Digital Twin of Reinforced Concrete Infrastructure for Intelligent Asset Management

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Problem

Concrete bridges are susceptible to deterioration from the applied loading and environmental conditions, leading to development of microcracks, typically; in the tensile section of the bridge (bottom side). These cracks lead the unwanted chemical compositions such chlorine and sulphate penetrate through the cracks path and lead corrosion development and impact the structural integrity and potentially failure of the structure. Regular inspections for structural health monitoring are undertaken at certain time intervals through visual inspection or Non-Destructive-Tests (NDTs) which limits the structural integrity during the unprecedented inspection and are based on human intervention of inspection. The current inspection methods are undertaken by vehicular platform, typically for large bridges, to inspect the bottom side of the bridge, shown in the diagram below. However, this technique is expensive, unsafe and not sustainable.

Aim

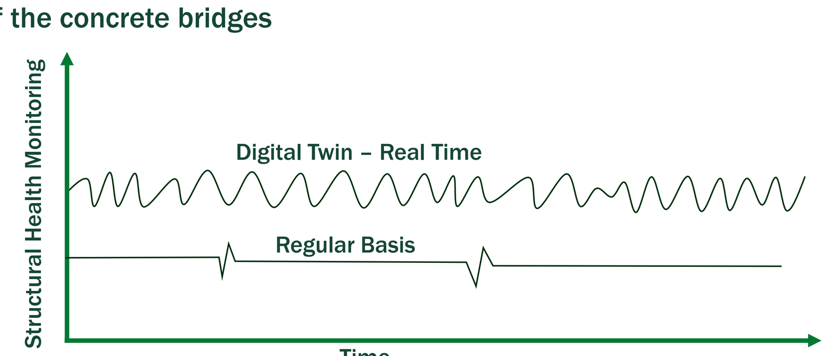
This project aims to shift the current methods of Structural Health Monitoring (SHM) to a more reliable, precise and sustainable method by advancing and integrating advanced technologies. Digital Twin (DT) is the process of developing the digital replica of a physical structure and by using the artificial intelligence (AI), a real time structural health monitoring can be achieved. Effectively, the real time applied loadings and structural integrity including the crack development are visualised and analysed simultaneously during the occurrence.

In this project two concrete bridges in Australia will be instrumented with wireless sensors and a complete digital twin for intelligent monitoring and maintenance of the bridges will be developed by integrating different techniques including the Terrestrial Laser Scanning, Drone images and laser ultrasound.

