AUSTRALIAN NETWORK OF STRUCTURAL HEALTH MONITORING

Newsletter

Issue 42, December 2024

Contents

President Report

Tommy Chan

Professor in Civil Engineering, Queensland University of Technology

Dear All,

This month has been one of the busiest in my life. We had numerous events, including our Annual Workshop on 21-22 November, the ANSHM Advisory Board Meeting, and the ANSHM Annual General Meeting. Additionally, we prepared our ITRP proposal for submission, among other activities. As a result, I've been starting work in my office at 6:00 AM every day, including weekends. Given the volume of events, I need to be selective to keep this monthly update concise.

Firstly, I would like to express my sincere gratitude to RMIT for hosting our 16th Annual Workshop. The efforts of the Local Organising Committee, led by A/Prof Lei Hou, are much appreciated. Those who attended will agree that Lei and his team did an outstanding job! Their meticulous planning and hard work made this one of our most successful workshops to date.

This month, we also had the ARC Linkage Project 2024 Round 1 outcomes announced on 6 November and the ARC Discovery Project 2025 outcomes on 26 November. It is heartening to see many ANSHM Executive Committee members receiving ARC funding support in these rounds, totalling $2,632,168.00.

Congratulations to Prof Hong Guan, Prof Tuan Ngo, Prof Richard Yang, and Prof Alex Ng!

Dr Shan-muganathan Gunalan; Associate Professor Benoit Gilbert; Associate Professor Hassan Karampour; **Professor Hong Guan**; Mr James Stringfellow	**Innovations to Enhance Sustainability and Resilience in Building Façades.** - Funding Awarded: $223,020 - Scheme: ARC Linkage Projects (LP240100388) This project aims to foster innovations to enhance sustainability and resilience in building façades. The project proposes to develop a novel composite façade frame using aluminium and timber through detailed experimental and advanced numerical studies. The proposed frame will be energy efficient, cost effective, durable, sustainable, and aesthetically pleasing while having the coupling mechanism for effective installation in curtain wall and window wall applications. Suitable design rules and detailing guidelines will also be developed for safe and economical design of these new façade frames. This should provide significant benefits to façade industry by mitigating environmental impacts and striving towards carbon neutrality.

Professor Tuan Ngo; Dr Tuan Nguyen; Professor Huu-Tai Thai; Professor Andrew Whittaker	**An innovative steel-concrete system for molten salt energy storage vessel.** - Funding Awarded: $647,384.00 - Scheme: ARC Discovery Projects (DP250101934) This project aims to develop a novel steel-concrete composite vessel for molten salt (MS) energy storage. By leveraging the merits of the two most prevalent construction materials, the developed vessel will provide the excellent performance and durability under extreme conditions of MS storage (high temperature and corrosion). Expected outcomes include advancing knowledge in the behaviours of steel-concrete composite under high temperature and corrosive environments, and developing a new generation of MS storage vessel that is highly scalable, efficient, and cost-effective. This should provide significant benefits to Australia in accelerating energy storage technologies and fostering the national and global renewable energy transition.
Professor Richard (Chunhui) Yang; Professor Yixia (Sarah) Zhang; Professor Wenyi Yan; Professor Brian Falzon	**3D Printing of Recycled Thermoplastic Polymer Nanocomposites.** - Funding Awarded: $697,299.00 - Scheme: ARC Discovery Projects (DP250103234) This project aims to develop a novel 3D printing technology, Fused Granular Fabrication, to integrate innovative nanotechnology and high-performance 3D printed nanocomposites using recycled plastic reinforced with carbon nanoadditives. It will focus on fabrication, testing, characterisation, modelling, optimal design, and optimal 3D printing for the enhancement of material properties using nanoadditives. This project will deliver sustainable manufacturing solutions for the urgent and critical plastic waste management issue for the nation and the world. The 3D-printed nanocomposites developed with superior mechanical, thermal and electrical properties could be widely used in primary industries such as aerospace, automotive and electronics.

Professor Ching Tai Ng; Professor Andrei Kotooussov; Dr Tingyuan Yin	**Revolutionising Non-destructive Inspection with Nonlinear Laser Ultrasonics.** - Funding Awarded: $544,078.00 - Scheme: ARC Discovery Projects (DP250102518) This project aims to develop a new inspection technology for structures with hard-to-inspect conditions using fully non-contact nonlinear laser ultrasonics. This will overcome the limitations of existing non-destructive evaluation (NDE) and structural health monitoring (SHM) techniques. The project will create a new concept and generate new knowledge on NDE and SHM. The expected outcomes are significant improvements in the capability and applicability of NDE and SHM to cutting-edge technologies, such as real-time monitoring of constructing objects in additive manufacturing, and structures with extreme conditions in the Space, Energy, Oli and Gas industry. This provides significant cost savings in the integrity inspection of structures.
Professor Hong Guan; Associate Professor Hassan Karampour; Associate Professor Benoit Gilbert	**Timber Reimagined: Structurally Efficient Two-Way Flat Plate Construction.** - Funding Awarded: $520,387.00 - Scheme: ARC Discovery Projects (DP250101210) This project aims to develop a novel post-tensioned two-way cross-laminated timber flooring system to transform the design of conventional timber buildings, whilst addressing the shortage in timber supply. The project will generate new knowledge in the safe and efficient design of timber buildings and public infrastructure. Expected outcomes include lightweight, thin and more sustainable timber floors and roofs, and leading edge practical guidelines for the engineering community. This will provide significant benefits in response to the Australian Government's commitment to increase timber construction by 2030 to build near-zero and resilient buildings, and the QLD Government's Brisbane 2032 commitment to deliver a carbon-positive Olympics.

