A Novel Hybrid YOLO Approach for Precise Paper Defect Detection With a Dual-Layer Template and an Attention Mechanism

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INTRODUCTION

Printed products, encompassing newspapers, books, magazines, reports, documents, and packaging, hold significant importance in both individuals' daily lives and professional endeavors. However, the production process of paper printing is susceptible to the emergence of surface imperfections on these materials, which can arise from external environmental pollution, equipment contamination, and mishandling by printing personnel. These flaws have the potential to compromise the overall quality, user experience, and visual allure of the paper, consequently diminishing its economic worth. Therefore, the detection of paper defects assumes a vital role in the papermaking process.

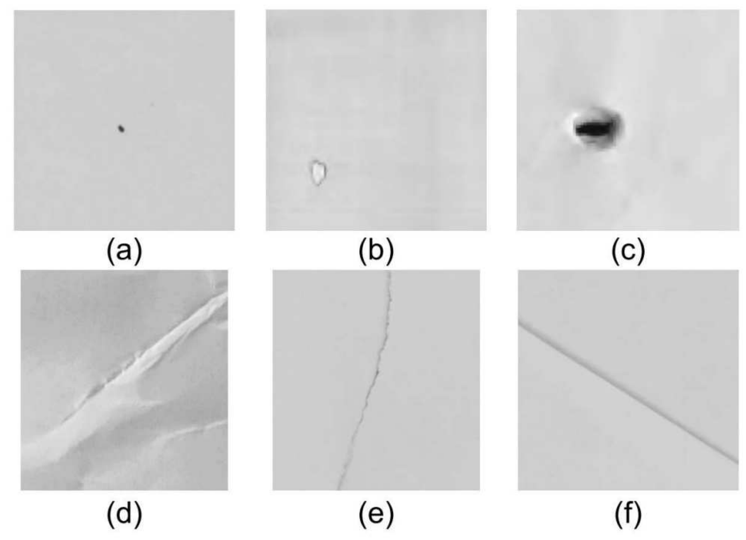

Fig. 1. Various degrees of surface defects. (a) Black spot. (b) Bright spot. (c) Hole. (d) Wrinkle. (e) Crack. (f) Block.

