Convolutional Autoencoder for Unsupervised Defect Detection in Brake Calipers

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Thesis Purpose and Research Area Description

This thesis aims to develop and evaluate an automatic defect detection system for brake calipers using advanced techniques in computer vision and machine learning. The primary goal is to provide a reliable and efficient method for identifying and classifying defects on brake calipers, thereby improving the quality and reliability of quality control in industrial production.

The research focuses on the application of computer vision and machine learning techniques to analyze images of brake calipers to detect and characterize various types of defects, such as bubbles, scratches, or surface deformations. By employing sophisticated image processing algorithms and machine learning models, the proposed system aims to automate the inspection process and identify defects with high precision and timeliness. Image analysis is performed considering variations in lighting, perspective, and environmental conditions to ensure the robustness and reliability of the system under diverse operational conditions. The ultimate objective is to develop a defect detection system capable of improving the efficiency and accuracy of industrial quality control, thereby reducing costs and production times.

Personal Contribution

Throughout the course of this research effort, several personal contributions have been made, culminating in significant achievements in the domain of automated brake caliper defect detection.

- Algorithmic Innovation: Novel algorithms have been devised and implemented for defect detection, using advances in convolutional neural networks (CNNs), image processing, and feature extraction. These algorithms were tailored specifically to address the challenges inherent in the detection and classification of brake caliper defects, demonstrating creativity and ingenuity in algorithm design. Two main algorithms were developed: one dedicated to searching for defective clusters combined across multiple photos of the same caliper at varying brightness levels, while the other algorithm relies on the combination of the SSIM (Structural Similarity Index Measure) function and clustering method to select among the candidate defects the ones that require specific attention.

- Custom Preprocessing Techniques: Custom preprocessing techniques were developed to enhance the performance and robustness of the defect detection system. These techniques encompassed image enhancement, noise reduction, and feature normalization, effectively preparing the input data for more accurate defect detection.

- Evaluation Metric Formulation: Robust evaluation metrics were formulated to assess the accuracy and reliability of the defect detection system. These metrics provided comprehensive insights into the performance of the system across various types of defects, lighting conditions, and surface geometries, facilitating rigorous evaluation and validation.

- Data Collection and Curation: Extensive efforts were dedicated to collecting, annotating, and curating high-quality datasets for training and validation purposes. This meticulous data collection process ensured the availability of diverse and representative samples, essential for training a robust defect detection model.

- Development of User-Friendly Interfaces: User-friendly interfaces and dashboards were developed for the defect detection system, enabling seamless interaction with operators and production personnel. These interfaces provided intuitive visualization of defect detection results, actionable insights, and streamlined workflow management, improving user experience and productivity.

Achieved Results

- Practical Utility: Extensive validation experiments conducted under real-world conditions validated the practical utility and reliability of the defect detection system. In particular, while real-time testing yielded some results that were not entirely positive, ensuring more stable physical conditions improves the adaptability of the approach across different contexts and can yield significant outcomes.

- Enhanced Productivity and Quality: The integration of the defect detection system into industrial production lines holds the promise of improving productivity and product quality. By automating the inspection process and detecting defects with high precision and efficiency, the system contributes to streamlining manufacturing operations and reducing costly errors.

- Cost Reduction: Implementing the defect detection system leads to a significant reduction in operational costs associated with undetected defects during production. By minimizing the number of defective products, the system helps optimize resource utilization and reduce waste, resulting in tangible savings for the company.

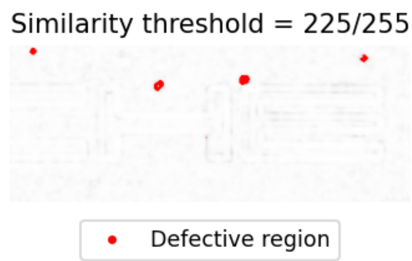
- Adaptability to Various Applications: The flexibility and adaptability of the system allow its application in a wide range of industrial contexts beyond the automotive sector. The same infrastructure and algorithms can be easily adapted and implemented for defect detection in other mechanical components or metal structures, thus expanding the potential impact of the system.

