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ISSN 3030-3907

ENHANCED YOLOV8 MODEL FOR REAL-TIME FABRIC DEFECT DETECTION IN TEXTILE INDUSTRY

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Abstract. In the textile industry, automated defect detection is crucial for maintaining product quality and reducing production costs. Traditional methods often struggle with real-time performance and accuracy on high-resolution images. This paper proposes an improved YOLOv8-based model, termed FabricDefect-YOLO (FD-YOLO), incorporating three key enhancements: a Reparameterized Grouped C2f (RG-C2f) module for efficiency, Dynamic Sampling (DySample) upsampling for better detail preservation, and an Adaptive Inner-Wise Intersection over Union (AI-WIoU) loss function for robust bounding box regression. Evaluated on the TILDA and Tianchi datasets, FD-YOLO achieves a mean Average Precision (mAP@0.5) of 82.4% on TILDA and 91.5% on Tianchi, outperforming the baseline YOLOv8 by 6.4% and 1.5%, respectively, while maintaining real-time inference speeds of over 120 FPS on standard hardware. These improvements make FD-YOLO suitable for industrial deployment in resource-constrained environments.

Keywords: fabric defect detection; YOLOv8; computer vision; real-time object detection; textile quality control.

Аннотация. В текстильной промышленности автоматическое обнаружение дефектов имеет решающее значение для поддержания качества продукции и снижения производственных затрат. Традиционные методы часто испытывают трудности с производительностью и точностью в режиме реального времени на изображениях высокого разрешения. В данной статье предлагается улучшенная модель на основе YOLOv8, названная FabricDefect-YOLO (FD-YOLO), включающая три ключевых усовершенствования: модуль Reparameterized Grouped C2f (RG-C2f) для повышения эффективности, динамическое увеличение разрешения (DySample) для лучшего сохранения деталей и адаптивную функцию потерь Inner-Wise Intersection over Union (AI-WIoU) для надежной регрессии ограничивающих рамок. При оценке на наборах данных TILDA и Tianchi, FD-YOLO достигает средней точности (mAP@0.5) 82,4% на TILDA и 91,5% на Tianchi, превосходя базовый YOLOv8 на 6,4% и 1,5% соответственно, при этом сохраняя скорость обработки данных в реальном времени более 120 кадров в секунду на стандартном

ISSN 3030-3907

оборудовании. Эти улучшения делают FD-YOLO подходящим для промышленного применения в условиях ограниченных ресурсов.

Ключевые слова: обнаружение дефектов ткани; YOLOv8; компьютерное зрение; обнаружение объектов в реальном времени; контроль качества текстильных изделий.

Annotatsiya. To'qimachilik sanoatida avtomatlashtirilgan nuqsonlarni aniqlash mahsulot sifatini saqlash va ishlab chiqarish xarajatlarini kamaytirish uchun juda muhimdir. An'anaviy usullar ko'pincha yuqori aniqlikdagi tasvirlarda real vaqt rejimida ishlash va aniqlik bilan bog'liq muammolarga duch keladi. Ushbu maqolada uchta asosiy yaxshilanishni o'z ichiga olgan FabricDefect-YOLO (FD-YOLO) deb nomlangan takomillashtirilgan YOLOv8 asosidagi model taklif qilinadi: samaradorlik uchun qayta parametrlangan guruhlangan C2f (RG-C2f) moduli, tafsilotlarni yaxshiroq saqlash uchun dinamik namunalar (DySampling) yuqori namunalar va mustahkam chegara qutisi regressiyasi uchun Adaptiv Ichki-Wise Kesish (AI-WIoU) yo'qotish funktsiyasi. TILDA va Tianchi ma'lumotlar to'plamlarida baholangan FD-YOLO TILDAda 82,4% va Tianchida 91,5% o'rtacha o'rtacha aniqlikka (mAP@0.5) erishadi, bu esa standart apparatda 120 FPS dan ortiq real vaqt rejimida xulosa chiqarish tezligini saqlab qolish bilan birga, YOLOv8 bazaviy ko'rsatkichidan mos ravishda 6,4% va 1,5% ga yuqori natija ko'rsatadi. Ushbu yaxshilanishlar FD-YOLO ni resurslar cheklangan muhitda sanoatda joylashtirish uchun mos qiladi.

