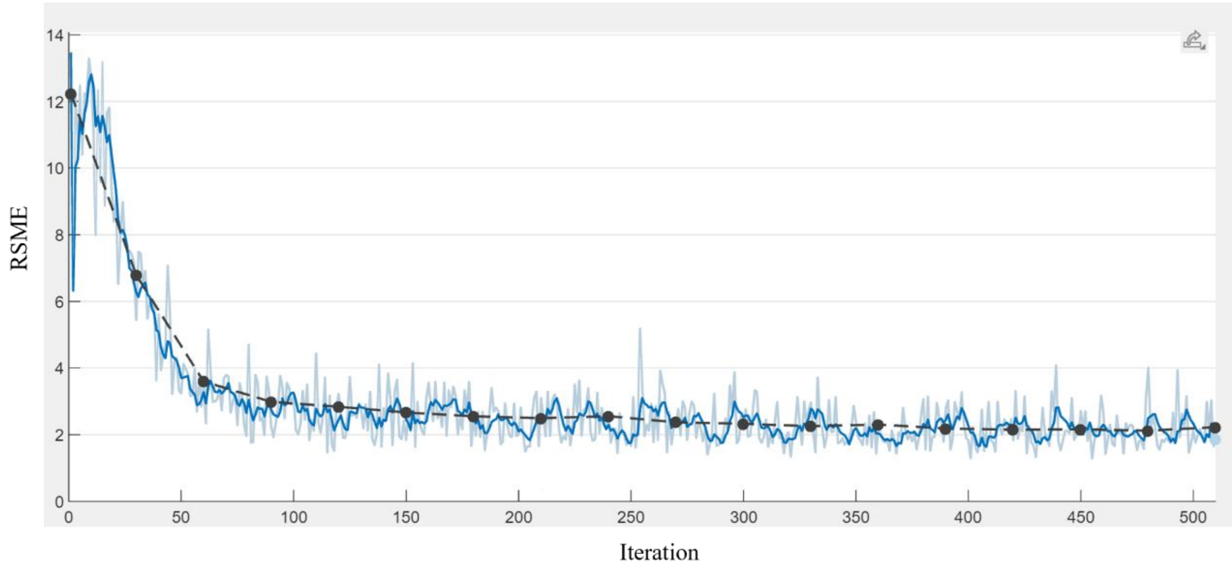

Fig. 13 Predicted result between the first round and the second round

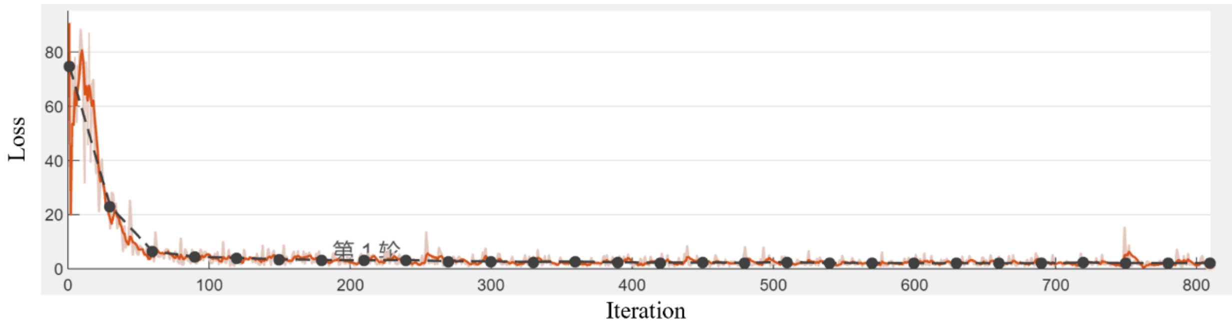

Fig. 14 Actual results between the first round and the second round

It is obvious that both the actual results and predicted results increase at first. After the RMSE reaches its peak, they decrease slightly. Before the second round, they tend to remain stable. When the time comes to the second round, the actual results stay around 0, while the predicted results are about 2.

Fig. 15 shows the predicted results after the second round. Fig. 16 shows the actual results after the second round.

