Scrap Steel Classification Model Based on Intelligent Algorithms

Yuan Shuo, Guo Zhiming, Su Zhenxiao, Zhang Jiayu
School of Artificial Intelligence, North China University of Technology, Tangshan, Hebei, China

Abstract: As a key green resource in the steel industry, the classification and grading quality of scrap steel directly affect enterprise costs and product quality. To address issues such as low efficiency, strong subjectivity, and high risk of traditional manual inspection, this paper proposes an intelligent scrap steel classification and grading method based on deep learning. the SeaFormer model is used to segment the wagon area, suppressing interference from complex backgrounds; a coordinate attention mechanism is embedded in YOLOv11 to enhance positioning accuracy and robustness in occluded and stacked scenarios; additionally, a slice-assisted super-inference framework is combined to improve small object detection in high-resolution images. Experimental results show that the CA-YOLOv11 achieves an mAP and F1 score of 87.6% and 87.3%, respectively, representing improvements of 1.3% and 0.6% over the baseline model. It performs excellently in detection accuracy, generalization ability, and real-time performance, providing a feasible solution for the intelligent recycling of scrap steel.

Keywords: Scrap Steel Classification; Machine Vision; Coordinate Attention Mechanism

1. Introduction

Research shows that for every ton of scrap steel used in steelmaking, 1.6 tons of iron ore resources can be saved, significantly promoting the achievement of the "dual carbon" strategic goals[1] . However, the current scrap steel recycling system is still mainly operated in a rough manner, with problems such as an imperfect classification management mechanism and low comprehensive utilization rate of resources, seriously restricting the production capacity of high-quality steel. With the rapid increase of scrap steel resources in society, developing an AI-based automatic scrap steel classification and quality assessment system has become an urgent need for the industry [2] [3] . This paper aims to construct a scrap steel recycling classification model using intelligent algorithms, innovatively adopting the SAHI framework to address the challenge of small target detection, while also utilizing the YOLOv11 model with an introduced CA attention mechanism for intelligent identification of scrap steel.

2. Materials and Methods

2.1 Dataset Preparation

Waste materials are labeled according to recycling standards: steel plates (thickness <3mm, 3–6mm, >6mm), non-steel plates (poor sealing, inclusions, overlength 1.2–1.5m, overlength 1.5–2m, scattered, ungraded), totaling 9 categories. To address the issues of insufficient data and class imbalance, augmentation methods such as brightness adjustment, cropping, mirroring, and rotation were used to generate 990 images. the data is split 9:1 into a training set (891 images) and a validation set (99 images).

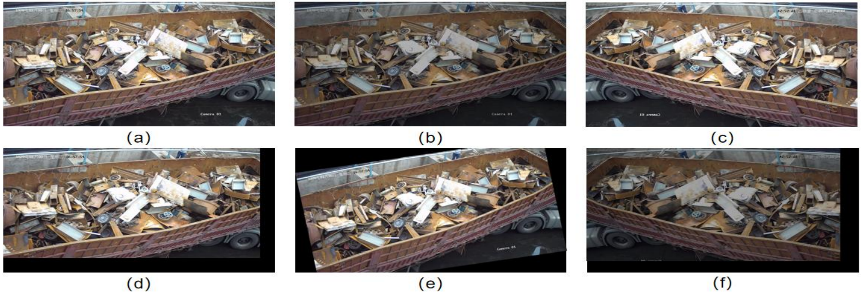

Figure 1. Image Enhancement Effects: (a) Original Image; (b) Brightness Adjustment; (c) Mirroring; (d) Cropping; (e) Rotation; (f) Random Combination

2.2 Method

2.2.1 Intelligent Scrap Steel Classification Model

Detection inside scrap steel carriages faces multiple technical challenges. Scrap steel comes in various forms and extremely different scales, and inside the carriage there is severe stacking, occlusion, and lighting variation, which leads to blurred target features and poor local identifiability. Existing YOLO models rely heavily on convolutional local receptive fields for spatial information modeling, making it difficult to effectively establish long-range dependencies and lacking positional sensitivity for scrap steel targets that are dispersed and irregularly shaped. To address this, the Coordinate Attention (CA) mechanism is introduced, whose core idea is to embed positional information into channel attention. By performing feature aggregation along the vertical and horizontal directions respectively, the network can capture global cross-channel context while retaining precise spatial orientation awareness.

2.2.2 SeaFormer Carriage Segmentation Model

To improve classification accuracy, the SeaFormer carriage segmentation model is used before recognition. This model combines axial compression attention with a detail enhancement mechanism, significantly reducing computational complexity while maintaining high-precision segmentation performance. SeaFormer leverages an efficient attention module, reducing the computational complexity of a traditional Transformer from quadratic to linear, supporting precise segmentation in complex scenarios.

