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APPLICATION OF A DEEP LEARNING-BASED AUTOMATED VISUAL INSPECTION SYSTEM FOR AUTOMOTIVE BUMPER DEFECT DETECTION

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Abstract. This article addresses the development of a Deep Learning-based automated visual inspection system for detecting defects on automotive bumper surfaces. The study analyzes the growing importance of quality control automation in the automotive industry, the limitations of traditional inspection methods, and the potential of computer vision technologies in this domain. Within the scope of the research, a YOLO-based approach is proposed for processing automotive bumper images, detecting defects, and classifying them. The proposed methodology includes the stages of dataset creation, image preprocessing, data augmentation, model training, and performance evaluation. The research aims to establish a theoretical foundation for the development of a practical scientific solution that enables the automation of automotive bumper quality inspection, reduces the influence of human factors, and improves defect detection accuracy.

Keywords: Deep Learning, computer vision, automated visual inspection, automotive bumpers, defect detection, artificial intelligence, YOLO, quality control, object detection, machine learning, automotive industry.

Introduction. In recent years, the automotive industry has witnessed a rapid adoption of digital technologies aimed at improving product quality and manufacturing efficiency. In particular, the automation of quality control processes on production lines, the reduction of human-related errors, and the acceleration of defect detection have become critical objectives. Automotive exterior components, especially bumpers, are among the key parts that directly influence both the aesthetic appearance and safety characteristics of a vehicle. Therefore, the timely detection of scratches, cracks, deformations, paint coating defects, and other manufacturing imperfections on bumper surfaces is of great importance.

In traditional quality control processes, defect inspection is primarily performed by human operators. However, this approach is often inefficient in large-scale manufacturing environments due to its high time consumption, errors caused by operator fatigue, and subjective assessment factors [1]. The adoption of automated optical inspection systems in industrial enterprises has provided an effective solution to these challenges. In particular, advances in computer vision and artificial intelligence technologies have enabled the development of new methods for automated defect detection.

Deep Learning technologies, especially Convolutional Neural Networks (CNNs) and models such as YOLO (You Only Look Once), Mask R-CNN, and U-Net, have demonstrated remarkable performance in detecting defects in industrial products [2]. Previous studies have shown that deep learning algorithms significantly outperform conventional image processing techniques in identifying complex textures, varying illumination conditions, and defects with diverse shapes and characteristics [3].

A study conducted by Ma et al. analyzed the effectiveness of deep neural networks for surface defect detection in industrial products and demonstrated that Deep Learning methods have become a fundamental technology in modern quality inspection systems [4]. Similarly, Gao et al. proposed a YOLO-based model for detecting defects on steel surfaces and achieved high accuracy in industrial production environments [5]. Furthermore, the YOLOv7 model developed by Huang and Zhu for

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defect detection in automotive components demonstrated superior performance compared with traditional algorithms, particularly in identifying defects of various sizes [6].

Research on the automation of visual inspection processes in the automotive industry has also confirmed the potential of Deep Learning technologies. Mazzetto et al. demonstrated the effectiveness of deep learning models in tasks such as object detection, semantic segmentation, and anomaly detection within automotive assembly lines [7]. However, most existing studies focus on general automotive components, while the specific problem of defect detection in plastic automotive bumpers remains insufficiently explored.

Moreover, the development of automated inspection systems faces several challenges, including variations in lighting conditions, differences in defect sizes and shapes, and the limited availability of defective samples in industrial environments. Therefore, the development of Deep Learning-based automated visual inspection systems capable of achieving high detection accuracy and real-time performance remains a significant scientific and practical challenge.

Materials and methods. This study proposes the development of a Deep Learning-based automated visual inspection system for detecting defects in automotive bumpers. The proposed system is designed to automatically detect and classify defects from images using computer vision algorithms. The primary objective of the research is to minimize human involvement in the quality control process while improving the accuracy of defect detection.

