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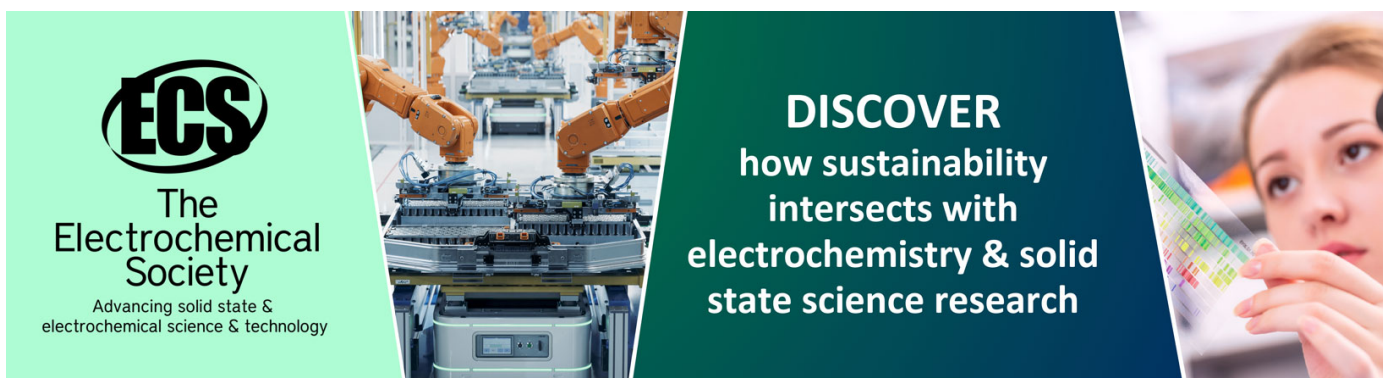
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A Two-Stage Detection Method of Rigid Pantograph Catenary Contact Points Using DCNNS

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Abstract. Pantograph catenary contact point is an important monitoring object during pantograph catenary operation, which reflects the state of pantograph catenary operation. However, due to the relatively small contact area of the target area, it is still a challenge to locate the contact point quickly and accurately. Therefore, we propose a two-stage detection method of rigid pantograph catenary contact points based on deep convolution neural network. Firstly, yolov3 network is used to locate the pantograph catenary contact part, which can obtain the target area including contact points. Then, four key points generated by the intersection of rigid pantograph and catenary can be obtained by using the key point detection network in the target area. Finally, the positioning of pantograph catenary contact points is obtained by geometric calculation. The experimental results on the railway operation data set collected by the traction Laboratory of Southwest Jiaotong University show the effectiveness of the method.

1. Introduction

Pantograph catenary system as the key power supply equipment in electrified railway, the quality of current received directly affects the safe operation of electric locomotive, which is shown in Figure 1. In order to ensure that the vehicle can continuously obtain electric energy, it is necessary to keep a good contact between the contact line and the sliding plate during the operation. Therefore, the pantograph catenary contact state must be monitored in real time to eliminate the hidden danger[1]. Our focus is to detect and locate pantograph catenary contact points, which are the basis of catenary dynamic parameters. The traditional maintenance method of pantograph mainly depends on manual climbing inspection within a certain period interval. During the maintenance, it is necessary to cut off the power supply of the catenary, so the maintenance efficiency is low[2]. In this paper, the non-contact image processing technology based on computer vision is used to dynamically detect contact points position of pantograph catenary system without stopping the vehicle. This method has advantages in automation and stability, which provides a research basis for the subsequent dynamic parameters acquisition.





