
AI-Driven Vision-Guided Robotic Arm for Real-Time Defect Detection in Smart Manufacturing

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Abstract.

Manual quality inspection is time-consuming and may miss small defects due to worker fatigue. This study proposes an automated inspection and sorting system using a camera, YOLO, CNN, CFNN, and robotic arm. The camera captures product images, YOLO detects object locations, and CNN identifies defects. CFNN classifies products as acceptable or defective, after which the robotic arm sorts them accordingly. Testing showed faster and more reliable inspection than manual methods, reducing human error, improving sorting efficiency, and supporting consistent product quality.

Keywords. Defect Detection, Robotic Arm, Computer Vision, Industrial Automation, Smart Manufacturing.

1. INTRODUCTION

Industry 4.0 has transformed manufacturing through automation, artificial intelligence (AI), robotics, connected sensors, and data-driven decision-making. Automated quality inspection is increasingly important because manual inspection is time-consuming, labor-intensive, and susceptible to fatigue and human error. Small defects such as cracks, scratches, dents, and surface marks may therefore remain undetected, affecting product quality and customer satisfaction [1-5]. Computer vision and deep learning provide effective solutions by enabling automated detection and classification of manufacturing defects. YOLO can locate products in real time, while Convolutional Neural Networks (CNNs) extract visual features for defect identification. A Convolutional Fuzzy Neural Network (CFNN) can further improve classification by handling complex defect patterns. However, integrating vision-based detection, deep learning, and robotic sorting into a unified system remains challenging [6-10]. This study proposes an AI-powered robotic inspection system that combines YOLO, CNN, and CFNN with a robotic arm for automated defect detection and sorting, aiming to improve inspection accuracy, reduce manual effort, and enhance production efficiency [11-14].



Fig.1.1 Structure of Robotic Arm

2. RELATED WORK

Recent studies have demonstrated the growing application of deep learning, computer vision, and robotics for automated manufacturing inspection. In 2025, a study proposed an improved VGG16 model for detecting manufacturing defects such as cracks and scratches. The model showed improved performance under varying lighting conditions and outperformed traditional inspection approaches [1]. Lin et al. (2024) developed a vision-based robotic arm for real-time defect detection and object classification using YOLO. Their system successfully detected and sorted products on production lines, demonstrating its potential for industrial applications [2]. Keshvarparast et al. (2023) reviewed collaborative robots in manufacturing and assembly, highlighting their benefits in safety, flexibility, and human-robot collaboration, while emphasizing the need for advanced sensing and learning capabilities [3]. Santos et al. (2024) developed a camera-guided robotic pick-and-place system capable of accurately locating and handling objects despite positional variations [4]. Similarly, Kim and Park (2023) proposed a vision-based inspection system that automatically detects surface defects during manufacturing [5]. These studies demonstrate significant progress in automated inspection and robotic systems; however, integrated systems combining YOLO-based detection, CNN-based feature extraction, CFNN classification, and automated robotic sorting remain limited.

3. METHOD, EXPERIMENTS AND RESULTS

3.1. Proposed Method

The proposed system automatically inspects products on a production line and separates defective products using computer vision and a robotic arm. An Arducam 8MP camera captures product images, which are preprocessed through noise removal, enhancement, and resizing. YOLO detects and localizes the product, after which a CNN extracts visual features and identifies defects such as cracks, scratches, dents, and damaged areas. The extracted features are classified by a Convolutional Fuzzy Neural Network (CFNN) as OK (normal) or NOK (defective). Based on the classification result, the robotic arm automatically sorts acceptable and defective products. Figure 1 illustrates the complete inspection and sorting workflow.

The experimental setup included an Arducam 8MP camera, Arduino Mega 2560, serial bus driver board, servo-motor robotic arm, and GPU-enabled laptop. Python, OpenCV, YOLO,

CNN, CFNN, and Arduino IDE were used for system development and processing. The dataset contained industrial component images categorized into OK and NOK classes and was divided into training and validation sets for model development and performance evaluation.

3.2. Experimental Results

The experiments demonstrated effective automatic quality inspection and classification. Training and validation accuracy increased gradually across epochs, indicating successful learning of defect patterns with minimal overfitting. Figure 3.2.1 presents the accuracy trends of the proposed system. The dataset analysis further showed that products were correctly classified into OK and NOK categories. As shown in Figure, most samples belonged to the OK class, while fewer were classified as NOK, confirming the system's ability to distinguish acceptable and defective products.

