The Foundation for Science and Technology
24th May 2017

Making Cities Work

The application of technology, science and infrastructure improvements to create a place where citizens wish to live

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University of Cambridge

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What makes a Smart City in which citizens wish to live?

- Environment
- Health & Well-being
- Culture
- Recreation
- Education and Employment
- Energy
- Transportation & Mobility
- Infrastructure – Physical & Digital

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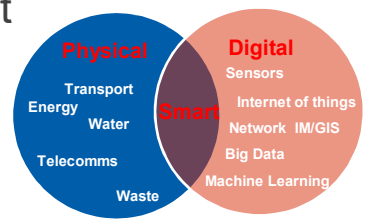
What is Smart Infrastructure?

'Smart infrastructure'

responds intelligently to changes in its environment, with the ability to influence and direct its own delivery, use, maintenance and support



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Challenges facing our city infrastructure

Age

Loading

Uncertain future

Implications for

Risk and Resilience

Asset management

Design

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Dawlish, February 2014

Tadcaster, December 2015

Climate change and infrastructure resilience

Cowley Bridge Railway Junction December 2012

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Vulnerability of city infrastructure

Bridge collapse Minnesota 2007

Metro station collapse Singapore 2004

Flooded electricity sub-station UK 2007

Burst water pipe Stoke Newington 2016

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I-35W Mississippi River Bridge, Minneapolis

8 lane, steel truss arch bridge, built 1967

140,000 vehicles daily

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I-35W Mississippi River Bridge, Minneapolis

6.05pm Wednesday 1 August 2007

13 killed, 145 injured, ~ 100 cars involved

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I-35W Mississippi River Bridge, Minneapolis

Bowed gusset plates photographed in 2003

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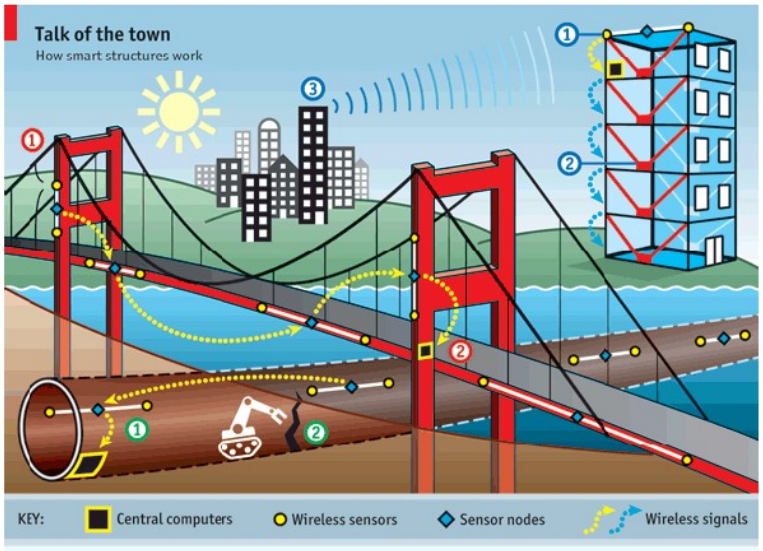
Smart City Infrastructure - The Vision



Source: The Economist, Dec 2010

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The Economist

Inside story

Superstructures

Engineering: Adding sensors and other devices to bridges, tunnels and buildings can turn them into "smart structures" capable of sensing and, in some cases, even responding to problems

Dec 9th 2010 | from PRINT EDITION

"If a car can be made smart enough to spot when the oil is low or a brake light has failed, why not do the same for bridges, tunnels and buildings?"