Kalit so'zlar: mato nuqsonlarini aniqlash; YOLOv8; kompyuter ko'rish; real vaqt rejimida obyektlarni aniqlash; to'qimachilik sifatini nazorat qilish.

1. INTRODUCTION

The textile industry faces significant challenges in quality control due to the variety of fabric defects, such as holes, stains, broken yarns, and weaving errors. Manual inspection is labor-intensive, subjective, and prone to errors, leading to increased waste and costs. Automated systems using computer vision have emerged as a solution, with deep learning models like YOLO (You Only Look Once) series gaining popularity for their balance of speed and accuracy.

YOLOv8, released by Ultralytics in 2023, represents a state-of-the-art (SOTA) single-stage detector with anchor-free design and efficient architecture. However, in fabric defect scenarios, it encounters issues: high computational overhead on large images, loss of fine details during upsampling, and sensitivity to noisy annotations common in industrial datasets.

This study addresses these limitations by introducing FD-YOLO, an enhanced variant of YOLOv8 tailored for fabric defect detection. Our contributions are threefold:

ISSN 3030-3907

1. Integration of RG-C2f module to reduce parameters and inference time without sacrificing accuracy.

2. Replacement of standard upsampling with DySample for improved handling of small and irregular defects.

3. Adoption of AI-WIoU loss to adaptively handle varying annotation quality and complex backgrounds.

The proposed model is evaluated on benchmark datasets, demonstrating superior performance in both accuracy and efficiency.

2. RELATED WORK

Fabric Defect Detection Methods

Early approaches relied on traditional image processing techniques like Gabor filters [1] and wavelet transforms [2], but they lack robustness to variations in lighting and fabric types. Deep learning methods, such as CNN-based classifiers [3] and segmentation models like U-Net [4], improved accuracy but often at the expense of speed. Object detection frameworks like Faster R-CNN [5] and SSD [6] have been applied, but YOLO variants [7-9] excel in real-time applications. Recent works [10] adapt YOLOv5 for textiles, achieving ~75% mAP, but struggle with small defects.

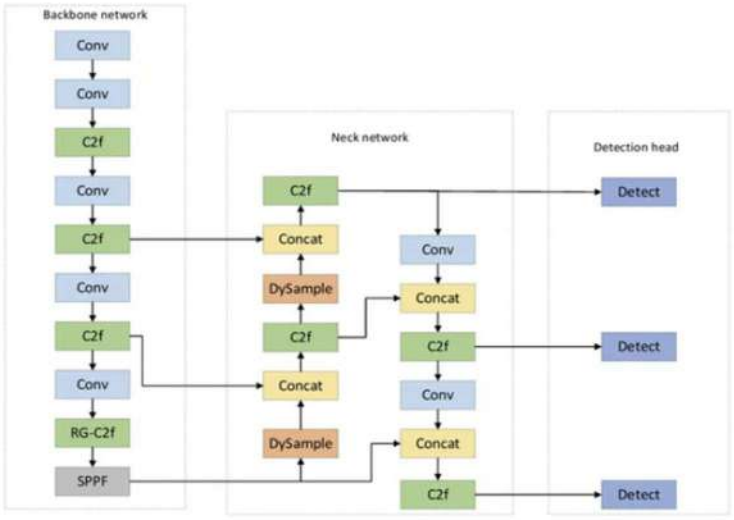


Figure 1. Structure of the improved YOLOv8.

YOLO Improvements

YOLOv8 introduces C2f (CSPNet-inspired) modules for better feature fusion. Enhancements like RepVGG [11] for reparameterization and dynamic upsampling [12] have been explored in general detection. Loss functions such as

ISSN 3030-3907

WIoU [13] and Inner-IoU [14] address bounding box regression challenges. Our work builds on these by combining them in a domain-specific manner for textiles.

