DROPPER-LENGTH-AWARE PREPROCESSING FOR ANOMALY DETECTION OF OVERHEAD CONTACT LINE FITTINGS

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Abstract

Overhead contact lines are essential for the stable operation of electric railways; however, because they are installed outdoors over long distances and exposed to severe conditions such as wind, rain, temperature changes, and vibrations caused by pantograph passages, they are prone to deterioration. As a result, regular inspections and other maintenance activities incur significant costs. Overhead contact line fittings, such as droppers and electrical connectors, which mechanically or electrically link the contact wire and messenger wire, may deteriorate or fail due to wire vibrations or relative displacement caused by temperature changes. In recent years, automatic detection of visual anomalies in these fittings using images captured by cameras mounted on rolling stock has attracted increasing attention, with deep learning emerging as a promising approach. However, the length of droppers varies significantly depending on installation conditions, leading to two major challenges when unifying input image sizes for deep-learning-based anomaly detection. First, when images of long droppers are resized to match the dimensions of short ones, the region near the contact wire, where anomalies frequently occur, may lose essential features. Second, dividing images according to dropper length requires multiple detection processes per image, thereby increasing computational cost. To address these issues, this study proposes a preprocessing method that detects the position of the contact wire in an image and then resizes only the central portion of the dropper while preserving the size and aspect ratio of the junction area between the dropper and the contact wire. We applied the proposed method to a dataset comprising images of normal droppers and droppers with simulated anomalies captured on a test overhead contact line. The results confirm that the proposed method preserves critical features in the junction area while achieving consistent input normalization.

Keywords: overhead contact line, droppers, anomaly detection, preprocessing, normalization

1 Introduction

Inspection of overhead contact lines has traditionally relied on periodic walking inspections, which inherently limit inspection frequency and spatial coverage. With the increasing demand for condition-based maintenance, image-based inspection methods using cameras mounted on railway vehicles have been actively studied as a means to improve inspection efficiency and objectivity. In recent years, deep-learning-based approaches have shown promising performance in the automatic detection of visual anomalies in overhead contact line fittings [1, 2]. However, practical deployment still faces challenges related to input normalization. In particular, droppers exhibit significant variations in length depending on their position within a span.

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This directly affects the representation of critical joint regions when images are resized to a fixed input size. In this study, we focus on this normalization issue and propose an image preprocessing method that accounts for dropper length variations while preserving important structural features. The effectiveness of the proposed method is verified through anomaly detection experiments using images captured on a test overhead contact line with simulated anomalies.

2 Background

2.1 Structure of overhead contact lines

An overhead contact line generally adopts a catenary structure composed of a contact wire and a messenger wire, as shown in figure 1, with the contact wire supported by droppers that mechanically connect the two. To maintain stable current collection, the contact wire must be installed at a constant height above the rail and as smoothly as possible, minimizing unevenness. In a catenary structure, the messenger wire sags more toward the center of the span due to its own weight and the load of the contact wire. The length of each dropper is adjusted to compensate for this sag so that the contact wire height remains constant. As a result, dropper lengths vary depending on their position within the span. For example, in a system with a tension of 9.8 kN per wire, a span length of 50 m, and a dropper spacing of 5 m, dropper lengths are approximately 855 mm near the supporting poles and 414 mm near the span center. Thus, droppers are structurally characterized by substantial variation in length.

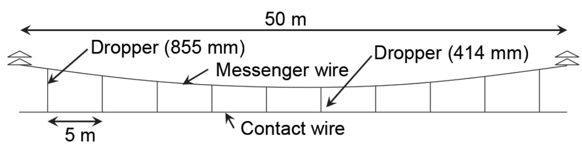

Figure 1 An example of structure of simple catenary overhead contact line

2.2 Types of fitting anomalies and conventional maintenance methods

Since overhead contact lines are installed outdoors, deformation or damage may occur due to external factors such as corrosion, flying-object impacts, or ground faults. In particular, the dropper is a critical fitting that mechanically connects the contact wire and messenger wire; anomalies at its joint regions may impair its supporting function, making it a key component requiring regular inspection. Conventional walking inspections limit the movement speed of inspectors, making it difficult to inspect wide areas at high frequency.