METHOD

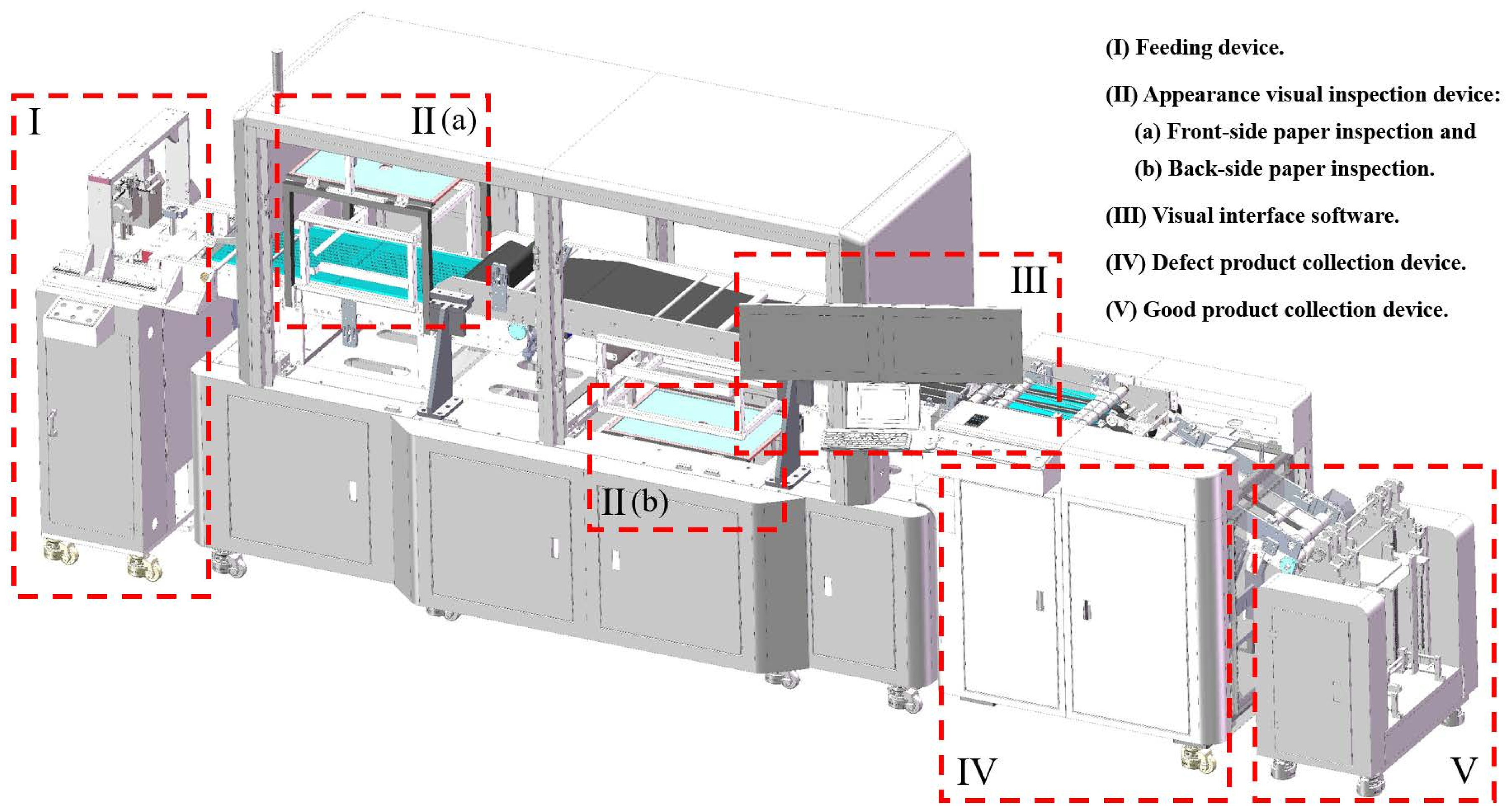

Fig. 2. Paper defect detection system.

A novel system, combining dual-layer templates and attention mechanisms, is proposed in this research for the visual inspection of paper products, aiming to effectively address surface defects encountered in print production. This device ensures the uniform presentation of the paper sheets upon their departure from the manufacturing facility. Its constituents encompass a framework, a feeding device, a primary conveyor platform, a secondary conveyor platform, a tertiary conveyor platform, an appearance visual inspection device, a waste removal mechanism, and a collection unit, as depicted in Fig. 2. By employing this equipment, the automated scrutiny and manipulation of the visual characteristics of individual paper sheets can be efficiently accomplished, thereby augmenting both production efficiency and standards of quality.