Below are the updates of the month.

16th ANSHM Workshop

As mentioned above, this Workshop stands out as one of the best in ANSHM history. We had 26 presentations, including 9 from the industry, highlighting the increasing involvement of non-academic organizations in SHM-related projects and their eagerness to share their experiences on the ANSHM platform. With 72 registrations—29 from academics and 43 from the government or industry—the event saw broad participation. I received numerous positive comments about the workshop, with many attendees staying from the Welcome to the Closing sessions (Photo 2 and Photo 5). This shows delegates highly valued each presentation and were keen to learn about the SHM work being done in both academia and industry. The Industry Forum (Photo 3) was again a highlight, discussing how ANSHM could bridge the gap between industry and academia. It was repeatedly mentioned that there is great anticipation for establishing the ANSHM ARC Industrial Transformation Research Hub to help transform the SHM community culture. Below are some photos from the two-day workshop. A/Prof Lei Hou is considering uploading the slides and recordings to the ANSHM site as our proceedings, pending presenter consent.

Photo 1 - Group Photo

Photo 2 - A/Prof Lei is giving his Welcome Address as the Chair of the Organising Committee

Photo 3 - Panel Discussion: Industry Challenges on SHM

(Starting from right: John Vazey (EngAnalysis), Thomas Kuen (Melbourne Water), Dr Desiiree Nortje (Transurban), Dr Arash Behnia (Robert Bird Group), Dr Yew-Chin Koay (MRPV), A/Prof Colin Caprani (Monash University)

Photo 4 - Banquet for guests

Photo 5 - Closing Address by A/Prof Lei Hou

ANSHM ARC Industrial Transformation Research Hub (SSI Hub)

As mentioned in the last monthly update, the title of our ANSHM ARC ITRH is *ARC Research Hub for Sustainable Smart Infrastructure through Digital Transformation* (SSI Hub or SSIDT).

I am delighted to announce that our ARC SSI Hub proposal, with over 400 pages of content, was successfully submitted on 26 November 2024, marking the culmination of over 8 months of effort. Preparation began in March 2024 following decisions made at the ABM and AGM held during the 15th ANSHM Workshop. Completing and submitting the proposal for the ARC SSI Hub is already a significant achievement, given the extensive ARC requirements in preparing the proposal and collecting all the required information and documents. Applying for ARC ITRH and ITTC can be extremely daunting, with many failing even to complete the submission process. The journey of preparing the application was truly adventurous. Even on the last day of submission, it was still filled with excitement. I submitted the application at 9:20 AM, but it was returned by our Research Office at noon with some issues to resolve. Thanks to everyone who promptly helped address these issues, the application was resubmitted less than two hours before the deadline. Our Research Office then forwarded it to ARC after confirming all issues were resolved. Our submission could be considered flawless.

I extend my gratitude to all those who dedicated their time and effort to this submission. I hope our hard work results in a successful outcome. The Hub will benefit not only the academic and partner investigators but also transform our infrastructure to be smarter, more resilient, environmentally friendly, sustainable, durable, and robust. I believe all ANSHM members will share the benefits of the Hub, using data for their research and collaborating on Hub projects. Please promote this Research Hub whenever possible to convey its significance and benefits. Due to space limitations, I will share more about preparing the ARC SSI Hub in my next monthly update.

Research Collaboration

On 12 November 2024, I was invited by the Asset Institute, an Industry Partner of our ARC SSI Hub, to chair and facilitate the workshop "Resilient Infrastructure" at the Asset Institute 2024 Annual Forum, alongside Professors Sisi Zlatanova and Nasser Khalili. The workshop commenced with a presentation by Professor Khalili, Director of the ARC Research Hub on Resilient and Intelligent Infrastructure Systems (RIIS). During the discussion forum, many industry attendees emphasized the necessity of implementing structural health monitoring and asset management techniques in Australia's aging infrastructure. These measures are crucial not only for effective management but also to ensure the safety and efficient operation of the infrastructure.