Figure 1. .Pantograph catenary system

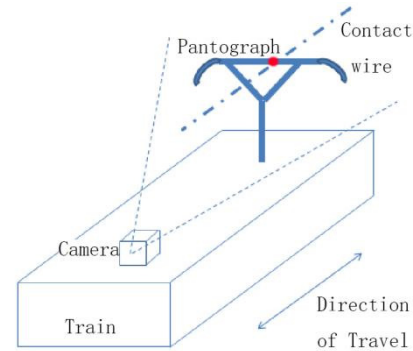


Figure 2. .Camera installation diagram

In recent years, with the rapid development of railway informatization, the real-time detection methods based on camera are gradually applied to railway detection. Liu et al.[3] proposed a method based on traditional image recognition algorithm in 2012, which can identify and detect the geometric parameters of pantograph catenary. But it is easy to be disturbed by external noise, such as weather changes or foreign matters. Through two high-resolution cameras, Shi et al.[4] collected the measurement features and processed the images, and finally realized the real-time measurement of the geometric parameters of the catenary. Zhou et al.[5] used the technology of multi camera stereo vision, and then studied the non-contact measurement method of catenary geometric parameters based on four linear array cameras. Kong et al.[6] proposed a two-dimensional space calibration method combined with Hough transform, which calculated the image coordinates of contact points. However, these methods are mainly implemented by sensor signal analysis or traditional image processing algorithms, which have high cost or can not adapt to complex environment.

Inspired by these, we propose a two-stage detection method of rigid pantograph catenary contact point based on deep convolution neural network. Firstly, the image of pantograph catenary operation is obtained by the camera installed on the roof. The installation position of the camera is shown in Figure 2. Then, we use the yolov3 network which has the advantages of speed and precision to extract the region containing contact points, and train the key point detection network to get four key points in this area. Finally, we can determine the location of contact points according to the geometric relationship.

2. Methodology

In Figure 3, we illustrate the overall framework of the pantograph catenary contact points positioning framework. The first step is given an input image of rigid pantograph and catenary obtained by camera, we use the improved yolov3 network[7] to detect the target area with contact points, which can detect small-scale targets better, and the enhanced network structure is described in detail in section 2.1.

The second step is to extract the image containing the contact point area, then the heat map of the coordinates of the four key points is obtained through the hourglass network[8], and they are marked on the graph. Finally, according to the geometric relationship of the image to calculate the coordinates of contact points. See 2.2 for details.

It can be clearly seen from Figure 3 that the position of pantograph catenary contact points is obtained by two-step detection method, which provides data basis for subsequent detection of pantograph catenary geometric parameters.

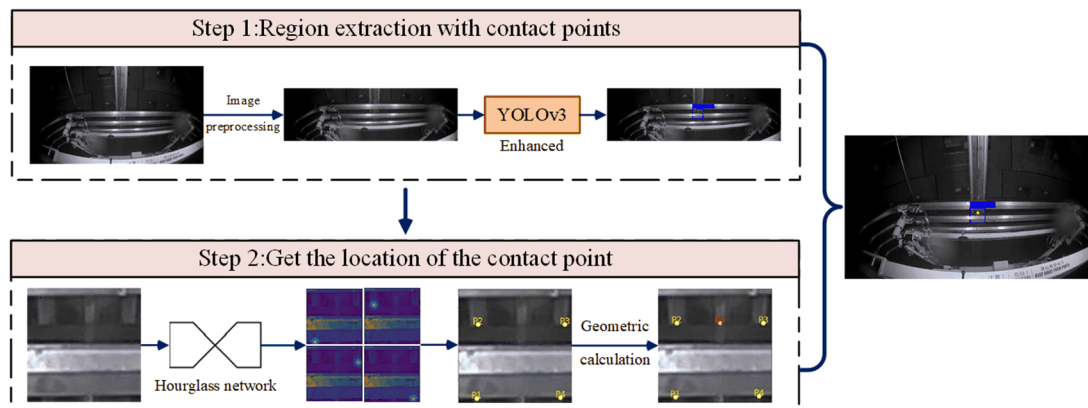


Figure 3. Overall architecture of contact points location.

2.1. Network design

In order to make the network model have a high recognition rate of contact points, according to the principles of the deep residual network (ResNet)[9] and yolov3, an enhanced yolov3 target detection network is constructed.

Because the feature map of 4 times down sampling of the original network contains more fine-grained information of small targets, the shallow feature mapping can be connected with the deep feature mapping. As shown in Figure 4, after the 52×52 feature map is sampled twice, it is connected with the output of the second residual block in yolov3, which forms a feature fusion target detection layer with four down sampling. In this way, the small target detection is realized on the scale of 104×104 feature map.

