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Self-attention and convolutional feature fusion for real-time intelligent fault detection of high-speed railway pantographs

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The Overall Algorithm Model

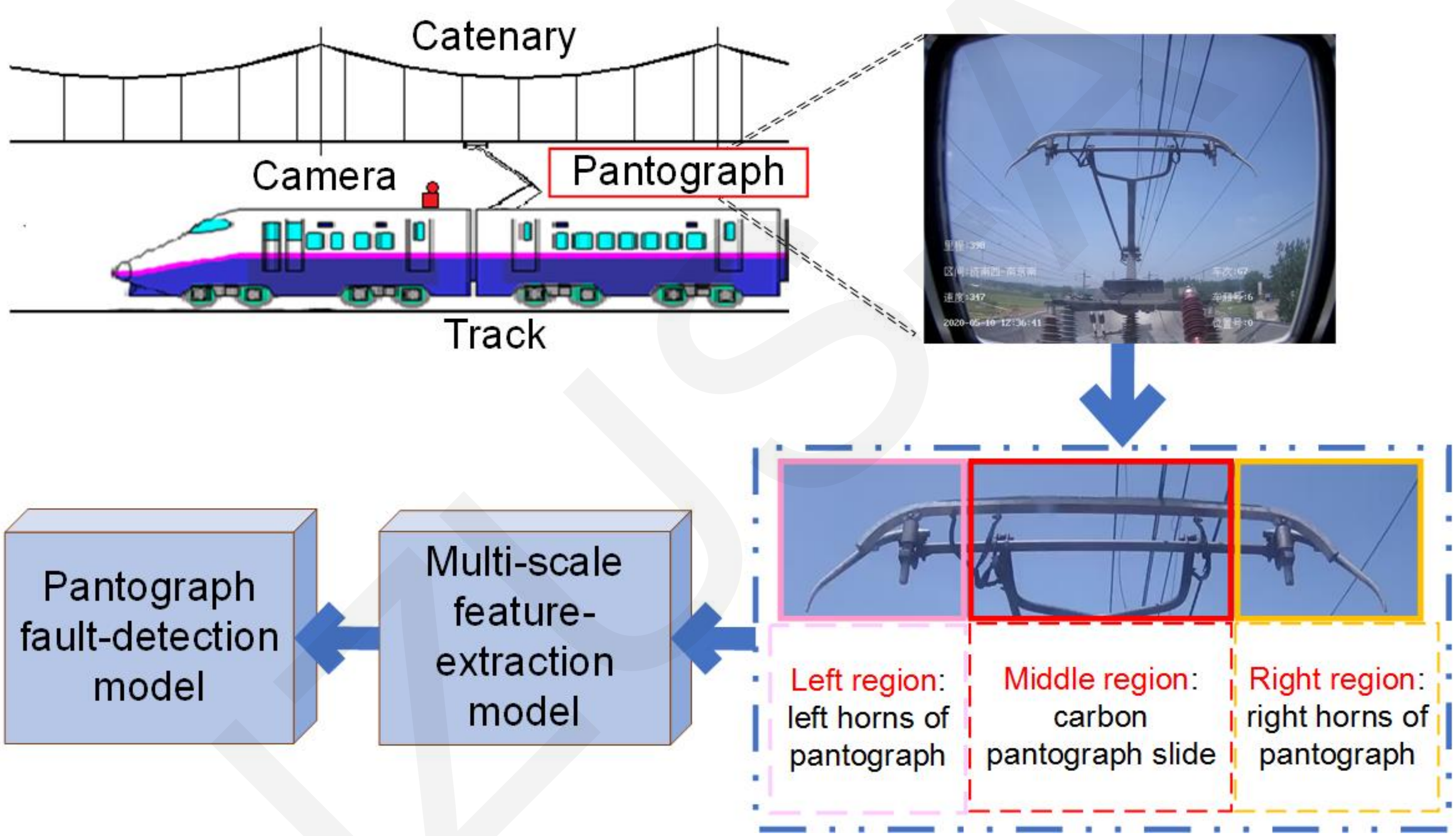


Fig. 1 Pantograph-catenary system and overall model

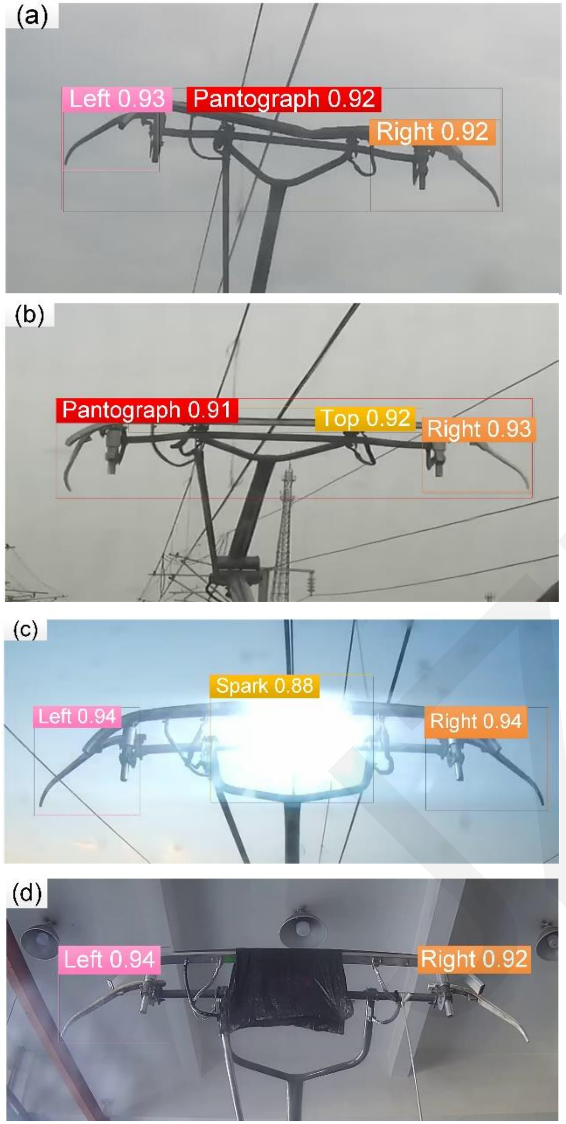
A multi-scale feature-extraction model

- The method integrates self-attention and convolutional features to improve the feature-extraction performance of convolutional networks and accurately identify pantographs in complex scenes.
- The lightweight multi-scale feature-extraction and fault-detection models are built to meet the requirements of real-time detection. Network parameters are reduced, and the model reasoning speed is improved.

A pantograph fault-detection model

- The training process of the pantograph fault-detection model
  - It begins with the input of normal pantograph collector heads, extracted by the target-recognition network, which is subsequently divided into three regions and fed into a multi-scale feature-extraction model.
  - Multiple independent logistic regression classifiers are utilized for training, resulting in the establishment of a feature sample library containing normal structures within these three regions.
  - Here, the pantograph image under examination is inputted into the model. Its features are then compared with those in the standard library, generating a confidence score..

Experimental testing and analysis



Pantograph fault-detection results: (a) carbon pantograph slide deformation.

Pantograph fault-detection results: (b) horns of the pantograph fault.

Pantograph fault-detection results: (c) discharge spark.