RESULTS

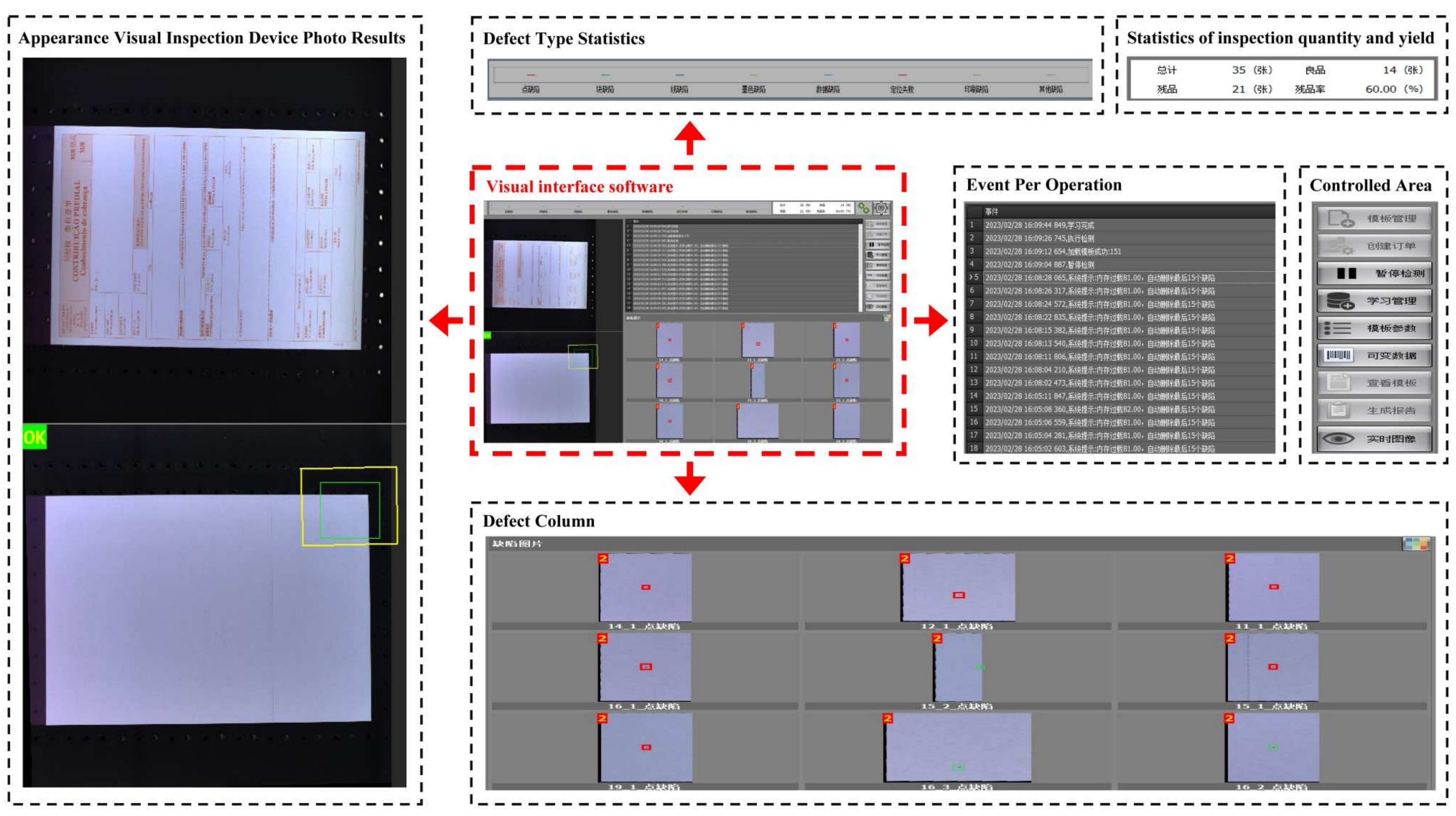

Fig. 3. Visual interface software verification.

This flexibility enables the system to meet diverse paper production needs and offer customized detection solutions. For instance, the interface can be set to halt operations automatically once 100,000 satisfactory sheets are produced, optimizing workflow and efficiency, as shown in Fig. 4. Testing over 100,000 newly printed sheets revealed that, out of 101,523 inspected, 100,000 met quality standards, while 1,523 were substandard. High-resolution defects like holes, wrinkles, cracks, and blocks, which occupy more target pixels, achieved 100% recognition accuracy, while black spots and bright spots reached 96.97% and 98.86%, respectively.

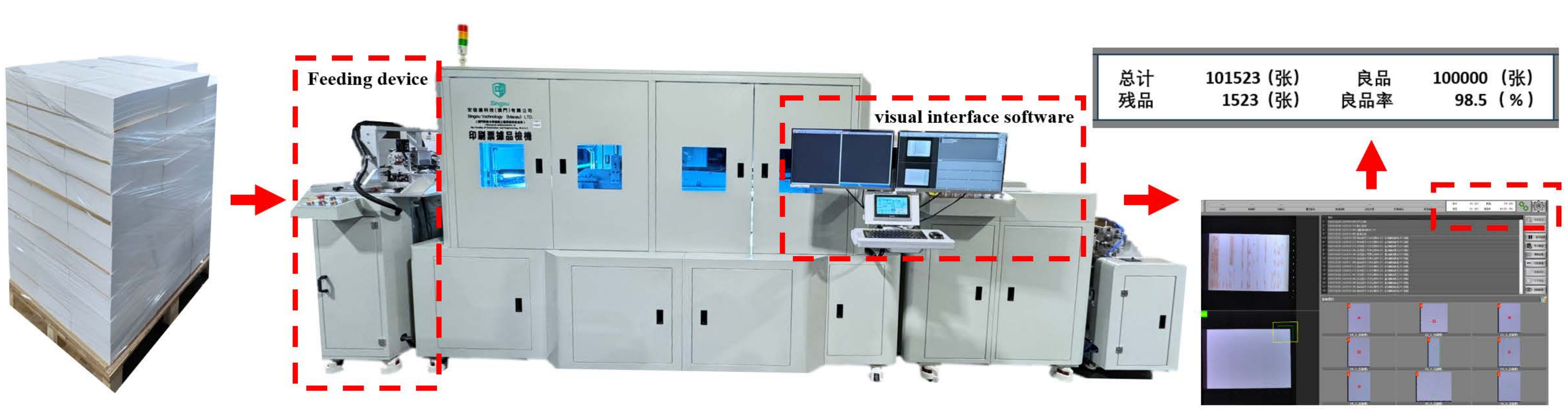

Fig. 4. Completing the inspection process for the collection of 100 000 good products.