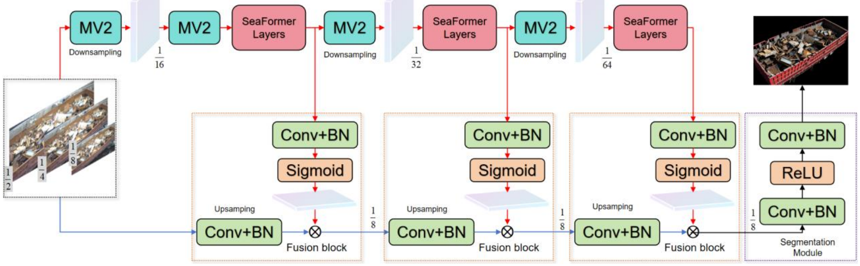

Figure 2. SeaFormer Carriage Segmentation Model

2.2.3 SAHI image slicing

Due to interference from the on-site environment, the actual detection accuracy is not high. This model uses SAHI. As a model-independent general framework, SAHI addresses the problem of small object information loss in high-resolution images caused by downsampling in traditional object detection models through dynamic slicing and super inference technology. It uses the existing detection model YOLOv11 to independently infer each slice, and then merges the results through intelligent stitching and NMS non-maximum suppression, improving the detection accuracy of small objects.

3. Results and Discussion

3.1 Model Evaluation Criteria

Mean Average Precision (mAP) across all categories is an important metric used to evaluate the performance of object detection models. Its range is 0 to 1, with values closer to 1 indicating better model performance, as shown in Equation (1).

$$mAP = \frac{\sum_{i=1}^{N} AP_i}{N} \qquad (1)$$

In the formula: N is the total number of categories; i is the i th category; AP is the average precision (average precision) for a single category.

3.2 Comparative Experiment

In order to validate the superiority of this model, different models were selected for comparison, including YOLOv7 and YOLOv8. Based on the comparative experimental results in Table 1, it can be seen that the proposed model shows significant advantages in multiple evaluation metrics. Specifically, compared with mainstream object detection models such as YOLOv7 and YOLOv8[5] [6] , this model achieved the best results in both mAP and F1 scores, reaching 87.6% and 87.3% respectively, confirming its superiority in detection accuracy and classification performance.

Table 1. Comparison of Different Models

Model	mAP(%)	F1(%)	GFLOPs
YOLOv7	85.8	86.5	103.3
YOLOv8	87.4	87.2	79.3
CA-YOLOv11	87.6	87.3	98.9

3.3 Ablation Experiment

In order to further verify that adding the CA attention mechanism to the YOLOv11 model can improve the model's performance, the ablation experiment in this paper is designed to compare the addition of the SE attention mechanism and the CA attention mechanism respectively. As shown in Table 2, the model's performance improves after adding both the SE attention mechanism and the CA attention mechanism, but the model with the CA attention mechanism shows superior performance, further validating the superiority of this model.

Table 2. Comparison of Different Models

Model	mAP(%)	F1(%)	GFLOPs
YOLOv11	86.3	86.7	80.3
SE-YOLOv11	87.5	86.9	88.3
CA-YOLOv11	87.6	87.3	98.9

4. Conclusion

This paper introduces a comprehensive intelligent scrap steel classification method that integrates carriage segmentation, attention mechanisms, and slice-assisted reasoning. Experimental results show that the constructed CA-YOLOv11 model, by introducing a coordinate attention mechanism, effectively enhances the network's ability to model the spatial distribution structure of scrap steel targets, significantly improving localization accuracy and detection robustness in complex scenarios such as occlusion and stacking. the model achieves mAP and F1 scores of 87.6% and 87.3% respectively, while maintaining computational complexity within a reasonable range, balancing detection accuracy and real-time performance. Overall, the proposed method demonstrates good detection accuracy, generalization ability, and real-time performance in intelligent scrap steel detection tasks, providing a feasible technical solution for the intelligent upgrading of the scrap steel recycling industry.

Acknowledgements:

Funding project: College Student Innovation and Entrepreneurship Training Project 'Full-process Waste Steel Processing System Based on Multimodal Perception and Intelligent Algorithms' (S202510081049).

References

[1] Ma Feiyue. Analysis and Prospect of the Current Situation of Waste Steel Classification and Grading [J]. Environmental Engineering, 2023, 41(S2):1163-1166.

[2] Xiao Pengcheng, Yin Jihu, Wang Chao, et al. Accurate Identification of Dense Small Scrap Material Types Based on YOLO-SNBP [J]. China Metallurgy, 2025, 35(07):216-227.

[3] Zhang Junxia, Xu Lingxiao, Ye Jinping, et al. Design of a Scrap Steel Impurity Recognition System Based on Machine Vision [J]. Metallurgical Equipment, 2025, (05):37-40.

[4] Zhang, C.; Zhu, L.; Yu, L. Review of Attention Mechanism in Convolutional Neural Networks. Comput. Eng. Appl. 2021, 57, 64–72.

[5] Xu, W.; Xiao, P.; Zhu, L.; Zhang, Y.; Chang, J.; Zhu, R.; Xu, Y. Classification and rating of steel scrap using deep learning. Eng. Appl. Artif. Intell. 2023, 123, 106241.

[6] Mei, Y. Research on Intelligent Classification of Scrap Based on Machine Vision and LIBS Technology. Ph. D. Thesis, University of Science and Technology Beijing, Beijing, China, 21 December 2020.