Pantograph fault-detection results: (d) foreign body attachment.

Pantograph-detection model test results

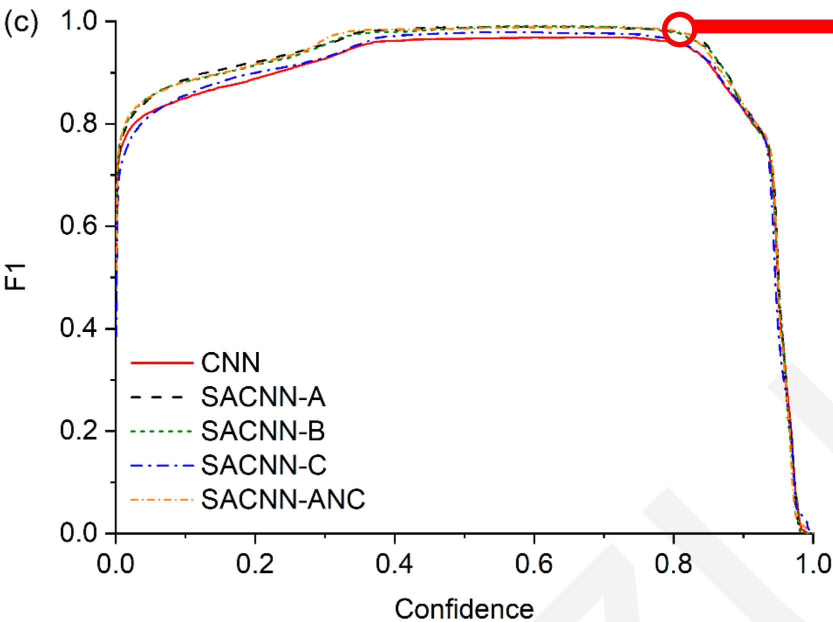


Fig. 10 F1 and confidence

The confidence of object detection is set at 0.8 as the threshold value in the fault-detection model.

Table 4 Comparison with other methods of pantograph fault detection

Model	Recall (%)	Precision (%)	Accuracy (%)	FPS (frame/s)	Memory (G)
SSD+PFDM	82.0	65.2	89.7	5.88	2.581
Faster-RCNN+PFDM	89.0	**99.5**	**98.1**	5.55	2.581
YOLOv3+PFDM	82.0	90.1	95.5	14.08	2.330
YOLOv5+PFDM	88.0	88.0	96.0	40.00	1.740
YOLOv7+PFDM	**100.0**	34.6	68.5	8.11	1.980
ACmix+PFDM	94.0	81.7	95.5	56.38	0.686
DPDN+IVFE	43.0	11.3	34.5	22.22	1.788
Proposed method	**100.0**	85.2	97.1	**62.50**	**0.686**

Conclusions

- In order to solve the problems involved in obtaining real-time intelligence on high-speed railway pantograph faults, we propose a lightweight deep learning model based on the fusion of self-attention and convolutional features to achieve real-time and high-accuracy recognition of key components of pantographs. Our experiments show that the fusion module can effectively improve the performance of the original convolutional network. High recall and accuracy are achieved in training and testing sets, and the algorithm model has good performance. We designed a pantograph fault-detection model, which achieves fast and intelligent fault detection and accurately identifies all the faults in the test set. The detection model proposed here provides a set of real-time and accurate tools for intelligent fault detection in pantographs of high-speed trains, and provides an efficient auxiliary means for engineers on board to assess pantograph faults.