Vision-Based Real-Time Weld Defect Detection Using a Crawling Robot

Mohammad Hossein Afsharmovahed, Ritesh Sharma, Son Nguyen, Genda Chen

Civil, Architectural, and Environmental Engineering Department

Introduction & Motivation:

Weld inspections ensure structural integrity. Defects are difficult to detect, especially in hard-to-reach bridge areas (e.g., inside box girders). Traditional methods are time-consuming & labor-intensive.
Solution: AI-powered climbing robot equipped with a microscopic camera for real-time defect detection.

Methodology:

Fabrication of Weld Samples:
Six fillet weld pieces were cast, each containing three different arbitrary defect types.

Creating three different arbitrary defect types:

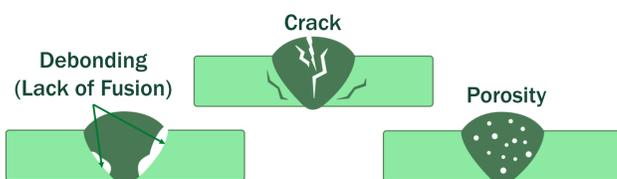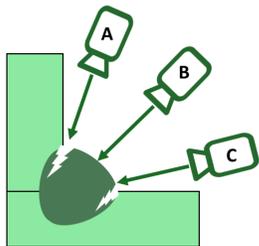Debonding (Lack of Fusion)
Crack
Porosity
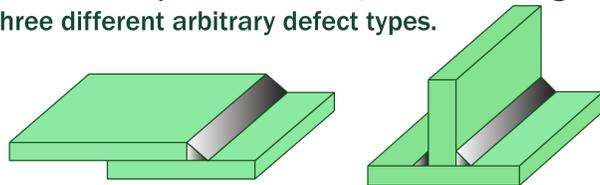
Image Collection:
A microscopic camera was used to capture high-resolution images of the weld samples from various angles, distances, and under different lighting conditions to ensure a diverse dataset. Thousands of high-resolution images were captured.

Data Preprocessing & Annotation:
741 of the collected images were selected and imported into Roboflow, where defects were manually annotated into three categories.
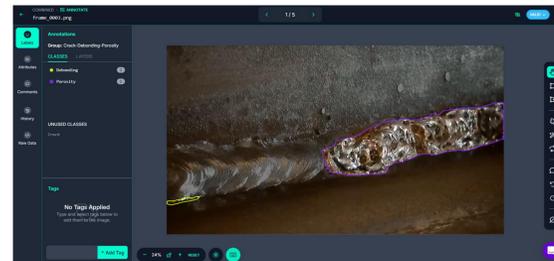
Preprocessing techniques, including image data augmentation, were applied to enhance model robustness.
**Dataset split:** 70% training, 10% validation, 20% testing

Model Implementation & Training :
The YOLOv11 model, pretrained on the COCO dataset, was fine-tuned using transfer learning on the annotated weld dataset. Nano, Small, and Medium versions of YOLOv11 were used.
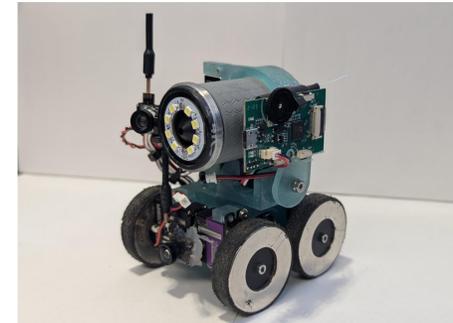
Client Machine Integration
The trained model was deployed on an NVIDIA Jetson computer, responsible for processing real-time video streams from the microscopic camera.

Video Stream → Client Machine: Frame Extraction → Inference with YOLO → Display Inference
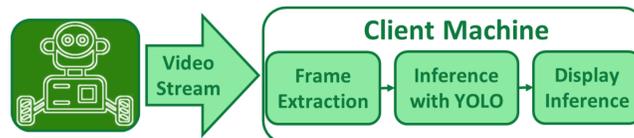
Development of a Climbing Robot:
A crawler robot with magnetic wheels was fabricated to navigate steel structures easily. The robot was equipped with a microscopic camera capable of Wi-Fi connectivity for seamless real-time video streaming.

## Results & Performance:

Real-Time Operation:
The microscopic camera streams video to the Jetson computer, which transmits frames to the client machine over Wi-Fi. The trained YOLOv11 model performs inference, detecting, and highlighting weld defect areas in real-time (defect segmentation). The results are displayed on a screen, providing immediate feedback for inspection.

Nano   Small   Medium
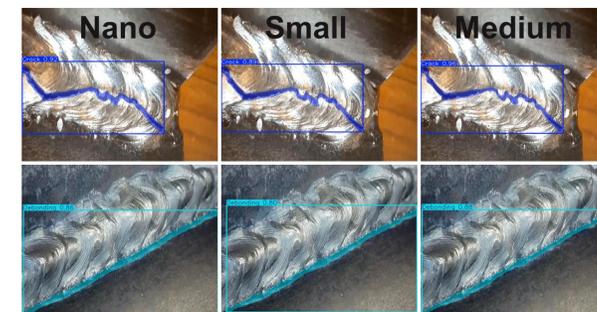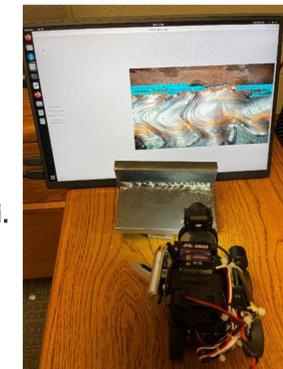
High detection accuracy due to the microscopic camera's fine details and the robustness of the AI model.
Based on Inference speed vs. accuracy trade-off between YOLOv11 models, nano version is chosen as the best real-time inference model on edge devices.

YOLOv11 Nano Performance

Epoch-mAP50

mAP50(Detection)   mAP50(Segmentation)
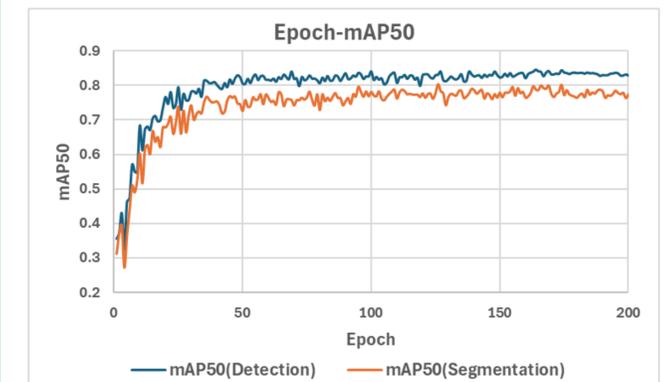
Conclusion & Future Work:

Achievements:
AI-based real-time weld defect segmentation showed high accuracy and confidence score.
Climbing robot enables safe, automated inspection.
YOLOv11 model successfully detects defects in real-time.

Future Improvements:
Expand dataset to include more defect types.
Optimize deployment for faster inference.
Explore YOLOv12 for improved performance.

Acknowledgments:

References:

[1] https://roboflow.com/ accessed on September 9th, 2024
[2] Jacob Solawetz, F. What Is YOLOv11? The Ultimate Guide. [2024]. Roboflow.