Photo 6 (left) – Giving an introduction to the Workshop; Photo 7 (right) – Facilitating the Discussion

The Advisory Board Meeting 2024

As our tradition, the Advisory Board Meeting (ABM) was held on the first day of the 16th ANSHM Workshop, at RMIT city campus.

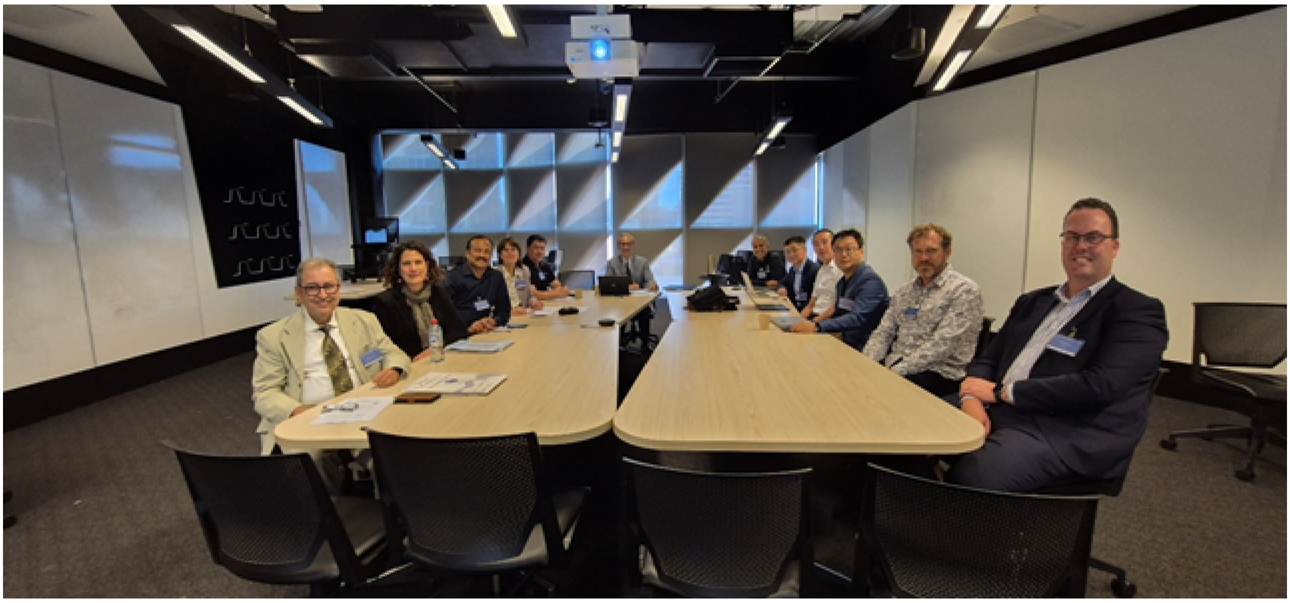

Photo 8 – ANSHM Advisory Board Meeting held after all the presentations of Day 1

Because of the space, I only report the following outcome of this ABM.

New Advisory Board Members

At our last Advisory Board meeting, we identified several key individuals in the field of SHM to invite as additional Advisory Board members. One of them is Dr. David Lo Jacono, ANZ Technical Director at Jacobs, who attended the 16th ANSHM Workshop. I was able to approach him quickly, and he was pleased to accept the invitation. I believe David will be instrumental in helping ANSHM understand how SHM can better meet industry needs and strengthen our relationship with the industry. We will continue to approach the other identified individuals and invite them to join the ANSHM Advisory Board.

Welcome on board, David!

The 15th ANSHM Annual General Meeting

The 15th Annual General Meeting (AGM) of ANSHM took place on the second day of the 16th ANSHM Workshop. Due to space constraints, I'll report two key outcomes from the AGM.

Photo 9 – 15th Annual General Meeting of ANSHM

a) Election of Executive Committee Officers

Jianchun Li (Deputy President), Hong Guan, Xinqun Zhu, Tuan Duc Ngo, me (President), and Ali Hadigheh were re-elected/elected to serve on the committee for 2 years of service (2025-2026). Therefore the Executive Committee in 2025 will consist of the following officers:

- Tommy Chan (President)
- Jianchun Li (Deputy President)
- Alex Ng
- Ali Hadigheh
- Andy Nguyen
- Colin Caprani
- Hong Guan
- Jun Li
- Lei Hou
- Mehrisadat Makki Alamdari
- Richard Yang
- Tuan Duc Ngo
- Xinqun Zhu

Ali, welcome on board!

b) Subscription Fee

I am pleased to inform you that we have decided to maintain the annual subscription fee for 2024 at zero.

Due to space limitations, I will report the other outcomes of the ABM and AGM in the upcoming monthly updates.

