UK COLLABORATORIUM FOR RESEARCH ON INFRASTRUCTURE & CITIES

Connected

Advanced optical technologies for a sustainable built environment

Authors:
Dr Haris Alexakis, Lecturer in Civil Engineering, Aston University

David J. Webb, 50th Anniversary Professor of Photonics, Aston University

Introduction

Harnessing the properties of light to understand - and indeed control - the physical world has been practised since the time of the ancient Greek philosophers Pythagoras and Democritus. In recent times, the term photonics has been coined to describe this technology, and it is having a transformative impact across multiple sectors, including medicine, manufacturing and of course telecommunications, where it forms the backbone of the internet. The ability to sense and communicate using light is also becoming very relevant in civil engineering where it can help address some increasingly important issues.

Transforming monitoring and maintenance

Civil infrastructure deteriorates due to material fatigue, overloading, seismic action, ground movement and environmental effects. These affect the serviceability and structural integrity of civil assets causing socio-economic disruptions and even loss of life.

Climate change and energy/resource depletion force infrastructure managers to minimise carbon-heavy activities, such as replacing and rebuilding ageing infrastructure, and at the same time guarantee public safety and the longevity of their infrastructure networks. That requires the transformation of current maintenance and operational decision-making practices to (i) effectively estimate the remaining life of deteriorating assets, (ii) quantify, prioritise and assess the effectiveness of retrofitting interventions, and (c) restrict operational loads when needed.

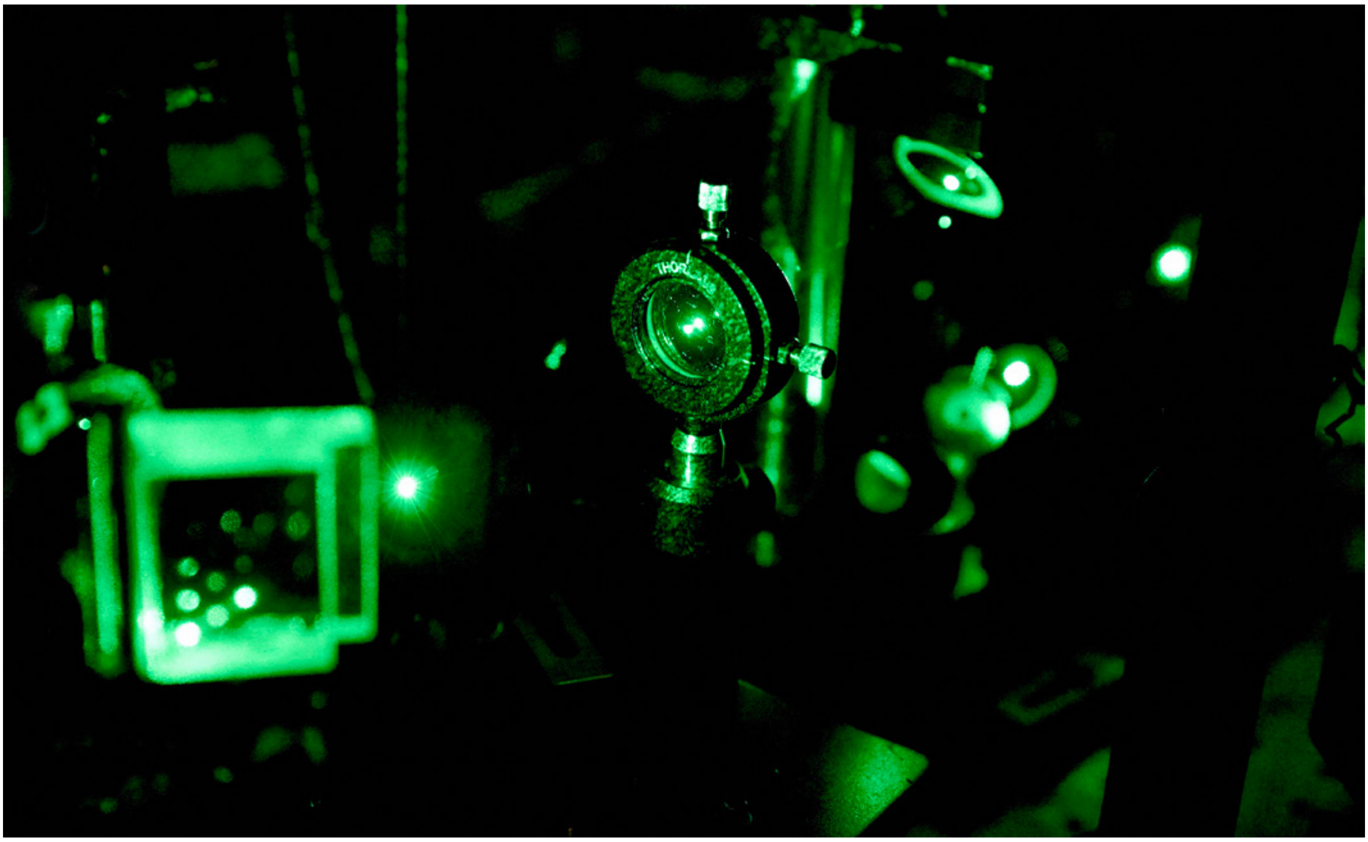
However, the challenges to manage civil infrastructure based on informed decisions are significant, due to the vast size of deteriorating infrastructure networks and the complexity of the structural systems, which are usually characterised by a high level of uncertainty due to material non-linearities and unknown mechanical parameters.

