

Review

Advancements in Smart Nondestructive Evaluation of Industrial Machines: A Comprehensive Review of Computer Vision and AI Techniques for Infrastructure Maintenance

Samira Mohammadi ^{1,2,3}, Sasan Sattarpanah Karganroudi ^{1,2,*}  and Vahid Rahmanian ¹

¹ Centre National Intégré du Manufacturier Intelligent, Université du Québec à Trois-Rivières, 575 Boul de l'Université, Drummondville, QC J2C 0R5, Canada; samira.mohammadi2@uqtr.ca (S.M.); vahid.rahmanian@uqtr.ca (V.R.)

² Équipe de Recherche en Intégration CAO-Calcul, Department of Mechanical Engineering, Université du Québec à Trois-Rivières, 575 Boul de l'Université, Drummondville, QC J2C 0R5, Canada

³ Department of Mathematics, Informatics and Engineering, Université du Québec à Rimouski, 1595 Bd Alphonse-Desjardins, Lévis, QC G6V 0A6, Canada

* Correspondence: sattarpan@uqtr.ca

Abstract: Infrastructure maintenance is critical to ensuring public safety and the longevity of essential structures. Nondestructive Evaluation (NDE) techniques allow for infrastructure inspection without causing damage. Computer vision has emerged as a powerful tool in this domain, providing automated, efficient, and accurate solutions for defect detection, structural monitoring, and real-time analysis. This review explores the current state of computer vision in NDE, discussing key techniques, applications across various infrastructure types, and the integration of deep learning models such as convolutional neural networks (CNNs), vision transformers (ViTs), and hybrid models. The review also highlights challenges, including data availability and scalability. It proposes future research directions, including real-time monitoring and the integration of Artificial Intelligence (AI) with Internet of Things (IoT) devices for comprehensive inspections.

Keywords: nondestructive evaluation; structural health monitoring; defect detection; deep learning models; predictive maintenance



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1. Introduction

Infrastructure is essential in modern society, supporting transportation, communication, and urban development. From bridges and highways to pipelines and buildings, the integrity and safety of these structures are essential [1]. The regular inspection and maintenance of such infrastructure are vital to prevent accidents, reduce maintenance costs, and extend the lifespan of structures [2]. Traditionally, these inspections have relied on manual methods such as visual inspections and basic testing techniques. However, these approaches are time-consuming, labor-intensive, and prone to human error [3]. Nondestructive Evaluation (NDE) refers to various techniques used to assess the condition of infrastructure without damaging structures [4]. These methods are crucial for evaluating critical infrastructure such as bridges, buildings, pipelines, and railways, as they allow for the early detection of defects and deterioration, thus preventing failures [5]. Traditional NDE methods include ultrasonic testing, radiography, thermography, and acoustic emission testing, which have been widely used for decades [6]. Each technique provides valuable insights: ultrasonic testing utilizes high-frequency sound waves to detect internal

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