2.3 Appearance inspection using onboard cameras

To overcome these limitations, appearance inspection technologies using cameras mounted on railway vehicles have been widely studied. The vehicle-mounted camera system considered in this study is intended to be applicable not only to dedicated diagnostic vehicles but also to commercial trains. Applying such inspection systems to commercial rolling stock would increase the temporal and spatial density of inspection data, thereby accelerating the accumulation of normal-condition images required for anomaly detection. The proposed preprocessing method is designed to be independent of the vehicle type, as it relies solely on image geometry and the structural characteristics of droppers. In this study, experimental validation was conducted using images acquired on a test overhead contact line under controlled conditions in order to isolate the effect of dropper-length-aware preprocessing.

2.4 Existing studies on input normalization for variable-length components

Deep-learning models generally require input images to have a fixed size. However, for components such as droppers that vary in length, simple resizing or cropping can cause loss of information in the joint region or misclassification due to altered aspect ratios. Although previous studies [3-6] have addressed individual differences among fittings and small components, no method has sufficiently considered differences in information content or structural characteristics arising from dropper length variations.

3 Problem statement

When inputting dropper images into a deep-learning model, resizing is required to unify input dimensions. However, because droppers vary in length, the following challenges arise:

- Feature loss due to uniform resizing: When a long dropper is reduced to match the size of a short one, the relative size of the joint region decreases, weakening features in the area where anomalies commonly occur. This widens the distribution of normal images in feature space, making it more difficult to distinguish normal from anomalous samples and ultimately reducing anomaly detection accuracy and usability.
- Increased computational cost in image-splitting approaches: An alternative method is to divide the image based on dropper length and perform anomaly detection separately for each region. However, this increases the number of processing steps and computational load.

4 Proposed method

4.1 Overview

We propose a partial resizing method that compresses only the intermediate region (low-importance area) while preserving the joint region (high-importance area), based on the structural characteristics of droppers. In anomaly images, the joint regions contain features where anticipated anomalies may occur, whereas the intermediate region holds relatively limited structural information and is less affected by scaling. This difference in regional importance is consistent with the concept of Seam Carving [7], which preserves important regions during image resizing. The proposed method keeps the joint regions at a fixed size and scales only the intermediate region, thereby normalizing dropper images of varying lengths into a unified 224×224 square image.

4.2 Detection of the wire position

To identify the joint regions, the positions of the contact wire and messenger wire must be detected. Although object detection models could be used, they would require separate models for each dropper type, limiting generalizability. In a simple catenary overhead contact line, the contact and messenger wires are always connected to the dropper and appear as horizontal linear regions in the image. Following SNCF's study [8], we detect the contact wire position by summing luminance values along the rail direction and identifying peak values.

4.3 Input normalization by partial resizing

After detecting the wire positions, the following steps are applied:

- clip the image 14 pixels above the messenger wire and 14 pixels below the contact wire
- resize the entire image while preserving aspect ratio so that the horizontal width becomes 224 pixels
- designate 90 pixels around the contact and messenger wires as the joint regions (based on typical dimensions)
- stretch or compress only the remaining intermediate region vertically to produce the final 224×224 normalized image.

Figure 2 illustrates the overall procedure of the proposed partial resizing process. This approach enables length-invariant normalization while preserving critical features in the joint regions. Existing approaches for wire and dropper defect detection include object-detection-based methods and image-splitting approaches. Object-detection-based methods can effectively detect predefined defect types but require large, labeled datasets, while image-splitting approaches mitigate information loss at the cost of increased computational complexity. In contrast, the proposed method preserves structurally important joint regions through a single-pass, length-aware normalization process, enabling compatibility with unsupervised anomaly detection without increasing computational cost.