Advancement in sensing technologies

Given the difficulty to model effectively such complex deteriorating systems, researchers have been increasingly adopting data-driven approaches that rely on comprehensive sensing systems to measure more directly the performance of infrastructure. This is done in an effort to minimise any uncertainties due to our lack of knowledge about their physical behaviour, or to better inform any existing physical models.

These approaches have become more attractive recently due to advances in sensing technologies, fast communication, cloud computing and machine learning. Optical sensing and telecommunication technologies offer unique advantages to support data-centric engineering to enable system-of-systems approaches to digitalise civil infrastructure and cities, and inform actions.

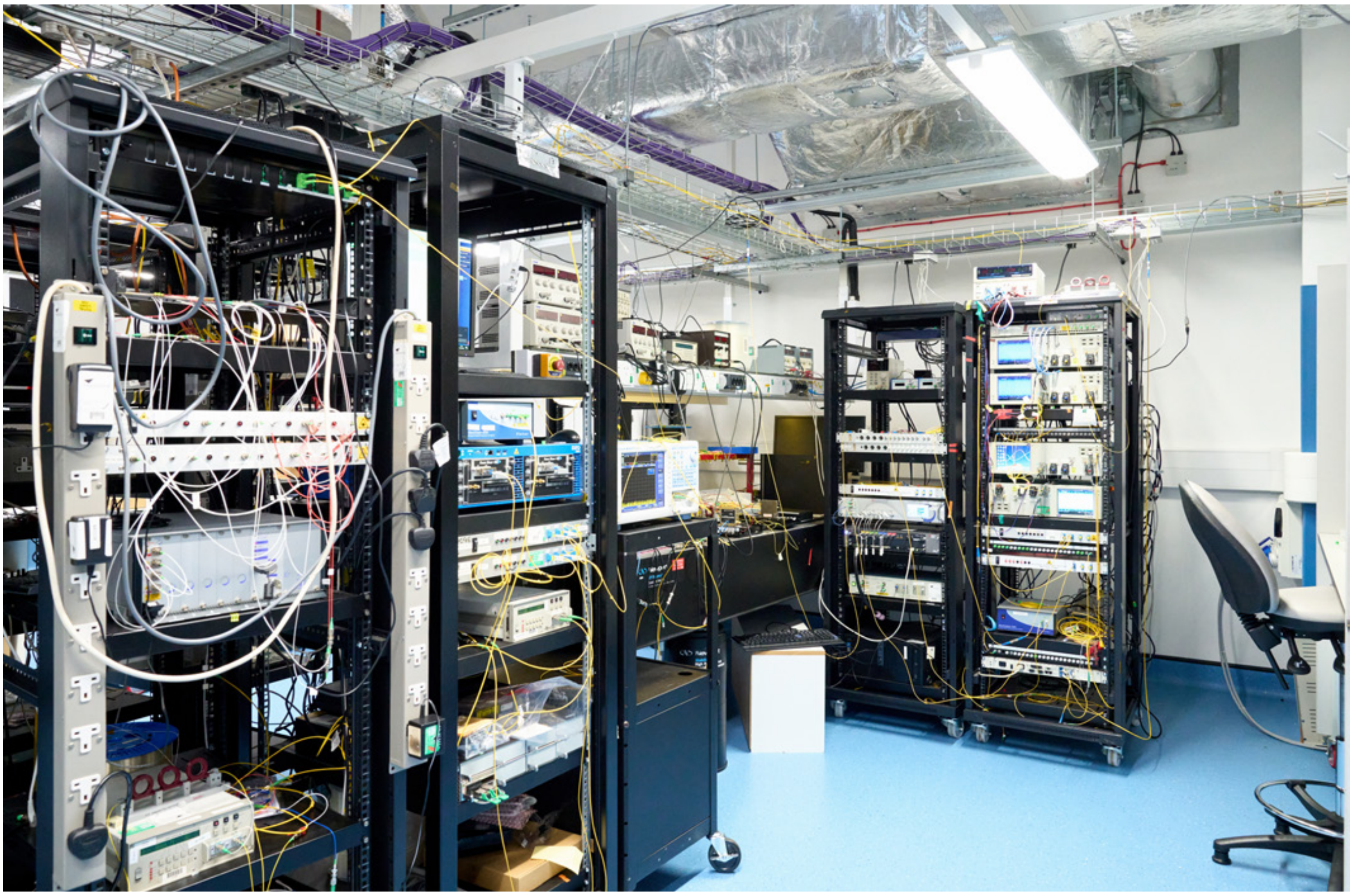
Optical techniques offer a complementary approach to more conventional, electrical and electronic sensors. Broadly speaking they can be divided into those exploiting optical fibres to measure various parameters and non-contact techniques. The latter effectively includes the time-honoured approach of visual inspection, but machine-based vision systems are able to exploit a much wider region of the electromagnetic spectrum, invisible to the human eye. Multi- and hyper-spectral imaging systems can record a complete spectrum for each pixel in an image, which for example can enable the properties of concrete to be assessed remotely.



