Application Research of Substation Power Inspection Robot Based on Image Recognition Technology

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Keywords: Faster Region-CNN(RCNN), YOLO, Image Recognition Technology, Substation Intelligent Inspection Robot, Image Recognition Algorithms.

Abstract: With the continuous development of the economy, substation intelligent inspection robot is widely used. Currently, the substation inspection robot has problems such as low accuracy and poor pointer accuracy in recognition technology. Therefore, this paper takes image recognition technology as the breakthrough point in instrument recognition, aiming to explore the application of instrument recognition in power inspection robot and analyze the factors affecting the image recognition of inspection robot. At the same time, this paper summarizes and explores the advantages and disadvantages of image recognition technology in application. This paper concluded that the traditional recognition technology algorithm needs the support of prior information in the recognition to be able to accurately identify and sensitive to the data quality, while in the noise environment, it will be seriously disturbed and the generalization ability is weak. The image recognition algorithm has high accuracy and fast speed in identifying small images. Faster Region-CNN(RCNN) can accurately identify multiple targets and save time. Through continuous improvement, the You Only Look Once(YOLO) algorithm has high accuracy and strong anti-interference in single target recognition. In the future, the development of image recognition technology in various fields of instrument recognition can be more accurate.

1 INTRODUCTION

With the development of science and technology, industrial production and people 's lives rely more and more on electricity. Therefore, it is necessary to ensure the smooth operation of the power systems. The failure of the power systems often brings unpredictable losses to the national economy, and the state puts forward higher requirements for the stable operation of the power systems. In order to ensure the stable operation of the power systems, the substation plays a key role as a transfer station for transmission and distribution in the power systems. Therefore, ensuring the normal operation of power equipment in substations is particularly important.

With the continuous development of science and technology, substations have gradually become intelligent. Power systems nationwide have carried out comprehensive transformation and innovation of existing old substations. However, due to various unfavorable factors, there are still many problems in the process of replacing traditional substations with modern intelligent substations. For example, a large number of old instruments are still retained in the traditional substation. These instruments cannot automatically upload digital data because they cannot be connected to the computer. This problem leads to the traditional substation needs to manually copy, and manual inspection will inevitably lead to missed detection and omission. In addition, due to the large number of old-fashioned instruments, risk of manual inspection increases. For example, in the harsh environment, the labor intensity of manual climbing is high, and the scope of work is significantly increased. At the same time, it will also cause personal issues safety, visual fatigue and misunderstanding caused by inattention, which will lead to accidents. Therefore, the development of intelligent inspection robots is of great significance to compensate for traditional inspection methods' limitations.

Many scholars have conducted profound research on the application of intelligent robots in substations. Wei Chao 's (2021) research mainly focuses on the basic principle and application of intelligent inspection robot inspection systems. He pointed out

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that the inspection robot reduced the staff's workload and improved the work efficiency in substation inspection, infrared temperature measurement, instrument data reading and equipment defect tracking and detection. However, the existing inspection robots have some problems in the accuracy and efficiency of instrument recognition technology, which is difficult to meet the actual needs. According to the algorithm with You Only Look Once(YOLO) v3 as the core, Song Dongmei (2023) improves a single target's detection efficiency and accuracy by fewer network layers. Wang Xinran et al (2024) proposed an improved Faster Region-CNN(R-CNN) instrument recognition algorithm using residual network (Resnet) 101 instead of the original Visual Geometry Group(VGG). The improved Faster RCNN has higher recognition accuracy for single and multiple targets. Sun Hui et al.proposed to quickly identify the position of the instrument by introducing the Convolutional Neural Network(CNN) detection model and perform targeted denoising on the identified image using the noise capture algorithm. For the influence of the external illumination environment, an improved single-parameter homomorphic filter is proposed, which reduces the amount of parameter adjustment and shortens the operation time. Finally, Wan Jilin et al.improved the image detection network RetinaNet and added a higher resolution fusion feature map on the original basis to solve the problem of too little information in the identification of small parts and used the correction method of the small probability of the transformer to correct the detection of small parts. This algorithm improves the recognition accuracy of small parts.