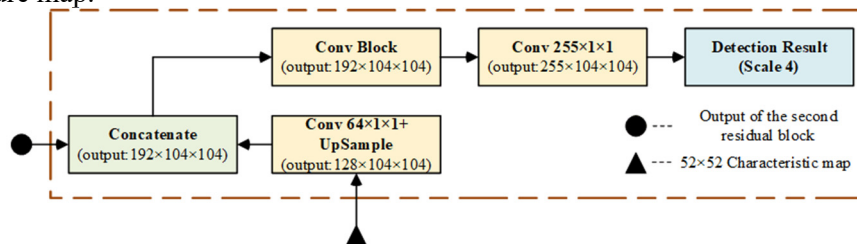


Figure 4. Feature fusion target detection layer.

Before the third prediction scale 52×52 of the original yolov3, a feature map with the size of 104×104 is added. The strong semantic features of deep network and the high resolution of shallow network are combined to construct the enhanced yolov3 network with four detection scales. Finally, multi-scale detection is realized, which enhanced the detection effect of small and medium-sized objects in the image and improved the detection performance of yolov3.

2.2. Geometric calculation

The intersection area of rigid pantograph and catenary in the image is an irregular quadrilateral similar to parallelogram, the contact point is 1/2 of the top edge when it runs to the middle, that is, the quadrilateral angle is 90 degrees. With the movement of pantograph and catenary, the inclination angle of quadrilateral will change gradually. However, because the rigid structure and the camera position remain unchanged, the position of the contact point can be calculated according to the four vertices.

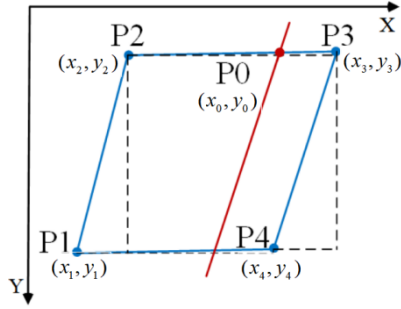


Figure 5. Quadrilateral coordinate diagram.

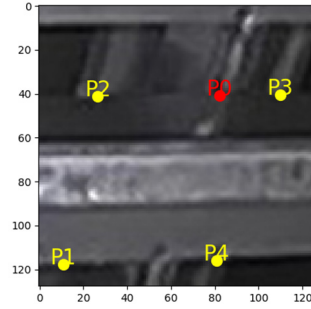


Figure 6. Calculation results.

The coordinate diagram of quadrilateral is shown in Figure 5, the horizontal and vertical coordinate of contact points P_0 are calculated as follows, the calculated results are shown in Figure 6.

$$x_0 = (x_2 + x_3) / 2 + ((x_2 - x_1) + (x_3 - x_4)) / 2 \quad (1)$$

$$y_0 = (y_2 + y_3) / 2 + ((y_3 - y_2) + (y_4 - y_1)) / 2 \quad (2)$$

2.3. Loss function

In the area detection stage, The loss function of yolov3 is shown in equation (3), which consists of positioning error, classification error and confidence error. Among them, the location error is the mean square error, the classification error and the confidence error are the binary cross entropy error.

$$Loss = Error_{localization} + Error_{class} + Error_{confidence} \quad (3)$$

In key points detection stage, the loss function of hourglass network is to calculate the mean square variance (MSE) of loss generated by the heat map and the real heat map.

3. Experiments and analysis

3.1. Experimental dataset and training process

Considering the effectiveness of the contact points and the cost of the equipment, the video data in this paper is from offline video recorded by the roof camera installed on an electric locomotive. The initial dataset used in the experiments are scene maps in traction substation, The dataset was split into 8:2. The training dataset included 3560 images, and the testing dataset included 890 images. Image resolution is 1920*1080.

The experimental environment in this paper is described as follows: Ubuntu 18.04 operation system, operation system, GPU: NVIDIA GeForce RTX 2080Ti GPU with 11GB memory, python 3.6.4, deep learning open-source software library Pytorch.