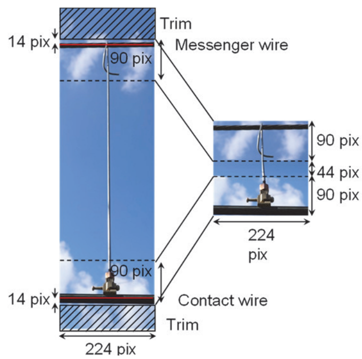

Figure 2 Partial resizing of dropper image

5 Experiments

5.1 Dataset construction and test overhead contact line

Droppers were installed on a test overhead contact line at the Railway Technical Research Institute, and images were captured under normal conditions and four types of simulated anomalies: joint loosening, intermediate bending, breakage, and detachment. The test overhead contact line was configured as a simple catenary system representative of conventional railway installations in Japan. The span length was approximately 24 m, with a dropper spacing of 4 m, resulting in dropper lengths ranging from approximately 740 mm near the span center to 910 mm near the supporting poles. This test overhead contact line was installed with a shorter span than that of operational lines in order to conduct various experiments within a limited site area. Example images of each anomaly type are shown in figure 3. Images were captured under daylight conditions using a DSLR camera. Dropper regions were manually cropped to focus the evaluation on the effect of preprocessing. An overview of the dataset is shown in table 1.

Table 1 Overview of the dataset

Mode	Category	Number
Train	Good	90
Test	Good	26
	Loosening	36
	Bending	30
	Breakage	30
	Detachment	9

5.2 Comparison methods

Three methods were evaluated:
- standard resizing: simple resizing of cropped dropper images to 224×224
- dmage-splitting approach (figure 4): resize the image to width 224 while preserving aspect ratio, crop fixed upper and lower 224×224 regions, resize the middle region to 224×224, perform inference separately, and integrate the results
- proposed method: preserve joint regions and scale only the intermediate region
- experimental conditions are provided in table 2.

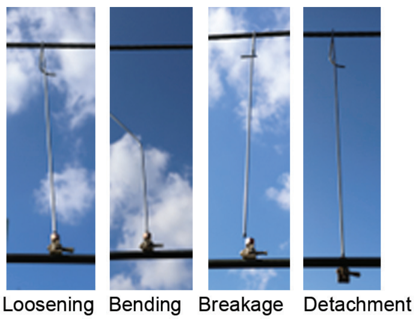

Figure 3 Example images of simulated anomaly categories

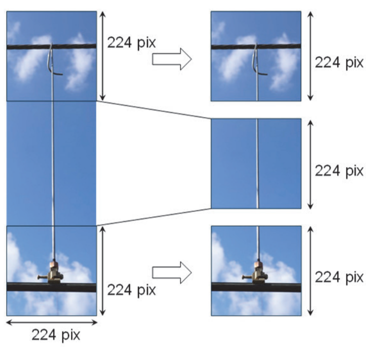

Figure 4 Overview of image-splitting approach

Table 2 Experimental conditions

Anomaly detection model	PatchCore [9]
Input image size	224×224
Nearest neighbors	3, 5, 7, 9, 11, 13, 15
Evaluation metric	AUROC

5.3 Results and discussion

The experimental results are summarized in table 3. Across all nearest-neighbor settings in PatchCore, both the image-splitting approach and the proposed method outperform standard resizing, indicating that mitigating information loss caused by dropper length variation is essential for improving anomaly detection performance. The proposed method consistently achieves the highest or near-highest AUROC values, with the best overall performance obtained when the number of nearest neighbors is set to 13. Unlike the image-splitting approach, which requires multiple inference passes per image, the proposed method maintains the same computational cost as standard resizing. Among the four anomaly types, joint loosening exhibits the smallest visual deviation from normal conditions and is therefore the most challenging to detect. The proposed method shows the largest improvement for this anomaly, suggesting that preserving the joint region stabilizes feature representations of normal samples and improves separability from anomalous ones. For anomalies with clear visual differences, such as bending and breakage, all methods achieve high AUROC values. However, the consistent improvement observed for subtle anomalies demonstrates the effectiveness of the proposed preprocessing method for detecting early-stage defects, which is particularly important for preventive maintenance.

Table 3 Experimental results

AUROC	(A) Standard resizing	(B) Image-splitting approach	(C) Proposed method
Nearest neighbors = 3	0.969	*0.953	0.983
1_loosen	0.923	0.897	0.950
2_bend	1.000	1.000	1.000
3_broken	1.000	0.978	1.000
4_off	0.949	0.936	1.000
Nearest neighbors = 5	*0.975	0.952	0.978
1_loosen	0.937	0.903	0.939
2_bend	1.000	1.000	1.000
3_broken	1.000	0.972	0.999
4_off	0.962	0.927	0.991
Nearest neighbors = 7	0.968	0.951	0.981
1_loosen	0.919	0.900	0.947
2_bend	1.000	0.999	1.000
3_broken	1.000	0.971	0.999
4_off	0.957	0.932	0.996