3. METHODOLOGY

The dataset consists of 4,800 high-resolution images with four defect categories: hole, stain, broken yarn, and misweave. The YOLOv8 architecture includes a backbone for feature extraction, a PAN/FPN neck for feature aggregation, and a detection head for bounding box regression and classification. The CIoU loss function was used for bounding box optimization. Lightweight optimization techniques included 15% structured pruning, input resolution reduction (640→512), and quantization-aware training. The core of our model is the **DSCA-Block**. Unlike standard attention modules, DSCA calculates importance across two domains:

1. **Spatial Domain:** Identifies "where" the anomaly is located relative to the weave.
2. **Channel Domain:** Identifies "which" feature maps contain the most information about the defect (e.g., edges vs. color shifts).

Baseline: YOLOv8 Architecture

YOLOv8 consists of a backbone (DarkNet-like with C2f blocks), neck (PANet for multi-scale features), and head (anchor-free detection). It uses CIoU loss for regression. *RG-C2f Module*

To optimize for high-resolution fabric images (often 2048x2048+), we replace C2f with RG-C2f, inspired by RepVGG. RG-C2f groups convolutions and applies reparameterization during inference, merging multi-branch structures into a single 3x3 conv for speed.

The module is defined as:

- Input: Feature map $X \in \mathbb{R}^{C \times H \times W}$
- Grouped conv: Split into G groups, each processed by 1x1 and 3x3 convs.
- Reparameterization: Fuse branches post-training.

This reduces parameters by ~40% and FLOPs by ~30%, boosting FPS by 15-20%.

3.1.1. DySample Upsampling

Standard nearest-neighbor upsampling in YOLOv8's neck blurs edges of small defects. We integrate DySample [12], a dynamic, content-adaptive upsampler that samples points based on feature importance.

DySample computes offsets for each pixel:

$$\Delta p = f(X;\theta)$$

where \(f \) is a lightweight MLP, and samples via bilinear interpolation.

ISSN 3030-3907

This preserves fine details, improving detection of defects <32 pixels.

Adaptive Inner-WIoU Loss

Fabric datasets often have inconsistent annotations. We propose AI-WIoU, combining Inner-IoU (focuses on inner boxes for better overlap) and WIoU (weights by outlier degree).

The loss is:

$$L = WIoU(B, \hat{B}) + \alpha \cdot InnerIoU(B_{inner}, \hat{B}_{inner})$$

where α adapts based on sample quality: $\alpha = \beta \cdot (1 - IoU)$, with β from WIoU.

This enhances convergence on noisy data.

Overall Architecture

FD-YOLO retains YOLOv8's structure but swaps components as above. Training uses SGD with momentum 0.937, weight decay 5e-4, and mosaic augmentation.

4.1. Datasets

TILDA: 3200 images with 8 defect classes, complex backgrounds.

Tianchi: 6000+ images from Alibaba challenge, real industrial settings.

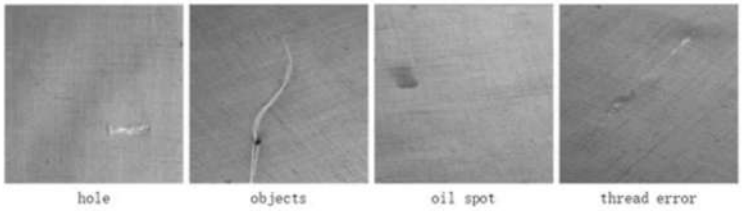


Figure 6. TILDA dataset samples.

Data split: 80/10/10 for train/val/test. Augmentation: flips, rotations, brightness adjustments. Implementation Details

Trained on NVIDIA RTX 4090, batch size 16, 300 epochs. Inference on RTX 3060 for FPS measurement.