Objectives

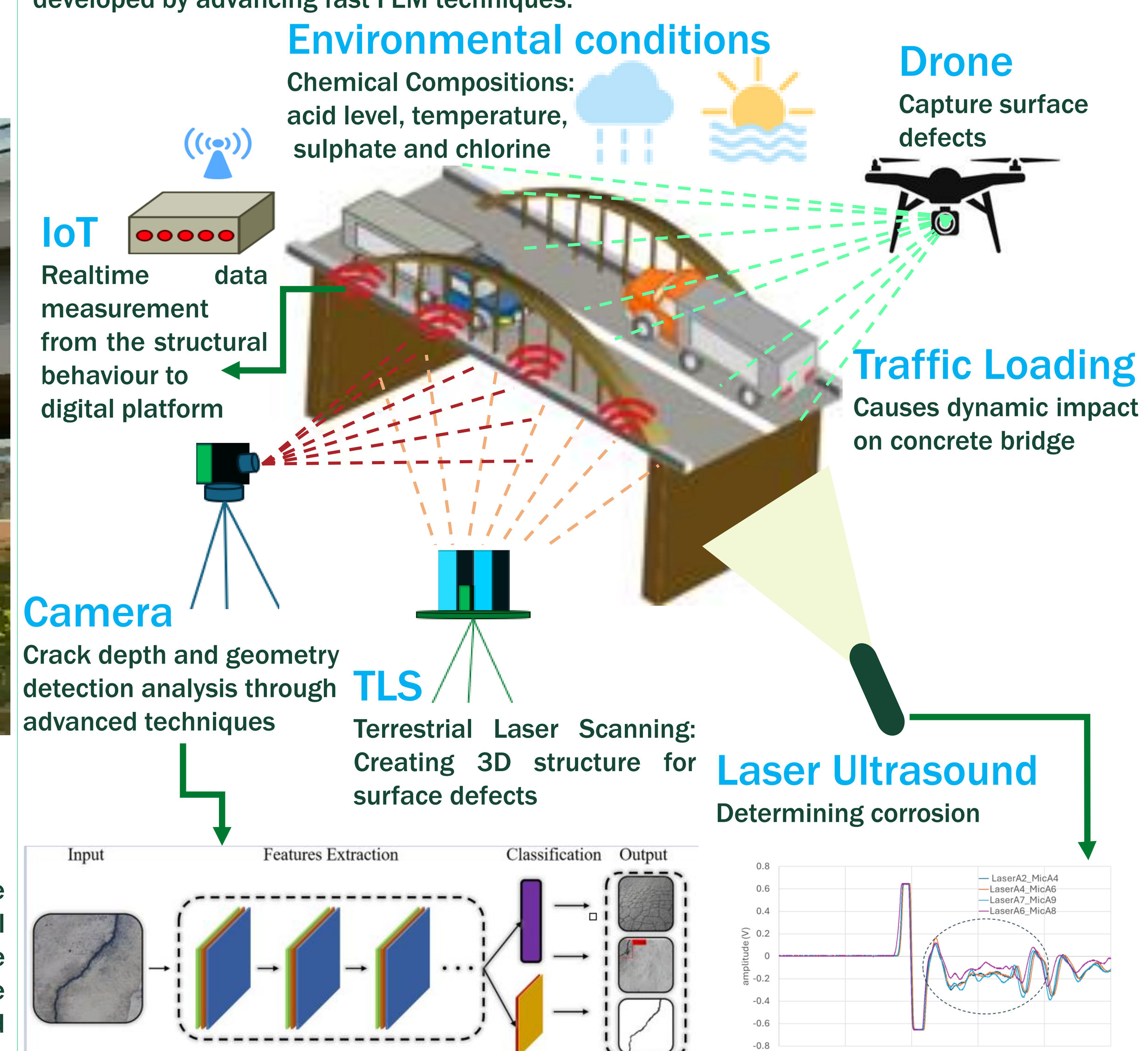
This research project shifts an important milestone towards the structural health monitoring of the concrete bridges. The main objectives of this research includes:

- Sustainable method of structural health monitoring by meeting the triple bottom lines of Sustainability (smoother transportation for users, environmentally friendly and economical)
- User friendly for the asset owners to inspect the structural performance
- The defects identification are more reliable in comparison to the conventional methods of inspection.
- The monitoring is in real time that allows the asset owners to instantly identify signs of any defects and undertake actions of maintenance/repairs, and
- Prolong the useful life of the concrete bridges

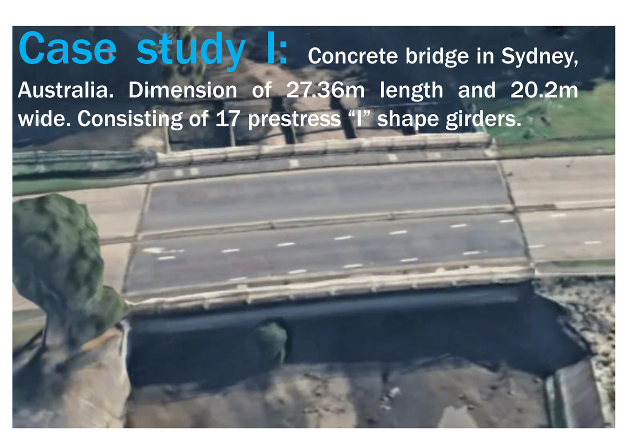


Methodology

Advanced technologies have been used in the development of the digital twin for structural health monitoring of concrete bridges. These technologies include Internet of Things (IoT) for the structural performance, Terrestrial Laser Scanning (TLS) for point could of the structure and drones or images for 3D visualisation of the structural defects, laser ultrasound for the corrosion detection and advanced camera for microcrack detection and 3D geometry evaluation. The data are wirelessly transferred to the digital platform and integrated data from different technologies are then visualised and numerical analysis are developed by advancing fast FEM techniques.



Field work conducted



Case study I: Concrete bridge in Sydney, Australia. Dimension of 27.36m length and 20.2m wide. Consisting of 17 prestress "I" shape girders.

Case study II: Concrete bridge in Melbourne, Australia. Dimension of 22.5m length and 10.3m wide. Consisting of 5 prestress "Super-Tea" shape girders over laid concrete slab.