Based on the above research background, this paper aims to explore the application of image recognition technology in the instrument recognition of power inspection robot in substation. First of all, this paper analyzes the development process by understanding the basic principles of image recognition technology. Secondly, this paper focuses on the specific application of image recognition technology and further explores its advantages. Finally, this paper analyzes the advantages and limitations of image recognition technology based on image recognition technology in instrument recognition technology, and then gives some prospects and suggestions.

2 IMAGE RECOGNITION TECHNOLOGY

2.1 Rationale

Image recognition technology, also known as computer vision technology, is a technology that can transform the input image information into meaningful digital or text information through digital image processing technology (Wang and Liu 2023). It mainly relies on computer technology to analyze, identify and process digital images. Through these steps, image recognition technology can quickly and accurately identify the information contained in countless images. Image recognition technology is based on the object's shape, size, color, texture and other features, according to these features to analyze and identify the objects in the image. The working principle of image recognition technology includes image acquisition, image preprocessing, feature extraction, pattern matching, recognition and classification.

Image acquisition refers to converting images in the real world into electronic signals through cameras, scanners and other devices and storing them in computers (Zhang et al 2023). Image preprocessing is the performance of operations such as denoising, enhancement, and edge detection on the acquired image during the preprocessing process to improve the image quality and highlight the characteristics of the target object. Feature extraction is an important part of image recognition. By extracting features from the image, the target object in the image can be distinguished from other backgrounds. The commonly used feature extraction methods include color features, texture features, shape features, etc. Classification and recognition is that the computer uses machine learning, deep learning and other algorithms to classify the extracted features in the classification and recognition stage, so as to realize the automatic recognition of the target objects in the image. The commonly used algorithms are VGG network, edge detection, YOLO, Faster R-CNN and other algorithms.

2.2 Application of Image Recognition Technology

With the rapid development of artificial intelligence and computer vision technology, the current image recognition technology mainly includes face recognition, object detection, scene classification, text recognition, image content editing, medical

image analysis, video surveillance, virtual reality and augmented reality, intelligent driving assistance and agricultural pest hazard detection and other fields.

Face recognition technology is the use of computer algorithms, through the analysis of facial features, to achieve automatic recognition and classification of faces. This technology is widely used in road safety, finance and other fields, such as access control systems and mobile payment. Object detection is the use of computer vision technology to realize the automatic detection and recognition of objects in images. This technology is used in intelligent construction, smart home intelligent security, and other aspects such as defect detection on automated production lines and intelligent vacuum cleaners. Scene classification is to automatically classify and label images according to the scene information in the image. Scene classification technology is reflected in intelligent photo albums, intelligent search engines and other software, such as automatic classification of photos according to the scene, intelligent recommendation related content. Image content editing is to realize the automatic editing and modification of image content. Image content editing is mostly used in image programming software such as Meitu Xiuxiu and Photoshop, which can automatically repair photo defects and realize intelligent whitening. Image recognition technology is widely used in the field of intelligent transportation. For example, traffic surveillance cameras can learn vehicle identification, vehicle counting and vehicle violation identification through image recognition technology, so as to improve the efficiency and accuracy of traffic management. In the field of medical imaging, image recognition technology can automatically analyze and recognize medical image images to help doctors make early diagnosis and treatment of diseases. For example, the early detection of breast cancer can automatically identify potential tumor areas through image recognition technology to improve the speed and accuracy of diagnosis. In the field of security monitoring, security cameras can realize human face recognition, behavior recognition and other functions through image recognition technology, helping monitors to detect anomalies in time and provide effective security warnings. In the field of Unmanned Aerial Vehicle, image recognition is mainly used for target tracking, terrain recognition and so on. UAV can automatically track the target object, carry out real-time shooting and monitoring, and carry out ground recognition to realize the autonomous navigation and flight control of UAV. In intelligent robots, image recognition technology is an indispensable part of robot intelligence. Robots can identify objects and people in the environment for autonomous navigation, target tracking, human-computer interaction and other tasks. In addition, in the field of service robots, robots can improve the service quality of robots in terms of face recognition and emotion recognition. At present, there are robots in major amusement parks to identify players in real time through cameras. They can also analyze facial expressions to achieve emotional interaction and improve the game experience. The intelligent inspection robot of the substation monitors and maintains the power equipment through the ability of image recognition technology, such as autonomous perception, autonomous planning, autonomous execution and autonomous learning, such as abnormal oil level of a transformer, excessive winding temperature, insulation damage, instrument aging and fouling. The intelligent inspection robot can independently analyze the corresponding decision-making according to the problems that arise.