Recent developments in sensor technologies provide major new opportunities for ensuring resilient infrastructure

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CSIC Cambridge Centre for **Smart Infrastructure & Construction**

An Innovation and Knowledge Centre
Funded by EPSRC and Innovate UK

Mission:

"Transform the future of infrastructure through smarter information"

Vision:

- **Enable step changes in construction practice**
- **Establish a world-leading sensing and monitoring industry**
- **Extend asset life & reduce management costs**

Phase 1 – 2011-2016 & Phase 2 – 2016-2021

www.centreforsmartinfrastructure.com

@CSIC_IKC

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£22m for 10 years from UK Government and Industry

Infrastructure Clients (Owners and Operators)

Consultants, contractors and asset managers

Technology & information supply chain

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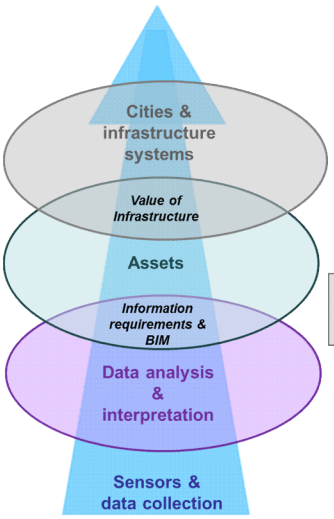
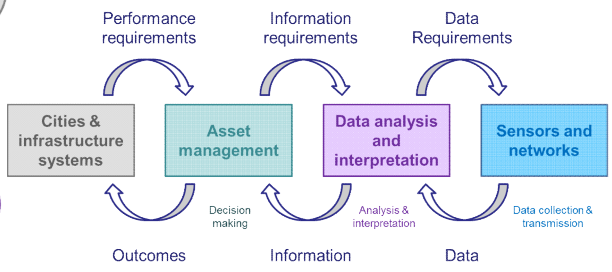
Four scales of challenge





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CSIC Approach

1. City scale

- Modelling urban development
- Human interaction with infrastructure
- Smart city standards

2. Asset scale

- Whole life value approaches to asset management
- Smart information for asset management, design and construction

3. Sensor scale

- Distributed fibre optic strain sensors
- Wireless sensor networks and MEMS devices
- Energy harvesting – sensors without batteries
- Computer vision

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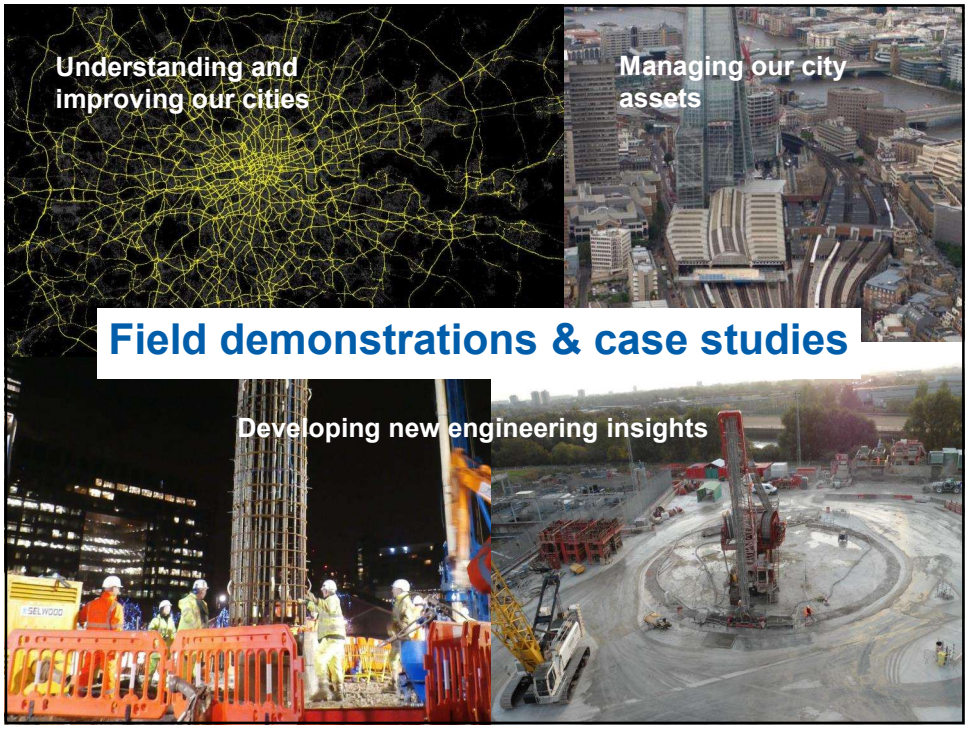