Dynamic Test

Dynamic sensors placement on surface of concrete bridge to obtained the dynamic behaviour of the bridge under trafficking. These data are used for Finite Element Model (FEM) validation.

TLS

Terrestrial Laser Scanning operated from different location including top and bottom side of the concrete bridges to create 3D visualisation of the concrete bridges for the two concrete bridge case studies.

Drone

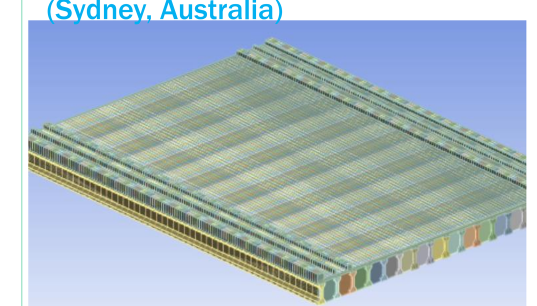
Advanced drone images undertaken for the top, side and bottom side of the concrete bridges for two concrete bridge case studies. These images will be used to develop a 3D section of the bridge showing the cracks and any defects.

Digital Twin Development

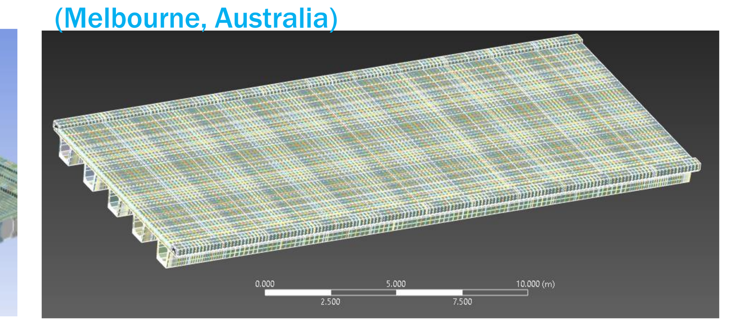
Finite Element Model

Finite element modelling with reinforcement were developed including the model's validation to determine the structural performance of the concrete bridges in real time conditions. Artificial Intelligence will be used to determine the structural integrity and numerical analysis of structural defects including the crack development and their locations.

FE model for concrete bridge (Sydney, Australia)



FE model for concrete bridge (Melbourne, Australia)

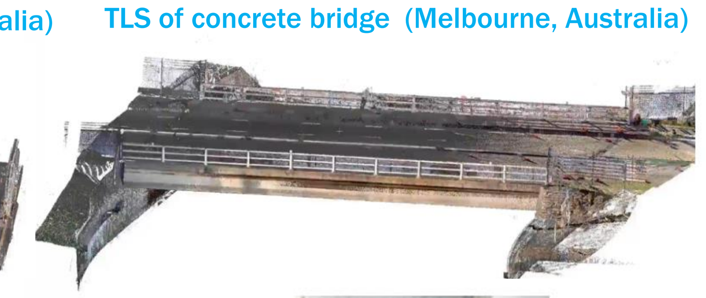


TLS

Digital 3D section of the two concrete bridges by using over 1.07million points obtained from the Terrestrial Laser Scanning visualising all surfaces of the concrete bridges. The 3D visualisation demonstrates the surface defects which might not be detected by the FE model. These defects might come from the environmental impacts that causes the structural deterioration of trafficking impacts such as the potholes or rutting.