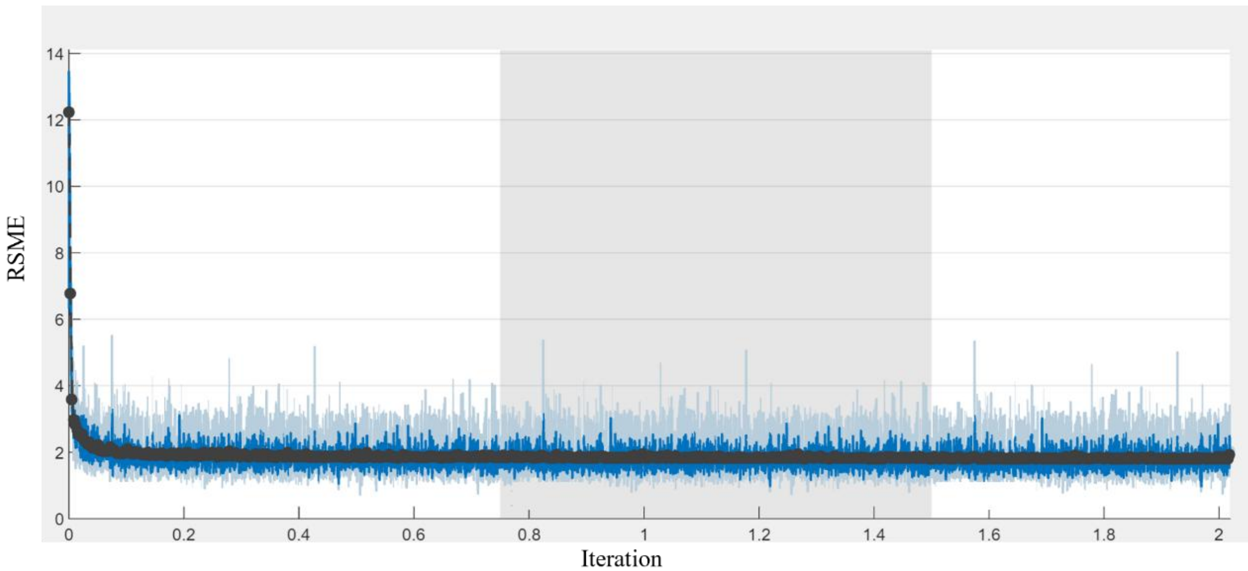

Fig. 15 Figure of predicted results after the second round

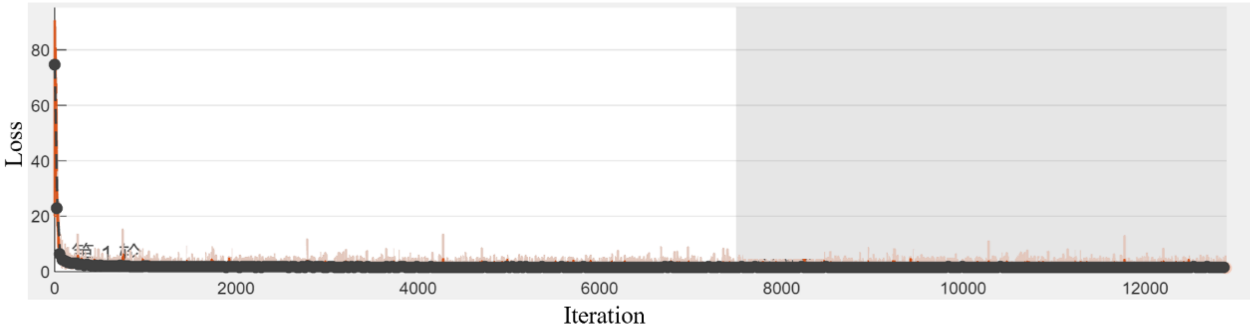

Fig. 16 Figure of actual results after the second round

The research also includes a transducer system. In the transducer system, the capacity of the garbage bin is set as 150 litres. Two kinds of transducers are considered: the pressure transducer and the light sensor. A pressure transducer can convert pressure into a signal to send information. Thus, it can calculate the distance from the garbage to the bottom by analyzing the signal. Pressure scanning values are known for their high-precision measurement of pressure [9]. This kind of sensor has good anti-interference capability and stability, making it suitable for outdoor use. A light sensor can examine the surrounding light and calculate the distance by analyzing the intensity and direction of the light. The principle of the light sensor is the photoelectric effect. However, traditional light sensors are large in area and small in dynamic range, and they do not consider the effects caused by dark current, which is inconvenient [10]. Light sensors may perform better if the distribution of garbage is uneven since the sensor is sensitive to different refraction rays. These two kinds of transducers are both set on the top of the garbage bin so that they can monitor the capacity. Data collected is transferred to capacity measurements every hour. This real-time capacity monitoring can prevent the garbage bin from overflowing.

To implement the sensor system, the research finally chooses the pressure transducer because of its high cost-effectiveness. Moreover, this kind of sensor is reliable in different outdoor conditions and is easier to install on the top of the garbage bin compared to the light sensor. Although the light sensor has higher accuracy than the pressure transducer, it is affected by different weather and climate conditions.

4. Conclusion

This study concludes that garbage can be efficiently managed and handled using a CNN-based control system. When a community street uses this kind of control system, CNN can help garbage trucks collect garbage and remind them when to leave. MATLAB can be used to simulate predicted and actual results. By comparing these two kinds of results, the research can determine how to further develop the control system. Simulink is also important, as it simulates three types of figures to show garbage pouring speeds. By analyzing these figures, the research finds that the control system is suitable for different garbage pouring speeds. By using a pressure transducer, the cost of the control system can be largely reduced. This control system is one possible solution to deal with the issue of garbage overflow. If people do not take action to address this problem, the environment may face serious challenges, since garbage overflow causes great harm to the environment. However, this control system still has limitations. It works better when the garbage load is heavy, because the pressure transducer does not function well otherwise. In the future, the author hopes to develop this control system by using another type of sensor that can be applied in all situations.

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