3.2. Experiment and result

After the training, we tested 890 pictures. Figure 7 shows the detection effect of rigid pantograph catenary contact points, from which we can see that the results can accurately display the contact area and locate the contact point position. In addition, in the next section, we will show the result graphs of different stages and carry out the corresponding structural similarity assessment.

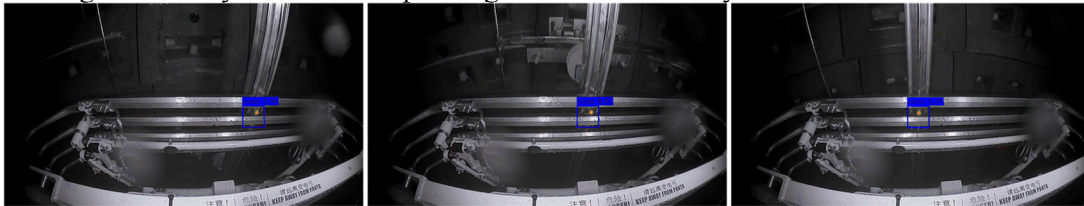


Figure 7. The acquisition results of some images in the test set.

3.3. Structural similarity analysis

The results of the first step are shown in Figure 8, we used precision and recall to evaluate the results of the first step. The precision represents the proportion of the contact point area correctly detected in all test results, the recall represents the proportion of the contact point area correctly detected in all test samples, the results are shown in Table 1.

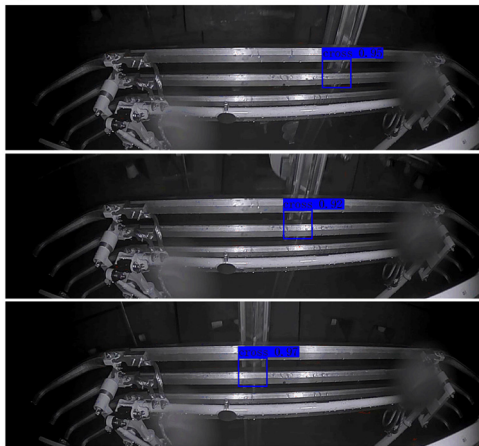


Figure 8. Detection results of target area.

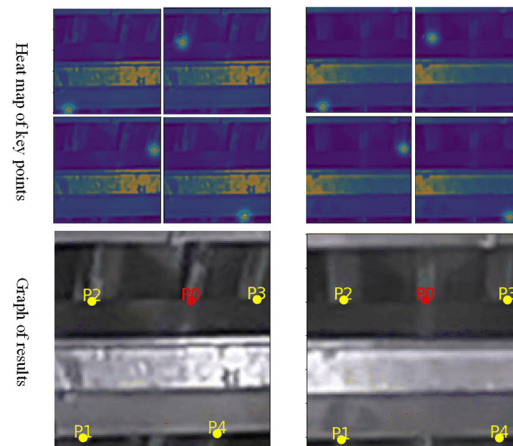


Figure 9. Positioning results of contact points.

TABLE 1. Evaluation of target area detection results.

TP	FP	FN	Precision(%)	Precision(%)
862	47	28	94.8	96.8

Among them, TP is the correctly detected area, FP is the error detected area, and FN is the undetected area. The results of the second step are shown in Figure 9, the similarity between the true value and the predicted results is calculated by the OKS (Object Keypoint Similarity) index. The result of calculation is 0.93, which is close to 1, so the key point location is accurately located.

4. Conclusion

In this paper, we propose a two-stage detection method of rigid pantograph catenary contact points based on deep convolution neural network. Firstly, yolov3 network is used to locate the pantograph catenary contact part, which can obtain the target area including contact points. Then, four key points generated by the intersection of rigid pantograph and catenary can be obtained by using the key point detection network in the target area. Finally, the positioning of pantograph catenary contact points is obtained by geometric calculation. Meanwhile, precision, recall and OKS index is utilized to compare the difference between the true value and the predicted results, and the experimental results on the railway operation data set collected by the traction Laboratory of Southwest Jiaotong University show the effectiveness of the method. The following research focuses on the calculation of dynamic parameters of pantograph network based on the research results of contact points position.

Acknowledgments

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