Modern drone technology facilitates the inspection of difficult to access areas of a structure. LiDAR (Light Detection and Ranging) systems can provide positional information allowing the geometry of a structure to be monitored over time, while Laser Doppler Vibrometry can be used to monitor the vibration of the surface of a structure in a non-contact manner.

The optical fibres used for telecommunications can be processed in a variety of ways to create sensors for a wide range of measurands, including temperature, strain, acoustic emission and various chemicals. Optical fibre sensors have several features that are potentially useful for structural health monitoring:

- Optical fibres can transmit light over long distances with very little loss; this enables sensors to be located many kilometres from a control room without the need for any signal amplification – an important advantage when monitoring large structures.
- Techniques exist for multiplexing many sensors along a single optical fibre, in some cases reaching several hundreds. This enables the cost per sensor to be kept reasonably low when monitoring large complex structures.
- Optical fibres are small in diameter (comparable to human hair), which means they can be incorporated inside a structural material without significantly affecting its integrity. Optical fibre sensors have been used in this way to monitor the rebars in reinforced concrete and to create "smart" carbon fibre reinforced plastic wraps used to repair decaying structures.
- Optical technology has enabled a unique form of monitoring – Distributed Fibre Sensing – in which measurements can be made all along an optical fibre, which can be up to 100km in length. Spatial resolution can be down at the cm level (though there is always a trade-off between spatial resolution, sensing length and measurement time). Distributed Fibre Sensors can be used to monitor strain, temperature and acoustic signals.



Cutting-edge capabilities

The Aston Institute of Photonic Technologies (AiPT) has recently joined UKCRIC to bring cutting-edge laser, optical sensing, and optical machine learning technologies with the potential to transform the current practices in the construction sector and suggest new ways to better interconnect and monitor the built environment. New interrogation techniques can enable dual-purpose sensing and communication networks for large scale monitoring of cities and linear infrastructure. Ultra-fast frequency comb lasers can enhance the sensitivity of existing technologies to an unprecedented level and allow multi-aspect sensing. Better spectroscopy and hyperspectral imaging could change the way we assess material degradation. Data from optical sensors and integrated end-systems can be naturally linked to the optical communication networks, and to data platforms for system-of-systems approaches of any scale, while potentially integrating optical and quantum computing in the near future.

Dr Haris Alexakis, Lecturer in Civil Engineering, Aston University

David J. Webb, 50th Anniversary Professor of Photonics, Aston University

Aston University
BIRMINGHAM UK

UKCRIC

UK COLLABORATORIUM FOR RESEARCH ON INFRASTRUCTURE & CITIES

DOI: 10.14324/000.rp.10193790

Connected

Thought Leadership

UCL, Chadwick Building, Gower
Street, London WC1E 6BT

www.ukcric.com
hello@ukcric.com
@ukcric

UKRI Engineering and Physical Sciences Research Council