

AI-Driven Framework for Automated Bridge Deterioration Detection and Management

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Abstract

Bridges constitute vital elements of Taiwan's transportation infrastructure; nevertheless, numerous structures have surpassed their intended service life, thereby posing safety hazards and amplifying the necessity for prompt maintenance. Conventional inspection methodologies, which predominantly depend on visual assessments, are labor-intensive, time-consuming, costly, and prone to human error. To address these limitations, this study introduces a multi-stage automated inspection and reporting framework that integrates unmanned aerial vehicle (UAV) sensing, computer vision, large language models (LLMs), and metaheuristic optimization. UAVs initially capture high-resolution imagery of bridge components to ensure exhaustive data collection while reducing inspector exposure to hazardous conditions. A Vision Transformer (ViT) is utilized for image classification. In contrast, the YOLO (You Only Look Once) model executes object detection and instance segmentation to localize deterioration, evaluate its severity, and estimate repair costs. The framework is further refined by incorporating a multimodal LLM, fine-tuned on a dataset of common deterioration types and structural components derived from bridge inspection records in Taiwan, to automatically generate descriptive reports that document deterioration conditions, recommend repair strategies, and maintain clarity and technical precision. Additionally, the hyperparameters of the integrated system are optimized through a newly developed metaheuristic algorithm, thereby ensuring enhanced efficiency and accuracy. Validation via cross-validation and language model performance metrics affirms the system's robustness and capability for generalization. By integrating UAV sensing, advanced computer vision, LLM-driven report generation, and optimization algorithms, the proposed framework markedly enhances the efficiency, accuracy, and safety of bridge inspections while equipping management agencies with cost-effective and sustainable decision-support tools for long-term infrastructure maintenance.

Keywords

Automated Bridge Inspection; Unmanned Aerial Vehicles; Computer Vision; Large Language Models; Metaheuristic Optimization; Structural Health Monitoring.

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Biographies

Jui-Sheng Chou earned his Ph.D. in Construction Engineering and Project Management from The University of Texas at Austin's Department of Civil, Architectural and Environmental Engineering. As a licensed professional engineer, he is the Chair of the Civil & Hydraulic Program at Taiwan's NSTC. He serves as a Chair Professor and

Vice President at the National Taiwan University of Science and Technology. He is also President of the Taiwan Construction Management Association. His expertise focuses on construction engineering, project management, data science, and AI to improve engineering management, with interests in civil and hydraulic engineering informatics, project management, energy management, analytics, and investment decisions. Recognized as a highly cited scholar by Scopus and ResearchGate, he was nominated for the Eni Award and ranked among the top scientists in Building, Construction, and ICT. Elsevier and ASCE note his contributions to peer review, with several papers designated as ESI Highly Cited and Most Cited articles. He has received numerous awards, including NSTC Outstanding Research and MOE Excellent Senior Faculty.

Chi-Yun Liu is an Assistant Professor in the Department of Civil Engineering at National Taipei University of Technology (Taipei Tech). His research focuses on applying data science and generative artificial intelligence (GAI) to solve complex problems in civil engineering and construction management. Besides his academic role, he also serves as the General Secretary of the Taiwan Construction Management Association (TCMA). Dr. Liu's scholarly work concentrates on integrating large multimodal models (LMMs) and optimization techniques to improve high-tech facility management, legal and regulatory consulting, and intelligent infrastructure systems. He has created and applied advanced computational frameworks that enhance decision-making, increase operational efficiency, and support innovative solutions for engineering management and infrastructure resilience.

Jhe-Shian Lien earned a B.S. in Civil Engineering from National Yang Ming Chiao Tung University. During his undergraduate studies, he took a graduate-level course in Construction Management of High-Tech Facilities, which sparked his interest in the field of construction management. He later earned an M.S. in Construction Engineering from National Taiwan University of Science and Technology, supervised by Chair Professor Jui-Sheng Chou. His research focused on AI in construction management, with a particular emphasis on Analyzing Bridge Structural Deterioration Patterns through the Integration of Vision Language Classification and Image Recognition. He developed a bridge maintenance cost estimation system using image recognition and construction cost concepts, which received the 28th Symposium on Construction Engineering and Management Outstanding Paper Award and a certificate of merit from the Taiwan Society of Architecture Medicine.

Chia-Hsiang Chang earned a B.S. in Civil Engineering from the National Kaohsiung University of Science and Technology. His undergraduate studies sparked a passion for construction management and IT. He then completed an M.S. in Civil and Construction Engineering at National Taiwan University of Science and Technology, supervised by Professor Jui-Sheng Chou. His research focused on using AI for infrastructure maintenance. His research combined multimodal language models with image recognition to create an automated bridge maintenance report system. The system identified deterioration, evaluated its severity, suggested repairs, and estimated the damage and associated costs. His work won the Best Paper and Best Presentation awards at the 29th Symposium on Construction Engineering and Management, recognizing its academic and practical value in the application of AI for infrastructure maintenance.

Benjawan Phakdee earned a B.S. in Civil Engineering from Rajamangala University of Technology Lanna in Chiang Mai, Thailand, in 2013. In 2020, she received her M.S. in Construction Engineering and Management from the Department of Civil Engineering at Chiang Mai University, a respected institution in Thailand. Currently, she is pursuing a Ph.D. under the supervision of Chair Professor Jui-Sheng Chou in the Division of Construction Management within the Department of Civil and Construction Engineering at the National Taiwan University of Science and Technology in Taipei, Taiwan. There, she is expanding her knowledge of computer vision in the field of engineering informatics and management. Her research focuses on applying computer vision to engineering informatics and management, combined with metaheuristic algorithms to enhance analysis, optimization, and decision-making in construction engineering.