PDF Name: INNA112325TPAIACHI20259045368565.pdf

Page Range: 3631 - 3641

DOI: 10. 13196/j. cims. 2024. S11

基于多维协同注意力机制的航空碳纤维构件缺陷轻量化实时检测模型

Lightweight real-time defect detection model for aeronautical carbon fiber components driven by multi-dimensional collaborative attention mechanism

MA Xubeng 1, WU Xuanyu 2, HU Bingtao 2, LI Yaonan 1, SUN Zhenghao 3, FENG Yixiong 2, LI Chuanjiang 4

马徐蚌, 吴轩宇, 胡炳涛, 李耀楠, 孙征昊, 冯毅雄, 李传江

1. College of Mechanical Engineering. Guizhou University. Guiyang 550025. China

2. State Key Laboratory of Fluid Power and Mechatronic Systems, Zhejiang University, Hangzhou 310027, China

3. Shanghai Academy of Spaceflight Technology, Shanghai 200240, China

4. State Key Laboratory of Public Big Data, Guizhou University, Guiyang 550025. China

Ma Xubeng - 3146444194@qq.com (Corresponding Author: No)

Wu Xuanyu - xuanyuwu@zju.edu.cn (Corresponding Author: No)

Hu Bingtao - hubingtao@zju.edu.cn (Corresponding Author: Yes)

Li Yaonan - 1687374924@qq.com (Corresponding Author: No)

Sun Zhenghao - sunzhh@163.com (Corresponding Author: No)

Feng Yixiong - fyxtv@zju.edu.cn (Corresponding Author: No)

Li Chuanjiang - licj@gzu.edu.cn (Corresponding Author: No)

Project supported by the National Natural Science Foundation. China(No. 52130501.52105281). and the Key R&D Program of Zhejiang Province, China(No. 2023C01214.2024C01029).

Abstract (English):

To address the challenges of high computational demands and resource constraints in real-time defect detection of aerospace carbon fiber components. a lightweight object detection framework was developed. An improved model based on the YOLOv11n framework was constructed by integrating Deformable Convolution (DCNv4) into the backbone network to enhance defect shape perception. A DualConv structure was employed to improve feature extraction efficiency, while the C3K2_MCA module incorporating a multi-dimensional collaborative attention mechanism was designed to strengthen multi-scale feature correlation and representation. Experimental results demonstrated that the improved model had achieved enhancements in both mAP and precision, along with a 20.6% increase in detection speed and a 23% reduction in computational resource consumption. This method effectively balanced detection accuracy, efficiency and computational cost. making it well-suited for real-time defect detection of carbon fiber components.

Keywords (English):

carbon fiber components; defect detection: YOLOv11n framework: multi-dimensional collaborative attention mechanism: lightweight model

References:

[1] OZKAN D.GOK MS. KARAOGLANLI A C. Carbon fiber reinforced polymer (CFRP) composite materials, their characteristic properties, industrial application areas and their machinability [M]//Engineering Design Applications III: Structures. Materials and Processes, Berlin, Germany: Springer-Verlag.2020 235-253.

[2] VANDENDRIESSCHE J. ORTA A H. VERBOVEN E. et al. Probabilistic ultrasound C-scan imaging of barely visible impact damage in CFRP laminates [J]. Composite Structures. 2022.284:115209. DOI:10.1016/j.compstruct. 2022. 115209.

[3] NAIN G.PATTANAIK KK. SHARMA G K. Towards edge computing in intelligent manufacturing: Past present and future [J]. Journal of Manufacturing Systems, 2022.62(7):588-611.

[4] LUO Dongliang CAI Yuxuan, YANG Zihao. et al. A review of deep learning methods for industrial defect detection. Science China, Information Sciences. 2022.52(6):1002-1039 (in Chinese). [罗东亮,蔡雨萱,杨子豪,等 工业缺陷检测深度学习方法综述 [J].中国科学:信息科学,2022,52(6):1002-1039.]

[5] CHENG Xiaoying. MA Gaoshen. WU Zhenyu.et al. Automatic defect depth estimation for ultrasonic testing in carbon fiber reinforced composites using deep learning[J]. NDT &. E International.2023.135(4):102804.

[6] LIU Ruilin ZENG Wei. Automatic detection of structural defects in tunnel lining via network pruning and knowledge distillation in YOLO [EB/OL]. [2025-03-29].https://journals.sagepub.com/doi/pdf/10.1177/14759217241289066. DOI: 10.1177/14759217241289066.

[7] SETYANTO A.SASONGKOT B. FIKRI MA. et al, Knowledgedistillation in object detection for resource-constrained edge computing [EB/OL]. (2025-01-24) [2025-03-21].https://openaccess, theevf.com/content/WACV 2022/papers/Matsubara_Supervised_Compression_for_Resource-Constrained_Edge_Computing_Systems_WACV_2022_paper.pdf.

[8] WANG Jikuo. QIAO Xu. LIU Changchun, et al. Automated ECG classification using a non-local convolutional block attention module [J]. Computer Methods and Programs in Biomedicine. 2021-203(7):106006.

