High-Precision Automatic Crimping Technology for Cable Splice Joints based on Artificial Intelligence and Multi-Sensor Assistance

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Abstract: This study aims to develop a high-precision automatic crimping technology for cable middle joints, using AI-assisted multi-sensor data fusion. A multi-sensor system, consisting of temperature, pressure, and displacement sensors, was designed to collect key parameters in the crimping process. The data was processed through filtering, denoising, and normalization to provide reliable input for the AI model. YOLOv5, a deep learning-based object detection model, was optimized and trained to detect key features of the crimping process. Experimental results show that the system can monitor the crimping status in real-time, make intelligent adjustments based on detected anomalies, and ensure high crimping quality. The proposed method improves the automation and precision of the crimping process, making it more reliable and efficient than traditional manual methods. The novelty of this paper lies in integrating multi-sensor fusion and AI to achieve adaptive control and precise crimping quality monitoring.

Keywords: Cable Splice Joints; Automatic Crimping; Artificial Intelligence Algorithms; Multi-Sensor; Deep Learning; YOLOv5; Intelligent Control

1. Introduction

The cable middle joint is the key component in the power transmission and communication system, and its compression quality [1] directly affects the electrical conductivity and service life of the cable. The traditional manual crimping process is affected by the operator's technical level, experience, and environmental factors, which often leads to the fluctuation and failure of the joint quality. With the rapid development of intelligent manufacturing and artificial intelligence technology, AI-based automatic bonding technology [2] has become an important way to improve the bonding accuracy and production efficiency. By combining multi-sensor technology and deep learning algorithm [3], a high precision automatic bonding scheme is proposed to improve the quality and stability of the cable intermediate joint.

2. Multi-sensor Data Acquisition and Processing

2.1 Multi-sensor System Design

In the process of automatic bonding, it is crucial to accurately obtain the real-time data of the compression environment. In this paper, [4], a multi-sensor data acquisition system based on temperature, pressure and displacement sensors, is designed to monitor the key physical quantities during the compression process in real time. The temperature sensor is used to monitor the possible thermal effects during the pressure joint process, the pressure sensor can monitor whether the applied pressure relay meets the standard, and the displacement sensor can obtain the deformation information of the pressure joint in real time. Through the comprehensive analysis of these sensor data, the system can effectively evaluate the crimping quality and provide accurate input data for the subsequent AI model.

2.2 Data Preprocessing and Feature Engineering

Since sensor data is often accompanied by noise and outliers, data preprocessing as shown in Figure 1, is a key step to improve model performance. In this paper, filtering, denoising and data standardization techniques are used to clean and transform the raw data [5]. Moreover, feature engineering further enhances the data validity and information density by extracting correlations between different sensor signals. These pre-processed data provide a solid foundation for the subsequent training of the deep learning models.

Figure 1. Data Preprocessing Flowchart

3. AI Algorithm Selection and Optimization

3.1 Multi-Sensor System Design

Target detection has achieved significant results in the field of image recognition. Traditional target detection algorithms such as SVM, Adaboost, and random forests perform well in specific scenarios, but often face issues with computational redundancy and difficulty in feature extraction when dealing with complex cable joint crimping tasks. In recent years, deep learning models based on convolutional neural networks (CNN), such as the YOLO (You Only Look Once) series networks, have achieved outstanding results in the field of target detection due to their efficient end-to-end training and real-time detection capabilities. Therefore, this paper selects YOLOv5 as the core algorithm, utilizing its efficient target detection performance and excellent real-time response capabilities to complete the detection and recognition of key features during the crimping process.

3.2 Dataset Construction and Annotation

In order to ensure the accuracy and diversity of the training data, 2000 cable images were preliminarily collected, and expanded to 8000 images by rotation, flip, and zoom. Using the self-developed annotation program to accurately map the image [6], to determine the five key points on the cable section, including the top, bottom and center points on both sides as shown in Figure 2. All annotation data are saved as txt file for the training use of YOLOv5.