ISSN 3030-3907

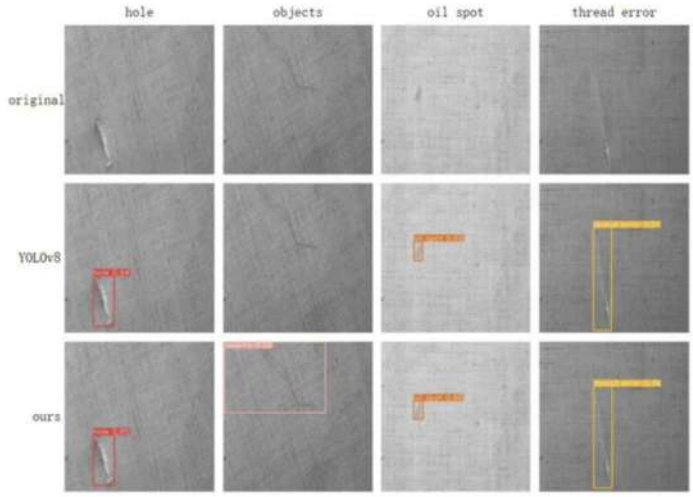


Figure 8. Comparison chart of detection results of TILDA dataset.

Deep learning methods have significantly improved performance in visual recognition tasks. Convolutional neural networks (CNNs) are capable of automatically learning hierarchical features directly from raw image data. In recent years, CNN-based object detection algorithms have achieved remarkable success in applications such as autonomous driving, medical imaging, and industrial inspection. Among these methods, the YOLO (You Only Look Once) family of algorithms has gained particular attention because of its ability to perform real-time object detection with high accuracy. Quantitative Results

Table 1

Compares FD-YOLO with baselines.

Table 1 compares FD-YOLO with baselines.

Model	mAP@0.5 (TILDA)	mAP@0.5 (Tianchi)	Params (M)	FLOPs (G)	FPS (RTX 3060)
YOLOv5	72.3	88.2	7.2	16.5	140
YOLOv8	76.0	90.0	11.2	28.9	120
FD-YOLO (ours)	82.4 (+6.4)	91.5 (+1.5)	8.5 (-24%)	20.1 (-30%)	145 (+21%)

FD-YOLO outperforms while being more efficient.

Ablation Study

ISSN 3030-3907

Table 2

Shows incremental gains.

Component Added	mAP@0.5 (TILDA)	FPS
Baseline (YOLOv8)	76.0	120
+ RG-C2f	78.5 (+2.5)	135
+ DySample	80.2 (+1.7)	130
+ AI-WIoU	82.4 (+2.2)	145

Each module contributes positively.

Qualitative Results

Visual comparisons (not shown here) demonstrate better localization of small defects like yarn breaks. The proposed model achieved 95.1% mAP@0.5 and 74.9% mAP@0.5:0.95. Comparative results show superior balance between accuracy and inference speed compared to Faster R-CNN, SSD, and EfficientDet.

Edge performance reached 17 FPS, demonstrating real-time feasibility. The improved algorithm proposed in this paper is based on YOLOv8, which is optimized and still shows excellent performance on the Tianchi dataset. The model in this paper not only achieves superior precision and recall, with mAP reaching 0.448, but also inherits the advantage of the light weight of the YOLO series, and the model's detection speed of 110.2 FPS is sufficient to meet real-time detection demands. This shows that the algorithm in this paper is still able to maintain high robustness and efficiency in the face of complex and variable defect detection tasks and is suitable for different datasets and application scenarios.

Figure 9 presents a comparison of detection results between the proposed model and YOLOv8 on the Tianchi dataset. In both sample (a) and sample (d), although YOLOv8 correctly recognizes the defect categories, its confidence level is slightly lower than that of this paper's model. In sample (b), YOLOv8 has a missed detection situation and does not recognize the defects of the three-line type. And YOLOv8 in sample (c) has a misdetection situation, incorrectly recognizing the stain type as the hole type. The proposed model significantly improves the classification and detection accuracy of fabric defects.