[9] ZHENG Tong, SA Liangbing, YU Chongchong, et al. DeFRCN-MAM DEFRCN and multi-scale attention mechanism-based industrial defect detection method [J]. Applied Artificial Intelligence. 2024.38(1): 2349981.

[10] LIU Yi.ZHANG Changsheng. DONG Xingjun. A survey of real-time surface defect inspection methods based on deep learning [J]. Artificial Intelligence Review. 2023.56(10): 12131-12170.

[11] TAO Xian. HOU Wei. XU De. A review of surface defect detection methods based on deep learning [J]. Acta Automatica Sinica, 2021.47(5):1017-1034 (in Chinese). [陶显 侯伟、徐德、基于深度学习的表面缺陷检测方法综述[J] 自动化学报,2021.47(5):1017-1034.]

[12] LI Shaobo. YANG Jing. WANG Zheng et al. A review of the development and application of defect detection technology [J] .Acta Automatica Sinica 2020.46(11):2319-2336 (in Chinese).[李少波,杨静,王铮,等 缺陷检测技术的发展与应用研究综述[J],自动化学报.2020.46(11):2319-2336.]

[13] WU Xuanyu. HONG Zhaoxi. LIU Jihong.et al. Collaborative model for intelligent design and verification of complex customized products[J]. Computer Integrated Manufacturing Systems. 2022.28(9):2700-2717 (in Chinese).[吴轩宇,洪兆溪,刘继红,等,复杂定制产品智能化设计与验证协同模式[J],计算机集成制造系统,2022.28(9):2700-2717.]

[14] TIAN Wei.JIAO Jiachen.L1 Bo. et al. A review of high-precision operation equipment and technology for aerospace manufacturing robots[J]. Journal of Nanjing University of Aeronautics and Astronautics. 2020,52(3): 341-352 (in Chinese). [田威,焦嘉琛,李波等 航空航天制造机器人高精度作业装备与技术综述[J],南京航空航天大学学报,2020.52(3):341-352.]

[15] KIRILLOV A.MINTUN E. RAVI N, et al. Segment anything [C]//Proceedings of the IEEE/CVF International Conference on Computer Vision. Washington. D. C. USA IEEE, 2023.

[16] SHORTEN C. KHOSHGOFTAAR TM. FURHT B. Text data augmentation for deep learning [J]. Journal of Big Data. 2021.8(1):101.

[17] ZHAO Yongqiang, RAO Yuan. DONG Shipeng et al. Areview of deep learning methods for object detection. Journal of Image and Graphics. 2020.25(4):629-654 (in Chinese).[赵永强,饶元,董世鹏,等、深度学习目标检测方法综述[J] 中国图象图形学报,2020.25(4):629-654.]

[18] XU Degang, WANG Lu. LI Fan. A review of typical deep learning-based object detection algorithms [J]. Computer Engineering and Applications. 2021.57(8):10-25 (in Chinese).[许德刚 王露,李凡 深度学习的典型目标检测算法研究综述[J] 计算机工程与应用 .2021.57(8):10-25.]

[19] KHANAM R. HUSSAIN M. YOLOv11: An overview of the key architectural enhancements [EB/OL]. (2024-10-23) [2025-03-21]. https://arxiv.org/html/2410.17725v1.

[20] XIONG Y.LI Z.CHEN Y et al. Efficient deformable convnets: Rethinking dynamic and sparse operator for vision applications [C]//Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition. Washington. D. C. USA IEEE.2024:5652-5661.

[21] ZHONG J.CHEN J.MIAN A. DualConv: Dual convolutional kernels for lightweight deep neural networks [J]. IEEE Transactions on Neural Networks and Learning Systems. 2022.34(11):9528-9535.

[22] YU Yang.ZHANG YI.CHENG Zeyu. et al. MCA Multidimensional collaborative attention in deep convolutional neural networks for image recognition [J]. Engineering Applications of Artificial Intelligence.2023.126,107079.

[23] THOPALLI K. THIAGARAJAN J J. Interaug: A tuning-free augmentation policy for data-efficient and robust object detection[C]//Proceedings of the IEEE/CVF International Conference on Computer Vision. Washington, D. C., USA, IEEE. 2023:253-261.

[24] KE Lei, YE Mingqiao, DANELLJAN M. et al. Segment anything in high quality. Advances in Neural Information Processing Systems.2023.36:29914-29934.

[25] FANG Yiming, GUO Xianxin. CHEN Kun, et al. Accurate and automated detection of surface knots on sawn timbers using YOLO-V5 model. BioResources. 2021.16(3):5390-5406.

[26] HUSSAIN M. YOLO-v1 to YOLO-v8. the rise of YOLO and its complementary nature toward digital manufacturing and industrial defect detection [J]. Machines. 2023.11(7) 677.

[27] SHARMA A.KUMAR V. LONGCHAMPS 1.. Comparative performance of YOLOv8. YOLOv9. YOLOv10, YOLOv11 and Faster R-CNN models for detection of multiple weed species. Smart Agricultural Technology. 2024.9,100648.

[28] XU Xiangyang ZHAO Mian. SHI Peixin. et al. Crack detection and comparison study based on faster R-CNN and mask R-CNN [J]. Sensors. 2022.22(3):1215.