2.3 The Characteristics and Classification of Image Recognition Technology Algorithm

The traditional algorithms of image recognition technology include: edge detection, morphological processing, linear fitting and other algorithms.

Edge detection is used to identify significant changes in the image, usually representing the boundary of the object. Instrument detection can be used to identify the edge of the scale line.

Morphological processing This is a method of analyzing shapes. Some shape features can be extracted or enhanced from the image through morphological processing. For example, it can be used to remove noise, connect broken lines or find objects of a specific shape. Line fitting : This may be necessary for recognizing lines (e.g., scale lines) in an image. The algorithm can determine which points should be regarded as a straight line and give its parameters (such as slope and intercept).

The CNN algorithm can directly use the instrument image as input, output the dial, pointer and scale after feature extraction and feature mapping, or output the indicator directly.

Image recognition technology algorithms are divided into two categories of algorithms: one-stage and two-stage.

The Faster R-CNN algorithm belongs to the two-stage algorithm. Its structure mainly includes convolution layer, RPN layer, region of interest pooling layer and classification regression layer. Faster R-CNN has superior performance, high-

precision detection performance, can solve multi-scale, small target problems, versatility and robustness.

The Scale-Invariant Feature Transform algorithm uses the convolution of the original image and the Gaussian kernel to establish the scale space, and extracts the scale invariant feature points on the Gaussian difference space pyramid. This algorithm has certain affine invariance, perspective invariance, rotation invariance and illumination invariance. The first step is the pyramid, which greatly reduces the amount of computation. The second step is the search of feature points. The third step is the feature description (Shi 2022).

The Speeded Up Robust Feature algorithm uses the approximate Harris method to extract the feature points for the shortcomings of the SIFT algorithm, which is too slow and computationally intensive. By using the integral image on different scales, the approximate Harris value can be effectively calculated, simplifying the construction of the second-order differential template and improving the efficiency of feature detection in the scale space (Gao2018).

Solid State Disk target detection algorithm is an end-to-end target detection method. SSD can achieve target detection through a single neural network and can detect multiple targets at the same time. The SSD algorithm only needs one forward transmission to detect the target. Therefore, the detection speed of the algorithm is fast and the accuracy is high.

The RetinaNet algorithm is mainly composed of backbone network ResNet, feature pyramid Feature Pyramid Networks, classification sub-network and regression sub-network. This algorithm generates feature maps of different scales through FPN, and constructs a feature pyramid from the feature map so that the network can detect the target.

3 APPLICATION OF IMAGE RECOGNITION TECHNOLOGY IN INSTRUMENT RECOGNITION IN SUBSTATION

Traditional instrument recognition technology requires reading manually according to the direction of the instrument pointer and the scale on the dial. When identifying the reading of the pointer instrument, it is first necessary to shoot the instrument through the camera. Then, according to the information collected of the image, the area containing the instrument pointer and the scale is segmented. Finally, the meter reading is calculated by the angle of the pointer rotation.