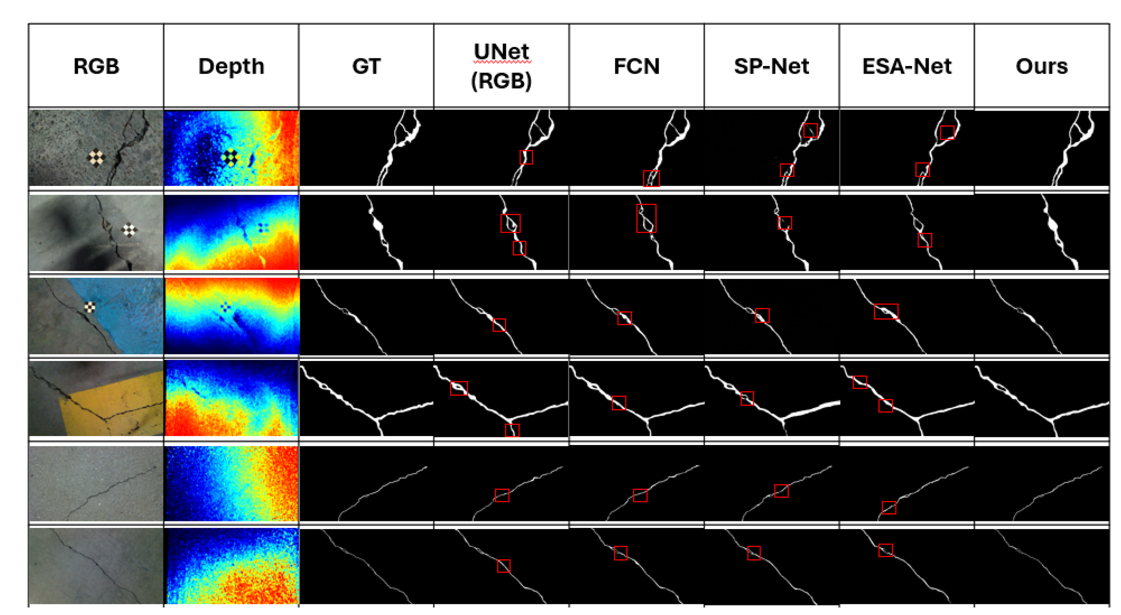
TLS of concrete bridge (Sydney, Australia)

TLS of concrete bridge (Melbourne, Australia)



Camera Images

Laboratory experiments investigating development of cracks and analysing the geometry of these based on different advanced techniques such as RED-Blue-Green (RBG) demonstrated the depth and crack path geometry. These techniques are implemented on drone images and the effectively camera installation on site.

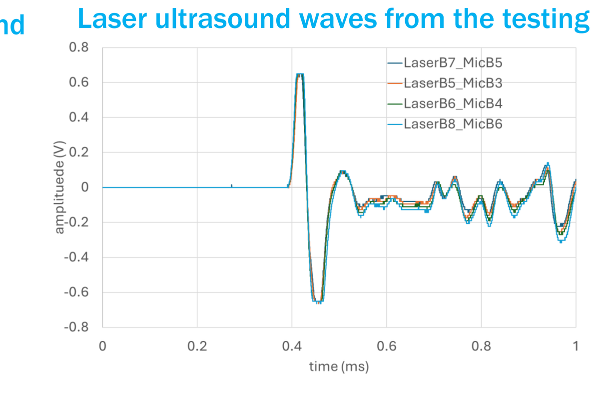


Laser Ultrasound

Laboratory experiments conducing the laser ultrasound determine the behaviour of the structure at laboratory scale. The technique determine the structural behaviour including the crack location and the conditions of the reinforcement. Site testing by using the ultrasound technique determine the reinforcement conditions.