ANSHM Mini-Symposium at EASEC-18

The ANSHM Mini-Symposium was successfully held at the 18th East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-18) from 13 to 15 November 2024 at the Shangri-La Chiang Mai, Thailand. The conference saw participation from over 350 attendees representing 20 countries. I extend my gratitude to Prof. Jun Li and Prof. Hong Guan for organizing the symposium. Unfortunately, due to preparations for the ARC SSI Hub application submission, I was unable to attend the mini-symposium.

Photo 10 (Left) - Presentation by Dr. Yancheng Li of UTS and Photo 11 (Right) - Presentation by Ms. Huiyue Qiao at ANSHM Mini-Symposium at EASEC-18

Special Session at IABSE Tokyo 2025

As previously mentioned, Dr. Fabien Rollet and our ANSHM Advisory Board Member, Dr. David Lo Jacono, Technical Directors at Jacobs, are organizing a special session at the International Association for Bridge and Structural Engineering (IABSE) Symposium in Tokyo (https://www.iabse.org/Tokyo2025/). This event will take place at Waseda University and the Rihga Royal Hotel from 18 to 21 May 2025, with support from ANSHM. The symposium's theme is "Environmentally Friendly Technologies and Structures: Focusing on Sustainable Approaches." The description details of the special session are as follows:

SS14: Dynamic Bridge Assessment and Performance
A dedicated session will focus on dynamic bridge assessment and structural performance using Digital Twin monitoring: combining Structural Health Monitoring (SHM) and advanced computer vision. International bridge and data science experts will share cutting-edge techniques and practical applications for all types of bridges. The session will highlight the crucial role of data science in bridge engineering: offering Invaluable insights and fostering collaborations within the global bridge community. The session explores practical applications and advancements: addressing gaps in current standards. It presents an opportunity to engage in discussions and share experiences with fellow bridge experts: making it a must-attend for anyone Interested in the intersection of bridge engineering and data science.

In the next section, we will have two articles from our members. The first article is from Dr Yancheng Li and his team from School of Civil and Environmental Engineering, University of Technology Sydney, to propose a method to enhance crack detection and quantification in concrete structures by fusing RGB and depth data from RGB-D cameras, overcoming challenges in segmentation accuracy and manual spatial ratio estimation and enabling full automation. In the second article, researchers from Curtin University propose a synthetic data-driven SHM framework, enabling the generation of customized datasets to simulate diverse structural and environmental conditions, and enhancing deep learning model performance while overcoming real-world data limitations.

With kind regards,

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Automatic quantification of pavement cracks using a deep learning framework with RGB-D information fusion

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Abstract

Crack detection and quantification on concrete structures have primarily focused on RGB image-based methods that use deep learning to segment cracks. However, these methods often struggle with accurately segmenting crack contours due to complex concrete surface textures and irregular crack shapes [1]. The spatial ratio, a key parameter for crack quantification, traditionally relies on reference objects, which makes the process prone to human error and unsuitable for large-scale applications [2]. To address these challenges, our research focuses on incorporating an additional dimension by using RGB-D cameras. By combining depth information with RGB features, both crack segmentation accuracy and quantification precision are improved, enabling full automation of the process. In this short paper, we will briefly introduce our work on crack detection and quantification using RGB-D information fusion through a demonstrative project in pavement.

Introduction

Pavement cracks are a major cause of damage, weakening the structure and posing safety risks to both the surface and nearby buildings. Traditional crack detection relies on manual inspection, which is time-consuming, subjective, and prone to human error. Over the past few years, deep learning-based pavement crack detection methods have evolved significantly, progressing from classification to object detection and semantic segmentation, which enable pixel-level crack identification [3,4]. Approaches such as DeepLab, ResNet, and hybrid CNN-Transformer models have improved detection accuracy but often struggle in complex environments, as relying solely on RGB features leads to segmentation inaccuracies [5-7]. In addition, crack quantification remains a challenge, as traditional methods for determining spatial ratios are impractical for automation due to their reliance on precise setups and vulnerability to human error and environmental factors.

Our work introduces a pavement crack detection and quantification framework that integrates RGB-D information fusion, and Fig. 1 shows the methodology of our work. A feature fusion Transformer-based segmentation network (FFSegFormer) is designed to combine RGB and depth features, enhancing segmentation accuracy by leveraging complementary information. The spatial ratio required for quantification is obtained using an RGB-D camera integrated with the YOLO v5 algorithm, while crack depth is extracted through depth map post-processing. The proposed system enables the measurement of crack length, width, and depth, offering an automated and practical solution for crack detection and quantification under diverse conditions.