- Future Prospects: The achievements and advances made in this research lay the foundation for future developments and innovations in automated defect detection. Continued research efforts will focus on further refining the system, exploring new avenues for improvement, and advancing the state of the art in industrial quality control.

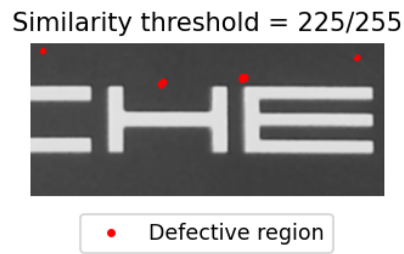
(a) Cropped, grayscale image of a defective caliper logo acquired during testing, with applied blurring.

(b) Image reconstruction of Figure 1a through the autoencoder during testing.

Figure 1: Autoencoder's inference process, displaying both the original and reconstructed images. Defects present in the original image are absent in the reconstruction. Defect detection method is based on the differences between these two images.

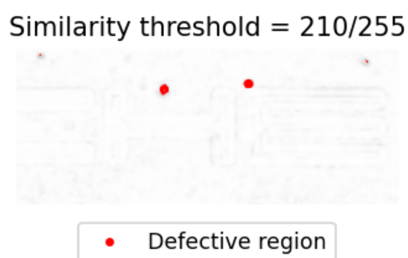


(a) Similarity map computed between the images in Figure 1a and in Figure 1b.

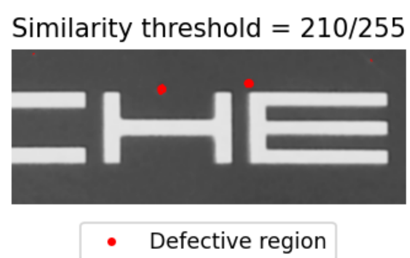


(b) Red pixels overlaid on the acquired image, highlighting potential defects.

Figure 2: In red are pixels with a Structural Similarity Index (SSIM) of 225 or less out of 255, indicating potential candidates for defects.

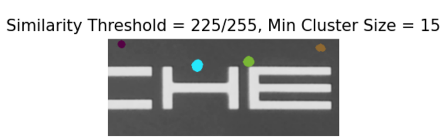


(a) Similarity map computed between the images in Figure 1a and in Figure 1b.



(b) Red pixels overlaid on the acquired image, highlighting potential defects.

Figure 3: In red are pixels with a Structural Similarity Index (SSIM) of 210 or less out of 255, indicating potential candidates for defects.



(a) Minimum cluster size of 15 pixels consolidates previously identified potential defect pixels (Figure 2) into coherent defective clusters.

(b) Minimum cluster size of 25 pixels excludes some previously identified potential defect pixels (Figure 3) from coherent defective clusters.

Figure 4: Detected defects using the DBSCAN clustering algorithm, where each color represents a different cluster, and the size of each cluster represents the size of the corresponding defect.

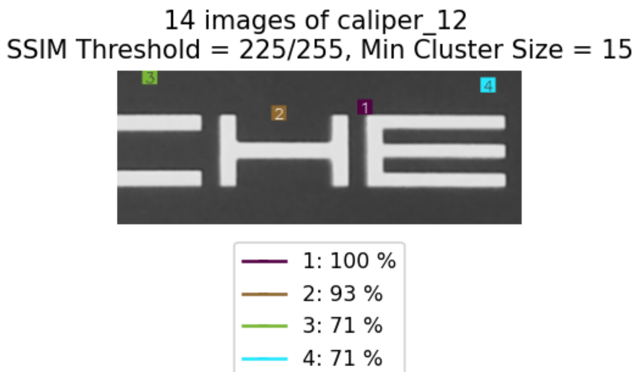


Figure 5: Evidence derived from 14 images of the same caliper, acquired under varying lighting conditions. Potential defective pixels are identified across all 14 images if their similarity index is equal to or less than 225. Moreover, only clusters with a minimum size of 15 pixels are considered. Each defective cluster detected across the images is represented as a percentage of appearance, indicating the proportion of images in which it appeared. For instance, a cluster identified in 93% of the images signifies its presence in 13 out of 14 images.