Innovative Fibre Optic Sensing

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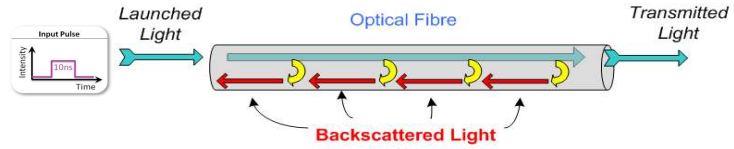
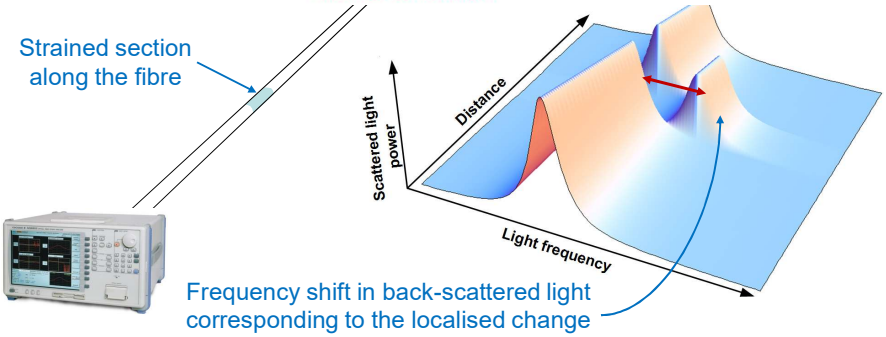
Innovative fibre optic sensing

Distributed (Brillouin) fibre optic strain (DFOS) sensing





Frequency shift in back-scattered light corresponding to the localised change in strain.

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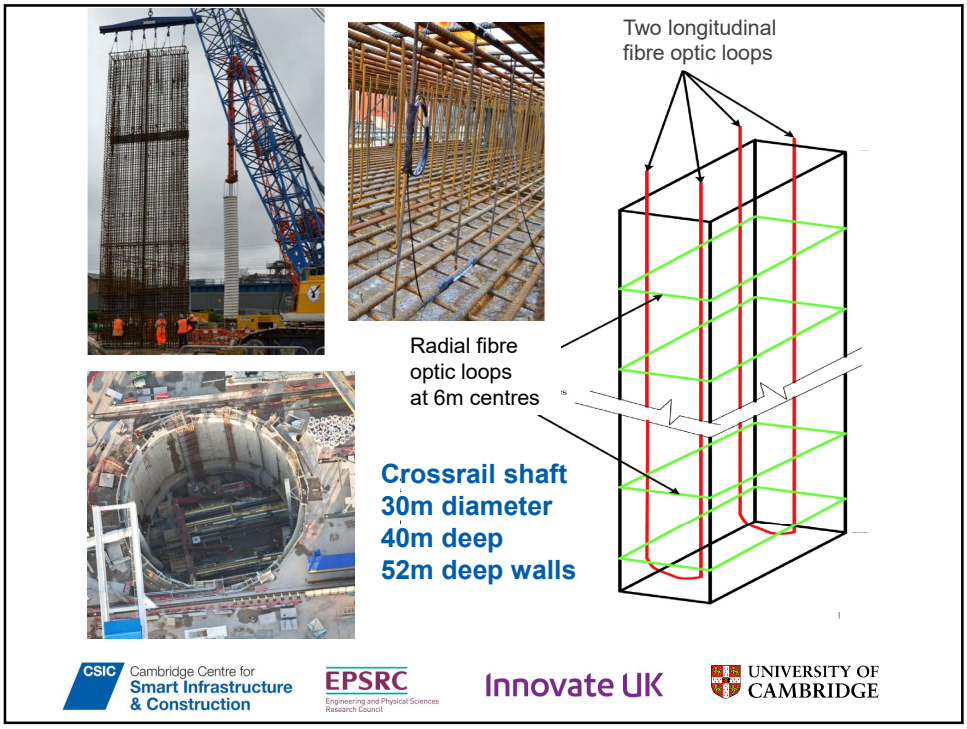
Two longitudinal
fibre optic loops
Radial fibre
optic loops
at 6m centres
Crossrail shaft
30m diameter
40m deep
52m deep walls
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Crossrail: fibre optics in sprayed concrete tunnel linings at Liverpool Street station

