Adaptive Inspection UAV: Real-Time Defect Segmentation and 3D Gaussian Splatting for Enhanced Infrastructure Diagnosis

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The $191.3 billion U.S. infrastructure repair backlog and unreliability of traditional manual visual inspections, which miss up to 94% of cracks, demonstrates the urgent need for improved infrastructure inspection methods. Current infrastructure scanning drones exist, but deliver 2D images without any meaningful context or annotation while costing at least $15,000. This research developed a $1,041 UAV that scans structures, identifies defects with machine learning, and reconstructs the scanned structures as 3-D models with defects marked at their precise locations. The UAV quadcopter was prototyped with a Pixhawk flight controller, NVIDIA Jetson Orin Nano, and camera. For defect detection, a YOLOv11 instance segmentation model was trained on 18,407 images spanning 3 classes (corrosion, cracks, and spalling), achieving a 76.2% mean average precision. Once deployed, the model enables the closed-loop adaptive reinspection, where the Jetson's real-time inferencing marks defects during flight and triggers additional scanning passes to develop more reliable 3-D localizations. The scan is then processed through a custom pipeline: defects are identified using the detection model and overlaid onto a photorealistic 3-D structure reconstruction created using 3-D Gaussian Splatting. Field testing verified the full collection pipeline: approximately 400 images were collected with autonomous adaptive reinspection and produced a 3-D model overlaid with 9 defects localized at their real positions in under one hour. The 3-D viewer combines detection and mapping to allow civil inspectors to orbit the structure and easily examine individual defects, enabling efficient inspection capabilities absent from conventional 2-D inspection workflows.

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Fourth Award of $600