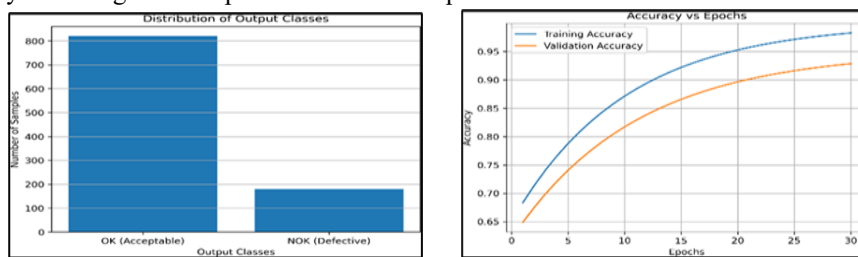


Fig. 3.2.1. Accuracy vs. epochs, Distribution of Output Classes

The combined YOLO, CNN, and CFNN approach improved defect detection and automated sorting. YOLO localized products, CNN identified surface defects, and CFNN classified them as acceptable or defective. The robotic arm then sorted products accordingly. The proposed system reduces manual inspection effort and human error while improving inspection accuracy and production efficiency. Integrating AI-based vision with robotic automation supports reliable quality control and demonstrates the practical potential of Industry 4.0.

4. CONCLUSION

Manual defect inspection really drags down the speed of manufacturing and, let's be honest, people make mistakes. This project aims to change that by building an automated quality control system that's actually smart. So, what's under the hood? It's a blend of computer vision, deep learning, and robotics all working together. The system uses YOLO to spot objects, CNNs to pull out important details, and CFNNs to figure out what kind of defect it's looking at.

5. REFERENCES

- [1] A. Baiganova, Z. Ubayeva, Z. Taskalyeva, and S. B. Nurgaliyev, "Automated Defect Detection in Manufacturing Utilizing Enhanced VGG16 Convolutional Neural Networks," *International Journal of Advanced Computer Science and Applications*, vol. 16, no. 1, pp. 102–110, 2025.

- [2] C. J. Lin, J. Y. Jhang, Y. J. Gao, and H. MHuang, "Vision-Based Robotic Arm in Defect Detection and Object Classification Applications," *Sensors and Materials*, vol. 36, no. 2, pp. 421–436, 2024.
- [3] A. Keshvarparast, D. Battini, O. Battaia, and A. Pirayesh, "Collaborative Robots in Manufacturing and Assembly Systems: Literature Review and Future Research Agenda," *Journal of Intelligent Manufacturing*, vol. 35, pp. 2065–2118, 2024.
- [4] A. A. Santos, C. Schreurs, and A. Ferreira da Silva, "Combining Artificial Vision and Image Processing into a Pick-and-Place Collaborative Robotic System," *Journal of Intelligent Robotic Systems*, vol. 110, no. 2, pp. 1–14, 2024.
- [5] S. W. Kim and H. J. Park, "Machine Vision-Based Defect Detection in Smart Manufacturing Using Deep Learning," *IEEE Access*, vol. 11, pp. 28741–28752, 2023.
- [6] A. Gupta and S. Patel, "Computer Vision-Based Automated Defect Detection System for Industrial Applications," *IEEE Access*, vol. 12, pp. 21011–21022, 2024.
- [7] V. D. Cong, L. D. Hanh, and L. Phuong, "Design and Development of Robot Arm System for Classification and Sorting Using Machine Vision," *FME Transactions*, vol. 50, no. 3, pp. 455–463, 2022.
- [8] S. Zhang, Y. Chen, and H. Li, "Smart Manufacturing Inspection Using Artificial Intelligence and Robotics," *IEEE Transactions on Industrial Informatics*, vol. 20, no. 1, pp. 211–220, 2024.
- [9] Y. Liu, J. Zhang, and Z. Li, "Real-Time Industrial Surface Defect Detection Using Deep Learning Networks," *IEEE Transactions on Industrial Informatics*, vol. 19, no. 2, pp. 1285–1294, 2023.
- [10] S. Chen and Y. Liu, "AI-Based Visual Inspection System for Smart Manufacturing," *IEEE Transactions on Automation Science and Engineering*, vol. 20, no. 4, pp. 2175–2186, 2023.
- [11] P. Kumar and M. Verma, "AI-Based Industrial Defect Detection and Robotic Sorting System for Smart Factories," *IEEE Access*, vol. 13, pp. 41200–41212, 2025.
- [12] M. Javaid, A. Haleem, R. P. Singh, and R. Suman, "Industry 4.0 Technologies and Their Applications in Manufacturing: A Review," *IEEE Access*, vol. 10, pp. 119602–119620, 2022.
- [13] G. Aceto, V. Persico, and A. Pescapé, "Industry 4.0 and Smart Manufacturing: A Review of Research Issues and Applications," *IEEE Internet of Things Journal*, vol. 9, no. 5, pp. 3211–3224, 2022.
- [14] V. T. Nguyen, P. T. Nguyen, and S. F. Su, "Vision-Based Pick-and-Place Control System for Industrial Robots Using an Eye-in-Hand Camera," *IEEE Access*, vol. 13, pp. 12845–12858, 2025.

Biographies



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