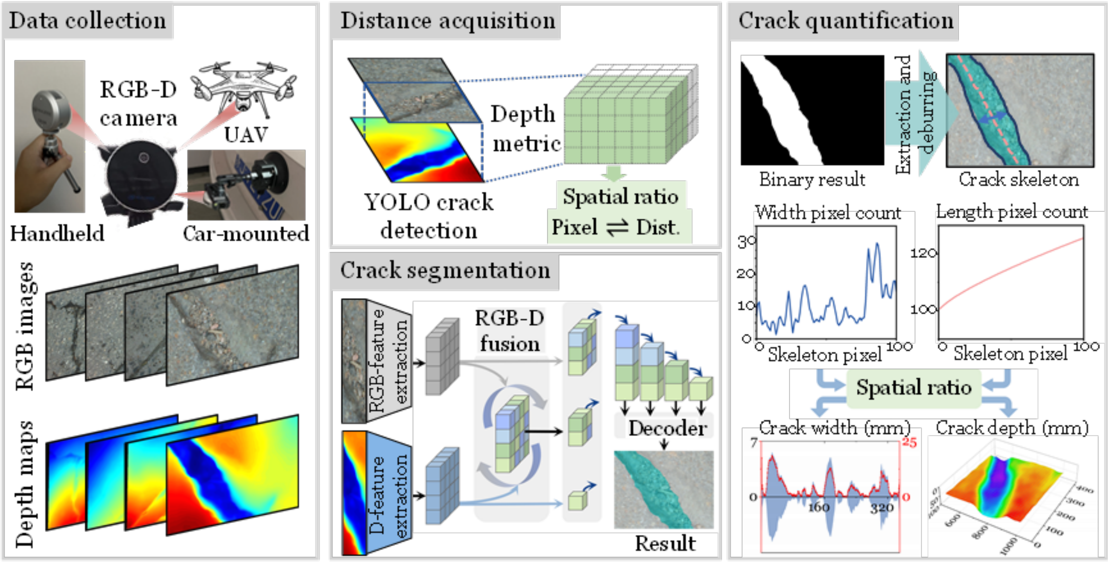

Figure. 1. Methodology of our work.

Proposed algorithm

FFSegFormer employs a standard encoder-decoder framework with a hierarchical encoder structure to extract and integrate multi-scale RGB and depth features. The encoder fuses feature from different scales and modalities, progressively restoring their dimensions to generate the final prediction map. RGB and depth images are processed for feature extraction, which are then passed through a Feature Fusion Transformer block that enhances feature interactions through an attention mechanism for effective integration.

The stem module performs downsampling and feature extraction on both RGB and depth features. Depth-wise convolutions are employed to expand the receptive field, enriching feature representation and minimizing information loss. The Feature Fusion Transformer block, which consists of multi-head self-attention mechanisms, applies attention to both RGB and depth features, enabling the model to capture relationships between the two modalities and fuse complementary information effectively.

For spatial ratio acquisition, YOLO v5 is integrated with the RGB-D camera. YOLO v5 detects crack regions using bounding boxes, and the depth values within these boxes are averaged to estimate the distance, enabling accurate real-time crack quantification.

Experiment results

The proposed FFSegFormer was compared with several CNN-based and Transformer-based networks on own-collected dataset. Fig. 2 shows the segmentation results of various algorithms, and the proposed FFSegFormer achieved the best performance, with a mIoU of 86.51%, outperforming algorithms that rely solely on RGB features by at least 4.27%. Additionally, modifications were made to these networks to enable the fusion of RGB-D features, and when compared with FFSegFormer, it outperformed these networks by at least 1.75%.

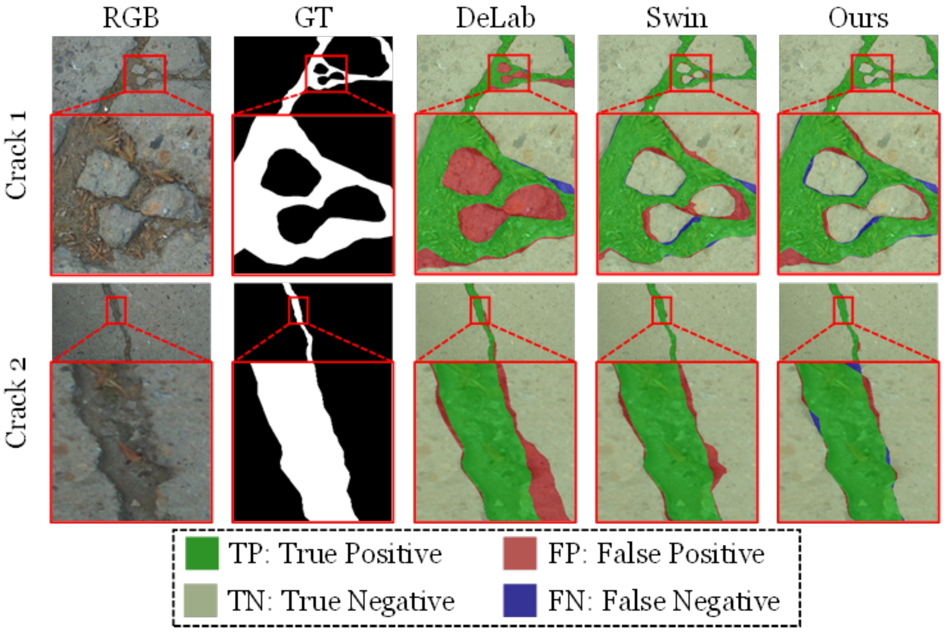

Figure 2. Segmentation results of various algorithms.