Laboratory experiment using laser ultrasound

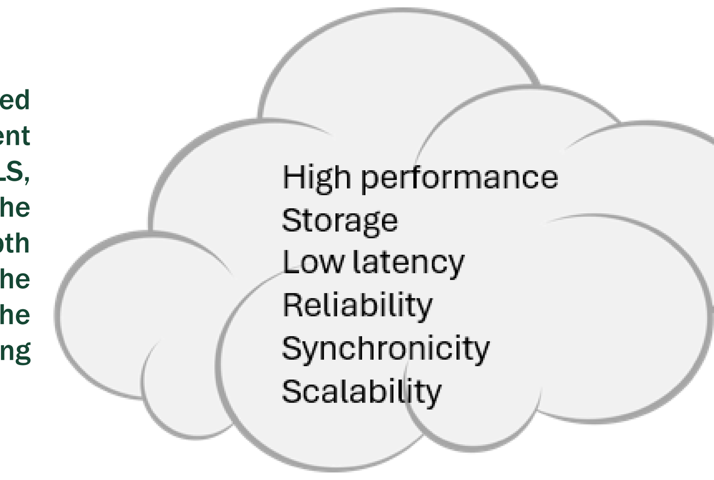
Laser ultrasound waves from the testing



Structural Health Monitoring and Decision Making

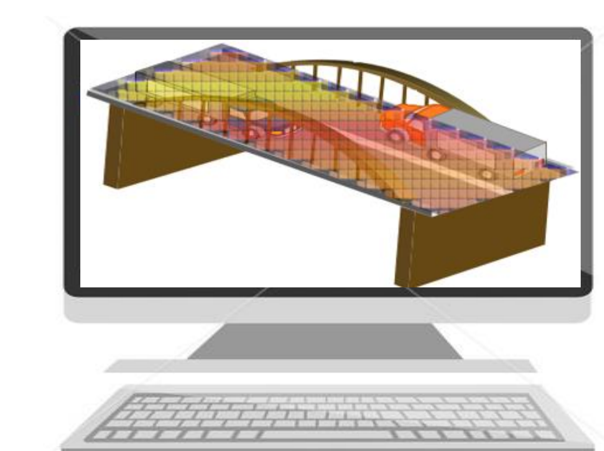
Digital Platform

A suitable digital platform has been developed that receives the real time data measurement from IoT and integrate them with the TLS, drone images. Then sends these data to the desktop and the crack geometry, depth location are then evaluated by using the different artificial intelligence techniques. The digital platform synchronises the receiving data and the sending data real time.



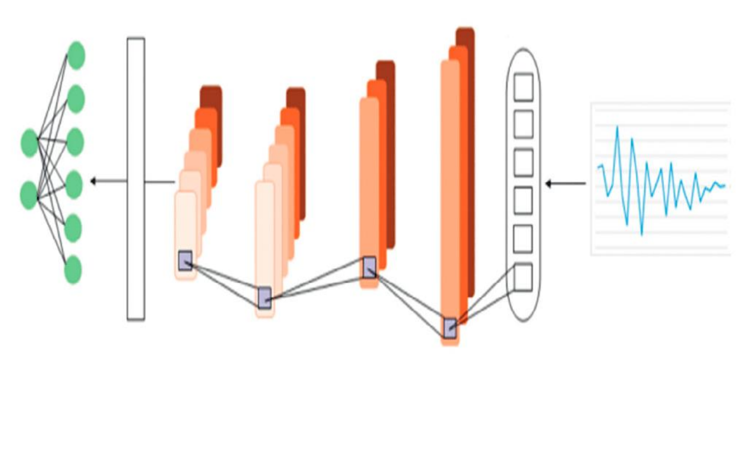
Structural Health Monitoring

Structural behaviour through the different techniques is visualised through the desktop. The numerical analysis for the structural integrity are also analysed while the real time data communication is in the progress. This allows the asset owners to understand the structural health through a real time monitoring.



Automated and intelligent Decision Making

Automated decision making will determine the structural performance and the remaining useful life of the structure based on the current conditions of the concrete bridge. History of the data of the maintenance and repairs coupled with the available methodologies of maintenance will be used to determine the optimum decision making in relation to the workability, economy of the structures and the financial aspects.



Final Decision Making

The intelligent decision making provides the most optimal decisions to be undertaken to maintain the concrete bridge conditions. The type of the maintenances depends on the constraints such as the financial aspects or the workability/accessibility. The asset owner can compare the constraints and the optimum maintenance implementation on the concrete structure.

Conclusion

This research is in collaboration with four universities in Australia, Transportation authorities Australia and a number of industry partners. The transitioning of this digital twin development has been achieved by initially conducting a laboratory scale bridge where the technology development of the digital twin in real time has been achieved. The full complete digital twin for concrete bridges is still under the development. Major field experiments such as taking drone images, Terrestrial Laser Scanning and finite element model validation by using the dynamic tests have been undertaken. The project is in progress for the full development of the digital twin in real time to monitor the structural health of concrete bridges in Australia.

Acknowledgement

The authors would like to acknowledge the support from SmartCrete CRC on the project entitled 'Digital twin of reinforced concrete infrastructure for intelligent asset management'. The project is led by RMIT University and supported by local governments, several universities and industry partners, including the Victoria State Government (Department of Transport and Planning), New South Wales (Transport of New South Wales), Melbourne Water, Australia Curtin University, Western Sydney University and the University of Technology Sydney, Beta International Associates, Upward Technology, Ash Development Association of Australia, Lastek, Macdonald Lucas and Bentley.

SmartCrete CRC | VICTORIA State Government, Department of Transport and Planning | NSW Government, Transport for NSW | Melbourne Water | Beta International Associates | Bentley | RMIT University | UTS | Western Sydney University | Curtin University | Ash Development Association of Australia | 朝上科技 Upward Technology | Lastek Photonics Technology Solutions | Macdonald Lucas | RMIT University