ISSN 3030-3907

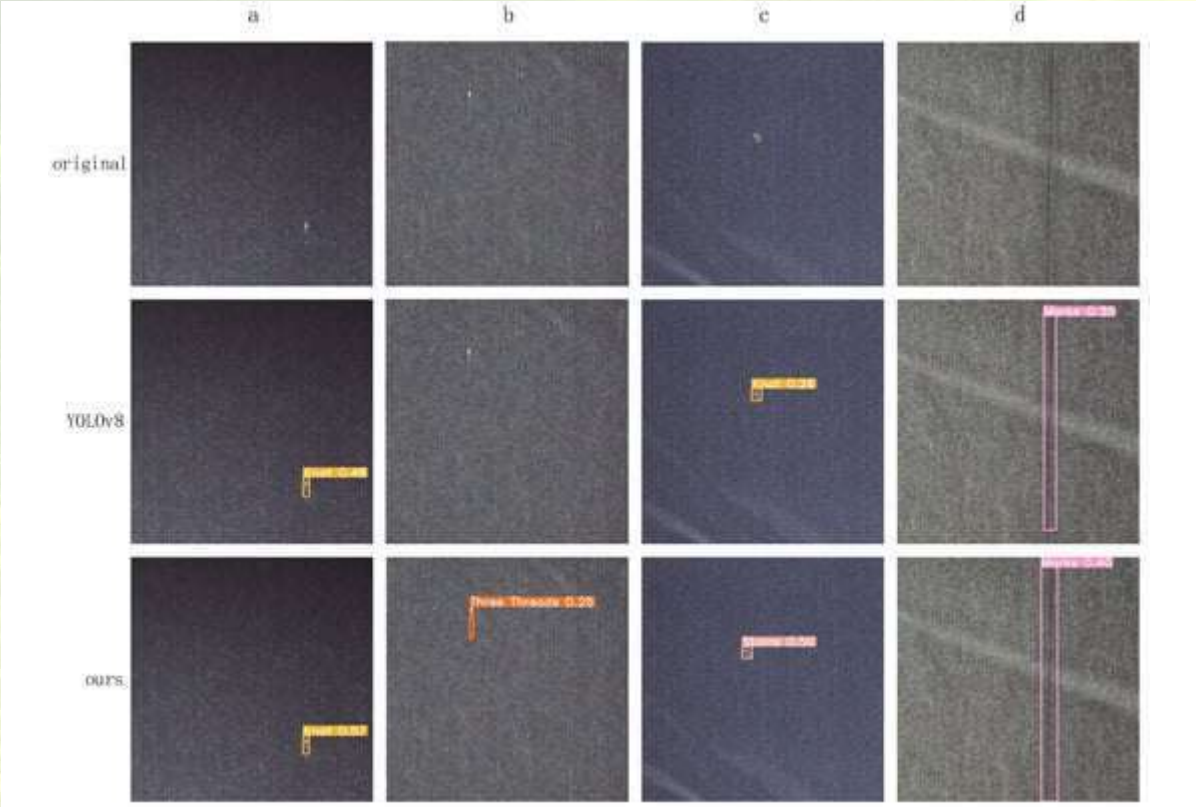


Figure 9. Comparison of results of Tianchi dataset testing, where (**a**) denotes the knot, (**b**) denotes the three threads, (**c**) denotes the stains, (**d**) denotes the marks.

6. CONCLUSION

FD-YOLO advances real-time fabric defect detection with targeted improvements to YOLOv8, achieving SOTA results on benchmarks. Future work includes edge deployment and multi-modal integration (e.g., with hyperspectral imaging). Although the improved model significantly enhances accuracy and efficiency, it still faces some limitations. False detections may occur in complex backgrounds and for defects with high similarity. Additionally, the model shows limited adaptability to fabrics under extreme color or lighting changes. The model's adaptability to various industrial environments and hardware platforms, especially in terms of resource consumption and inference speed for real-time inspection systems, also requires further verification. Future work can focus on improving the model's robustness and adaptability for broader application scenarios.

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ISSN 3030-3907

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