Table 1 presents the crack width, length, and depth quantification results, comparing the predictions of our method with those of DeepLab (DeLab) and Swin Transformer (Swin). For crack width, 100 crack widths were randomly selected and manually measured along the direction of crack skeleton lines for testing. It can be seen that the prediction results of FFSegFormer are closer to the manually measured values, with the lowest relative error rate of 11.95%. For crack length, four cracks were selected for measurement, and the average value was calculated. The predicted result of our method was 474.5 mm, with a discrepancy of only 9.25 mm compared to the manual measurements. For crack depth, we selected 25 points along the crack and compared FFSegFormer's predictions with the manual measurements. Despite the inherent errors associated with manual measurements, the proposed method demonstrated greater consistency, with a relative error rate of only 6.18%.

Table 1. Quantification results of crack width, length, and depth.

		Prediction results of various methods (mm)			Relative error rate (%)		
	Manual measurement (mm)	DeLab	Swin	Ours	DeLab	Swin	Ours
Width	5.66	6.24	6.41	5.34	37.16	32.93	11.95
Length	484.75	432.25	452.75	475.5	12.1	8.88	2.19
Depth	8.17	-		8.07	-		6.18

Conclusion

This work presents a method for pavement crack detection and quantification by integrating an RGB-D camera with deep learning algorithms. The proposed method utilizes YOLO v5 algorithm to capture RGB-D datasets and incorporates depth information, enhancing segmentation accuracy through the FFSegFormer. Experimental results demonstrate that integrating depth features improves crack detection and quantification, providing more accurate predictions of crack dimensions compared to methods relying on RGB features.

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Synthetic Data-Driven Deep Learning for Structural Health Monitoring

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Abstract

Structural Health Monitoring (SHM) increasingly relies on deep learning (DL) to identify structural damage and assess integrity. However, the availability of high-quality, diverse datasets remains a significant challenge for developing robust SHM models. To overcome this challenge, the synthetic data-driven SHM framework is proposed, leveraging synthetic data generation to create task-specific, customized datasets for SHM applications. Through this framework, various structural and environmental conditions can be simulated, enhancing the effectiveness of deep learning models without the constraints imposed by real-world data collection.

Introduction

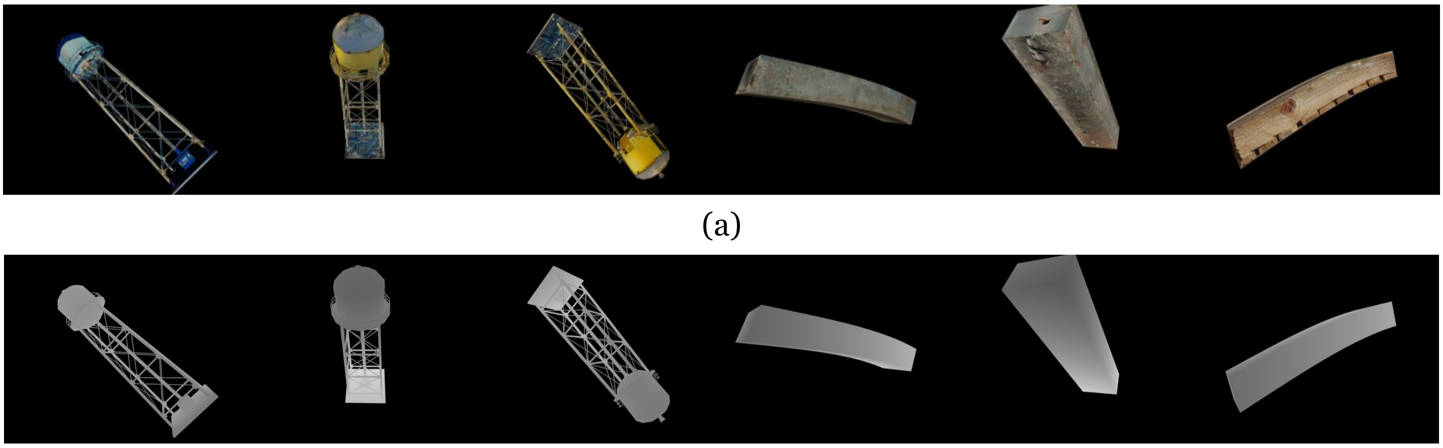
Traditional SHM inspection methods, often visual and labour-intensive, are increasingly being replaced by automated, data-driven techniques leveraging computer vision (CV) and DL [1, 2]. These modern approaches enhance precision and efficiency in identifying structural issues such as cracks, displacement, deformation and so on. However, building robust ML models requires extensive datasets [3]. It is a significant challenge in SHM due to access limitations, environmental constraints, and the high costs of data collection. To overcome this challenge, a scalable, synthetic data-driven SHM framework is proposed to generate custom, task-specific datasets that enhance model robustness and adaptability. This framework serves as a flexible platform for creating synthetic data across various SHM tasks, supporting diverse applications without the constraints of real-world data collection.