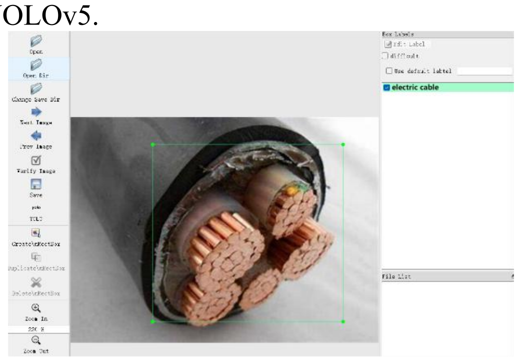

Figure 2. Annotated Cable Dataset

3.3 Optimization and Training of YOLOv5

YOLOv5 Compared with the previous generation model, it has higher accuracy and faster inference speed, [7]. During the training process, Mosaic data augmentation technology was adopted to crop, deform and splicing four random images to generate more diverse training samples, which improves the generalization ability of the network. In addition, the adaptive anchor frame calculation and adaptive image compression technology in YOLOv5 further optimize the performance of the model and ensure its efficient identification during the middle joint of the cable.

4. Camera Distortion Correction and Image Processing

Due to the manufacturing and installation process limitations of the camera lens, the radial distortion and the tangential distortion [8] often appear in the cable image, which affects the accuracy of the image as shown in Figure 3. The radial distortion makes the pixel size of the image center and the edge inconsistent, while the tangential distortion is caused by the lens is not completely parallel to the image plane. In order to improve the image quality, this paper uses Zhang's calibration method to calibration the camera and correct the image through the distortion correction function of OpenCV, which significantly improves the accuracy and availability of the image.

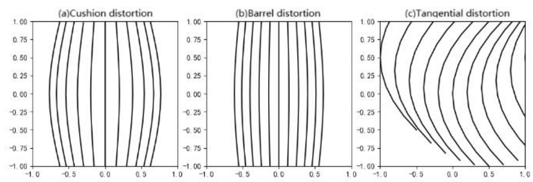

Figure 3. Camera Distortion Correction

5. Experiments and Results

5.1 Intelligent Decision-Making Model

During the crimp process, the AI model is not only used to detect the status of the middle cable interconnector, but also responsible for intelligent decision [9] based on real-time monitoring data. By analyzing the sensor data and visual information, the system can judge the abnormal situation in the crimping process and adjust the crimping parameters in time. For example, in the event of abnormal pressure or temperature fluctuations, the system can automatically adjust the pressure relay or suspend the operation to avoid the occurrence of unqualified joints.

In a complex manufacturing environment, the foreign body may affect the compression quality, so the system also integrates the foreign body detection function. Through real-time image analysis, the system can detect possible foreign bodies in the cable section, and timely send out alarm information for operators to process. This function effectively improves the robustness and adaptive ability of the system.

5.2 Evaluation and Testing

After completing the training of the YOLOv5 model, we extensively test and evaluate the model as shown in Figure 4. The results show that the mAP (mean Average Precision) value of the trained model is stable above 0.98, and the precision (Precision) and recall (Recall) [10] are 0.89 and 0.98, respectively, indicating that the model can efficiently and accurately identify the key features of the cable intermediate connector and meet the requirements of high precision compression.

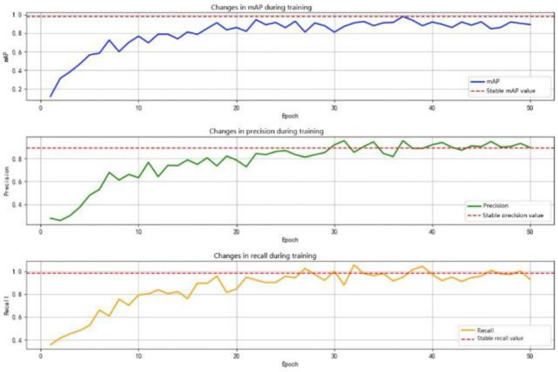

Figure 4. Training Process

By integrating the optimized AI model with sensor data, the automatic crimping system of this study demonstrated outstanding performance in practical applications. The system can provide real-time feedback on the status of the crimping process and automatically adjust crimping parameters based on detection results to ensure that each joint meets quality standards.

6. Conclusion

The high-precision automatic crimping technology for cable joints based on multi-sensor and AI assistance, proposed in this paper, successfully addresses the instability issues of traditional manual crimping. Through the combination of deep learning algorithms and intelligent decision-making systems, key parameters during the crimping process can be monitored and adjusted in real-time, ensuring the stability and high precision of crimping quality. In the future, with the continuous development and optimization of technology, this system is expected to be applied in a broader range of intelligent manufacturing fields.

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