The first stage of the proposed system involves the collection of automotive bumper images and the creation of a comprehensive dataset. The dataset is intended to include both defective and non-defective samples. Acquiring images under various lighting conditions and from different viewing angles is expected to improve the model's generalization capability and robustness in real-world manufacturing environments.

In the next stage, the collected images undergo preprocessing procedures. These procedures include image size standardization, noise reduction, and the application of data augmentation techniques. Previous studies have demonstrated that data augmentation plays a significant role in improving neural network training performance and reducing the risk of overfitting.

For defect detection, the YOLO (You Only Look Once) architecture is proposed as the core model. YOLO performs object detection and localization within a single neural network framework, enabling real-time operation. Recent research has shown that models from the YOLO family achieve high performance in detecting surface defects in industrial products, making them suitable for automated inspection tasks.

Subsequently, the dataset is divided into training, validation, and testing subsets. During the training process, model parameters are optimized to identify the configuration that provides the best performance. The effectiveness of the model is planned to be evaluated using widely accepted performance metrics, including Precision, Recall, F1-score, and mean Average Precision (mAP).

The overall workflow of the proposed methodology consists of the following stages:

1. Collection of automotive bumper images;
2. Image preprocessing;
3. Defect annotation and labeling;
4. Training of a YOLO-based detection model;
5. Evaluation of the model using test data;
6. Automated defect detection and visualization;
7. Analysis of the obtained results.

The proposed approach is expected to contribute to the automation of quality control processes in automotive manufacturing by reducing inspection time and improving defect detection accuracy.

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Furthermore, the outcomes of this research may provide a scientific and practical foundation for the broader adoption of artificial intelligence technologies in the automotive industry and support the development of recommendations for intelligent quality inspection systems.

Results and Discussion

As a result of this study, a conceptual framework for a Deep Learning-based automated visual inspection system for detecting defects on automotive bumper surfaces is expected to be developed. The proposed system has the potential to improve the automation of quality control processes in the automotive industry and enhance inspection efficiency.

The research is intended to investigate the capabilities of computer vision and deep learning technologies for detecting defects in automotive bumpers. In particular, the feasibility of employing a YOLO-based model for identifying scratches, cracks, deformations, and paint coating defects is planned to be explored.

A review of the existing literature indicates that although numerous studies have been conducted on defect detection in industrial products and automotive components, research specifically focused on automated inspection systems for plastic automotive bumpers remains relatively limited. Therefore, the scientific novelty of this work lies in proposing a Deep Learning-based visual inspection system concept specifically designed for defect detection on automotive bumper surfaces.

Based on the anticipated research outcomes, it is expected that the processes of automotive bumper image processing, defect detection, and defect classification can be integrated into a unified inspection framework. Such an approach may provide a theoretical foundation for implementing real-time quality control systems within automotive production lines.

Another important aspect of the proposed approach is its focus on reducing the influence of human factors and increasing the objectivity of defect assessment. The findings of this research may also serve as a methodological basis for future studies on the implementation of artificial intelligence technologies in the automotive industry, contributing to the development of more intelligent and efficient quality inspection systems.

Conclusion. Quality control in the automotive industry is one of the key factors in ensuring manufacturing efficiency and product reliability. Modern computer vision and Deep Learning technologies provide extensive opportunities for automating quality inspection processes and improving their effectiveness.

This article presented the concept of a Deep Learning-based automated visual inspection system for detecting defects in automotive bumpers. Based on the review of the scientific literature, it was found that modern neural network architectures, particularly YOLO, demonstrate high effectiveness in detecting defects in industrial products. The proposed methodology can serve as a foundation for the future development of a practical system for automating quality control of automotive bumpers.

Future research will focus on the creation of a comprehensive dataset of automotive bumper images, the training of the proposed model, and the evaluation of its performance through experimental testing. Such studies are expected to validate the effectiveness of the proposed approach and contribute to the broader adoption of artificial intelligence technologies in automotive manufacturing quality control.

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