Within this framework, two example methods are presented: A method for synthetic 3D structural data generation (3DGEN), which generates customizable 3D models with varied textures, deformations, and viewpoints to simulate realistic structural behavior under different loading conditions, enabling the training of DL models for tasks like 3D surface reconstruction, displacement measurement, and deformation analysis; and synthesized crack image generation (CRKGEN) for damage assessment, where a text-to-image generative framework synthesizes high-quality crack images across diverse environmental conditions, supporting tasks such as crack classification, object detection, and segmentation. These examples underscore the framework's flexibility, allowing researchers to tailor synthetic datasets to specific SHM needs. By providing scalable, adaptive data solutions, this framework advances the development of accurate, data-driven SHM tools for civil infrastructure monitoring.

Synthetic Data Generation Methods for Structural Health Monitoring

Method 1: 3DGEN for Synthetic 3D Structural Data

3DGEN is a synthetic data generation tool for creating 3D models and corresponding depth maps of civil structures. It generates varied 3D models with customizable textures, deformations, and viewpoints to train models for 3D surface reconstruction, displacement measurement, and deformation analysis. The framework employs a generative texturing neural network [4] for surface textures and uses Blender [5] to render multi-view images, depth maps, and camera parameters. This approach accelerates DL in SHM by providing scalable, high-quality datasets as alternatives to real-world data. Some example images of a water tower and a beam-shaped structure, along with their corresponding depth maps, are presented in Figure 1.



(a)

(b)

Figure 1: Synthetic images and depth maps of a water tower and beam structure.

Method 2: S CRKGEN for vision-based damage detection

For more focused applications in damage assessment, a text-to-image generative model [6] framework is developed for crack image synthesis. This approach utilizes ChatGPT [7] to generate text prompts, guiding a diffusion model in producing high-quality crack images. The diffusion process consists of two phases: forward diffusion, where noise is incrementally added to an initial image x_0, and reverse diffusion, where noise is progressively removed to restore a realistic image. In the forward diffusion phase, noise is added at each time step t such that:

$$x_t = \sqrt{1-\beta_t}\,x_{t-1} + \sqrt{\beta_t}\,\varepsilon_{t-1} \quad (1)$$

where β_t represents the noise variance at step t, and $\varepsilon \sim N(0,1)$. Over time, this process transforms the initial image x_0 into a noisy state x_t. During reverse diffusion, the probability distribution $p(x_{t-1}|x_t)$ is estimated to progressively denoise the image back towards x_0. This distribution can be expressed as:

$$p(x_{t-1}|x_t, x_0) \propto exp(-\frac{1}{2}(\frac{(x_t - \sqrt{\alpha_t}\,x_{t-1})^2}{\beta_t} + \frac{(x_{t-1} - \sqrt{\bar{\alpha}_{t-1}}\,x_0)^2}{1-\bar{\alpha}_{t-1}} - \frac{(x_t - \sqrt{\bar{\alpha}_t}\,x_0)^2}{1-\bar{\alpha}_t})) \quad (2)$$

Training of the text-to-image model leverages a pretrained encoder that translates images and text into latent spaces, enabling efficient data representation. For reconstruction, the Multimodal Diffusion Transformer integrates text and image encodings with diffusion timesteps, enhancing context integration through attention mechanisms and modular layers. This diffusion approach, combined with the large language model's text prompts, allows for generating diverse crack images that incorporate various crack types, materials, and lighting conditions. Figure 2 shows some sampled crack images generated by CRKGEN.

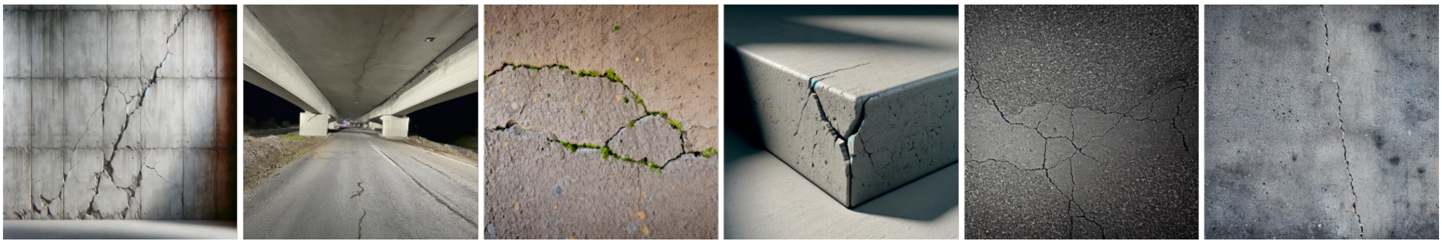


Figure 2: Synthesized rack images generated using the CRKGEN.