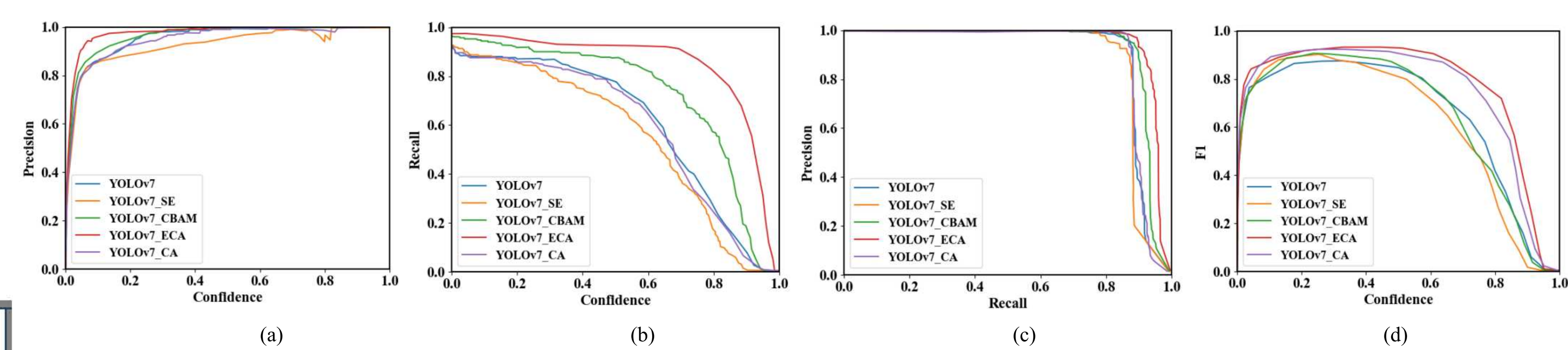

Fig. 5. Effect of attention mechanism on model. (a) Precision curve. (b) Recall curve. (c) Precision–recall curve. (d) F1-score curve.

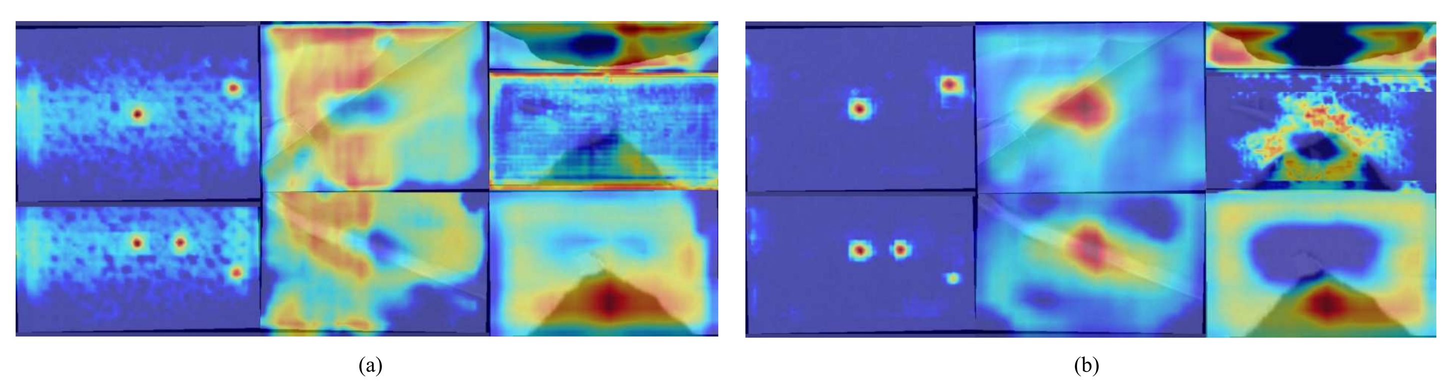

Fig. 6. Comparison of YOLOv7 Heat Maps: Before and After Improvement.

CONCLUSION

A novel system integrating dual-layer templates and attention mechanisms is proposed for paper product inspection, effectively addressing surface defects in print production. A visual interface provides a customized defect detection solution, enabling automatic flaw detection and removal to enhance efficiency and reduce labor costs. To address the limited field of view of array cameras for large paper sizes, a synergistic approach with controllers and paper detection sensors is introduced. By matching template images and leveraging an enhanced YOLO algorithm, the system significantly improves detection accuracy and speed. Ablation experiments show an average precision of 95.2%, a 7.9% improvement over the original algorithm.

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X. Li, H. Yan, K. Cui, Z. Li, R. Liu, G. Lu, K. C. Hsieh, X. Liu and C. Hon, "A Novel Hybrid YOLO Approach for Precise Paper Defect Detection With a Dual-Layer Template and an Attention Mechanism," **IEEE Sensors Journal**, vol. 24, no. 7, pp. 11651-11669, April, 2024. DOI: 10.1109/JSEN.2024.3356356. (Q1)