The reason why the intelligent inspection robot can accurately identify the instrument is that it depends on the existence of the original information. For example, information such as categories and range units contained on the instrument can be input to the intelligent inspection robot, which can reduce the error probability and also significantly reduce the universality. The traditional recognition method is fast and accurate for low-resolution images, but the traditional recognition technology lacks generalization in the face of interference. At the same time, it needs prior information when detecting and segmenting images, so it is difficult to apply it to the external environment (Zhang et al 2023).

At present, instrument recognition faces two main problems instrument detection and pointer segmentation. In order to solve these problems, target detection algorithms in image recognition technology, such as Faster R-CNN and YOLO, are applied to instrument detection. Through Mask R-CNN, the meter pointer's area and the dial's scale is segmented and the reading is performed. The Faster R-CNN algorithm is optimized on the basis of the original algorithm R-CNN, which solves the problem of long calculation time, inability to be applied in practice, and low accuracy in detecting small targets. Some scholars have proposed a pointer meter reading method R-YOLOv5 based on the rotating target detection algorithm. This method is an improvement on the YOLOv5 algorithm (Zhang 2023). It does not need to detect the direction and scale of the pointer. This method can simultaneously predict the direction of the pointer and locate the scale. Finally, the angle method is used to read the instrument, and then the data is collected. Some scholars have improved the Faster R-CNN algorithm to solve the problem that the accuracy and efficiency are still not very high in complex scenes such as instrument overlap and occlusion detection. Due to the long training time, large storage capacity, loss of information and loss of VGG16 network, ResNet101 is introduced to replace the original VGG16 feature network. Through experiments on different feature extraction networks, it is concluded that the recall rate, accuracy and time of single target image detection of ResNet101 are better than VGG16 (Feng 2022). Then, the original recursive feature pyramid is improved to improve the ability of the backbone network to extract features and make the positioning of the target more accurate.

4 THE FUTURE DEVELOPMENT OF IMAGE RECOGNITION TECHNOLOGY

With the further optimization of deep learning algorithms in the future, especially the continuous advancement of image recognition technology, more optimization algorithms will be proposed. These algorithms can be used to improve the speed and accuracy of image recognition, while reducing the consumption of computing resources. For example, a new model structure is developed to accelerate the training of the model. At present, image recognition is mainly based on single mode, but in many application scenarios, researchers need to identify cross-modal images. For example, the radar signal or infrared image is converted into a human-recognizable image, and the data collected by multiple sensors is fused to improve image recognition accuracy. With the rise of technologies such as artificial intelligence and unmanned driving, image recognition technology is developing in the direction of multi-modal fusion. For example, the traditional image data, sound, video and so on are fused to provide users with reliable information. However, image recognition technology will face the challenge of heterogeneous data. For example, in the field of unmanned driving, image recognition technology needs toidentify external weather, road conditions and traffic signs accurately. This requires image recognition technology combined with sensor technology and real-time data processing technology for research. In the use of image recognition technology, it is inevitable to encounter privacy leakage and lack of security. Researchers need to consider how to use image recognition technology efficiently to improve security performance in the future.

5 CONCLUSION

This paper introduces the application of intelligent inspection robot in substation based on image recognition technology. It mainly takes image recognition technology as the breakthrough point in instrument recognition, and points out that the accuracy of traditional instrument recognition technology in identifying complex images is not high. At the same time, prior information is needed when detecting and segmenting images, so the impact on the external environment is difficult to apply in practice. The basic principles of image recognition technology are described. For example, the traditional image recognition algorithm has high accuracy and fast speed in identifying small images. Faster RCNN can accurately identify multiple targets and save time. YOLO algorithm has been continuously improved. This algorithm has high accuracy and strong anti-interference in single target recognition. Image recognition technology algorithms can be used to improve the speed and accuracy of image recognition and reduce the consumption of computing resources. However, when identifying and collecting a large number of images, information is sometimes lost, and privacy protection is insufficient. The application of cross-modal image technology is more promising because with the development of new energy trams, more and more people are proposing driverless technology, which can help people with disabilities bring convenience when they travel.

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