Applications of the Synthetic Dataset

3DGEN for Column Shape Structural Surface 3D Reconstruction

The 3DGEN framework generated a synthetic dataset of 39K deformed column shapes: 20K cantilevers and 19K simply supported beams. This included 40K images and depth maps from varied viewpoints, capturing a range of column geometries and deformations. The generated column dataset is used to train a neural network for monocular depth estimation [8], facilitating 3D surface reconstruction. Trained on the generated image-depth pairs, the custom network successfully reconstructed 3D point clouds from web-sourced images of column-shaped structures, confirming its robustness and adaptability to real-world applications. Two examples of column-shaped structure images and their 3D point clouds, reconstructed using a monocular depth estimation neural network fine-tuned with the synthetic dataset, are shown in Figure 3.

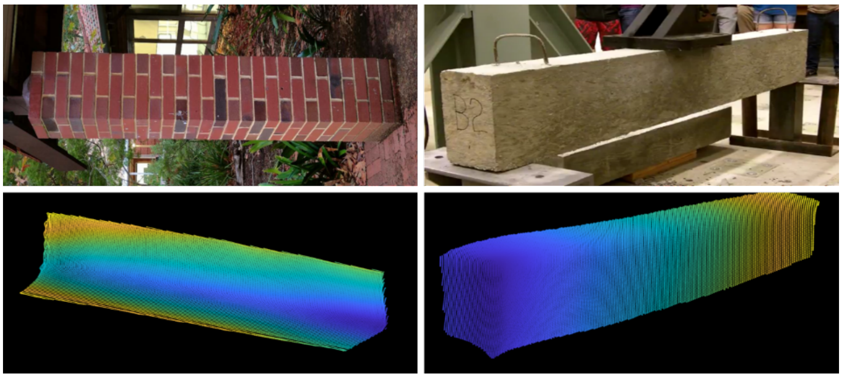


Figure 3: RGB images and 3D point clouds of column-shaped structures.

Synthesized Crack Images for Structural Crack Detection

To evaluate the impact of synthesized data on crack object detection, the YOLOv5 [9] model is trained using the Comprehensive Crack Detection Dataset (CCDD) as a baseline. For testing, the Web-sourced Crack Evaluation Dataset (WCED) is used, containing diverse real-world crack images sourced from web. Synthesized crack images (1.2K positive samples) generated by the proposed framework are incrementally added to the CCDD in stages (400, 800, 1.2K images). The inclusion of synthesized data consistently improved model accuracy. Precision increased from 0.2425 (baseline) to 0.8382, while mAP-0.5 rose from 0.2983 to 0.8374, and mAP-0.5:0.95 improved from 0.0762 to 0.6797. These results indicate that the synthetic data significantly enhanced the YOLOv5 model's ability to accurately detect cracks and generate bounding boxes.

Table 1. Performance of YOLOv5 across different stages of synthesized data integration

Training Data	Testing Data	Precision	Recall	mAP-0.5	mAP-0.5:0.95
CCDD	WCED(P)	0.2425	0.3818	0.2983	0.0762
CCDD+400 SCD(P)	WCED(P)	0.6700	0.6873	0.6599	0.4346
CCDD+800 SCD(P)	WCED(P)	0.7656	0.8009	0.7946	0.6325
CCDD+1.2K SCD(P)	WCED(P)	0.8382	0.8454	0.8374	0.6797

Conclusion

This study introduces a synthetic data-driven framework for SHM, demonstrating the effectiveness of custom datasets in advancing machine learning models for civil infrastructure. Using 3DGEN, comprehensive 3D datasets of column-shaped and silo structures are generated, enabling accurate monocular 3D surface reconstruction. Additionally, synthesized crack images significantly enhanced the precision and robustness of crack detection in the YOLOv5 model. These results underscore the value of synthetic data in overcoming real-world data limitations, offering a scalable and adaptable resource for SHM applications.

Acknowledgments

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Conference News

1. **Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2025 (SSN06)**
   Date: 17-20 March 2025
   Location: Sheraton Vancouver Wall Centre, Vancouver, B.C., Canada
   Website: www.spie.org/SSN06call
2. **Tokyo Symposium of the International Association for Bridge and Structural Engineering (IABSE)**
   Date: 18 to 21 May 2025
   Location: Waseda University and Rihga Royal Hotel, Tokyo, Japan
   Website: https://iabse.org/Tokyo2025
3. **13th International Conference on Structural Health Monitoring of Intelligent Infrastructure (shmii-13)**
   Date: 1 to 5 September 2025
   Location: Graz University of Technology (TU Graz), Austria.
   Website: https://www.tugraz.at/events/shmii-13/home

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