Table 3 Experimental results - table extension

AUROC	(A) Standard resizing	(B) Image-splitting approach	(C) Proposed method
Nearest neighbors = 9	0.970	0.948	0.982
1_loosen	0.923	0.890	0.947
2_bend	1.000	0.999	1.000
3_broken	1.000	0.973	1.000
4_off	0.957	0.932	1.000
Nearest neighbors = 11	0.975	0.949	0.980
1_loosen	0.935	0.894	0.942
2_bend	1.000	0.999	1.000
3_broken	1.000	0.972	1.000
4_off	0.966	0.932	1.000
Nearest neighbors = 13	0.967	0.947	*0.986
1_loosen	0.918	0.889	0.960
2_bend	1.000	0.999	1.000
3_broken	1.000	0.971	1.000
4_off	0.944	0.927	0.996
Nearest neighbors = 15	0.964	0.949	0.985
1_loosen	0.906	0.895	0.956
2_bend	1.000	0.997	1.000
3_broken	1.000	0.969	1.000
4_off	0.953	0.936	1.000

* Maximum score of AUROC

6 Conclusion

Due to variations in dropper length, size normalization for deep-learning-based anomaly detection has been a challenge. This study proposed a partial resizing method that preserves the joint region while scaling only the intermediate region. Experiments using a dataset with simulated anomalies demonstrated that the method improves anomaly detection accuracy without increasing computational cost. Future work includes validation using real-world datasets acquired from operational railway lines and extension to other overhead contact line fittings (e.g. connectors).

References

[1] Yu, L., Gao, S., Zhang, D., Kang, G., Zhan, D., Roberts, C.: A Survey on Automatic Inspections of Overhead Contact Lines by Computer Vision, IEEE Transactions on Intelligent Transportation Systems, 23 (2022) 8, pp. 10104–10125, DOI: 10.1109/TITS.2021.3119023

[2] Yang, H., Liu, Z., Cui, H., Ma, N., Wang, H., Zhang, C., Song, Y.: An Electrified Railway Catenary Component Anomaly Detection Frame Based on Invariant Normal Region Prototype With Segment Anything Model, IEEE Transactions on Transportation Electrification, 2025., DOI: 10.1109/TTE.2025.3628607

[3] Dong, Y., Chen, Z., Liu, X.: Machine Vision-based Research on the Inspection of Dropper Defects of Overhead Contact Line, China Railway Science, 2021.

[4] Li, Z., Rao, Z., Ding, L., Ding, B.: YOLOv5-SC: A Lightweight Detection Model for Railway Catenary Dropper, 5th International Conference on Intelligent Control, Measurement and Signal Processing (ICMSP), Chengdu, China, pp. 189–192, 2023, DOI: 10.1109/ICMSP58539.2023.10171051

[5] Luo, C., Tang, H., Li, S., Wan, G., Chen, W., Guan, J.: YOLOv11s-CD: An Improved YOLOv11s Method for Catenary Dropper Fault Detection, IEEE Transactions on Instrumentation and Measurement, 74 (2025), pp. 1–10, DOI: 10.1109/TIM.2025.3604118

[6] Tan, P., et al.: Multialgorithm Fusion Image Processing for High Speed Railway Dropper Failure–Defect Detection, IEEE Transactions on Systems, Man, and Cybernetics: Systems, 51 (2021) 7, pp. 4466–4478, DOI: 10.1109/TSMC.2019.2938684

[7] Avidan, S., Shamir, A.: Seam Carving for Content-Aware Image Resizing, ACM Transactions on Graphics (SIGGRAPH 2007), 26 (2007) 3, 10, pp. 1–10, DOI: 10.1145/1275808.1276390

[8] Pascal, C., Vincent, D., Philippe, D.: De nouveaux outils pour la surveillance caténaire à grande vittese, Revue Générale des Chemins de Fer, pp. 23-3, 2006.

[9] Roth, K., Pemula, L., Zepeda, J., Schölkopf, B., Brox, T., Gehler, P.: Towards total recall in industrial anomaly detection, 2021., arXiv:2106.08265