Fibre optic sensor installation to monitor joint movement in London Underground tunnel

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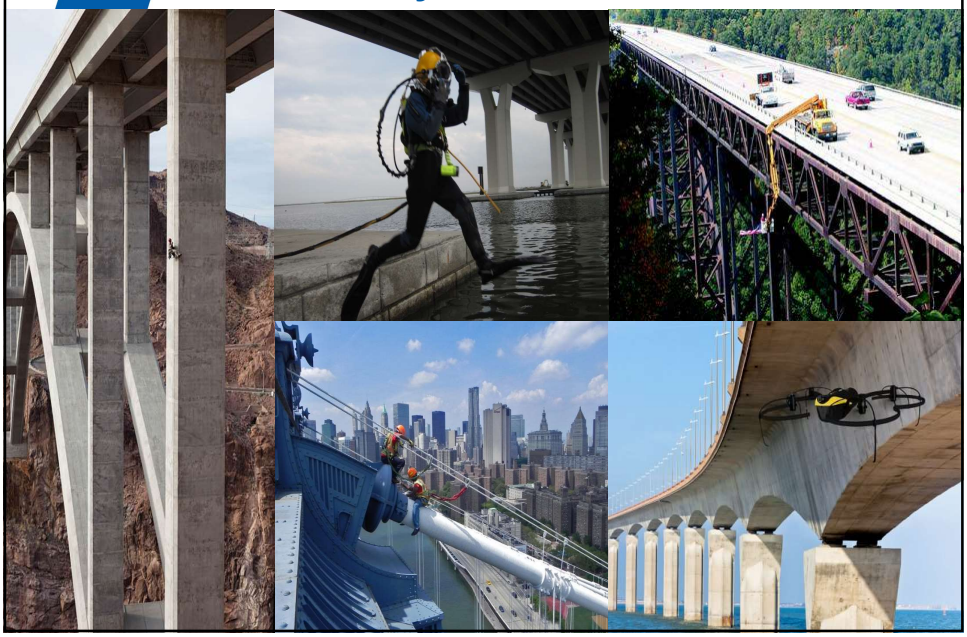
CSIC Traditional asset management of bridges relies heavily on visual observation data



Masonry arch bridges

- 18,000 bridges in the UK are constructed of masonry in uncertain condition
- 3 instances of partial masonry bridge collapse in the UK in 2015 & 2016 alone

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Vulnerability of masonry bridges

- Axle loads today are 2-3 times higher than 19th century
- Train cars today are twice as long (24m typical)
- Many masonry bridges are noticeably damaged
- Speed restrictions for railway bridges causing delays

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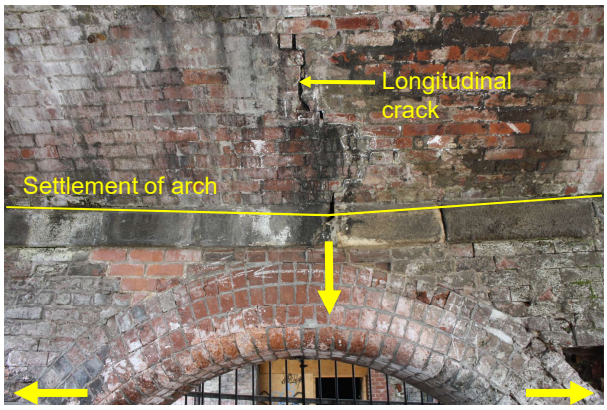
Structural issue for Leeds masonry railway bridge: cracking around relieving arch



Need for train speed restrictions?

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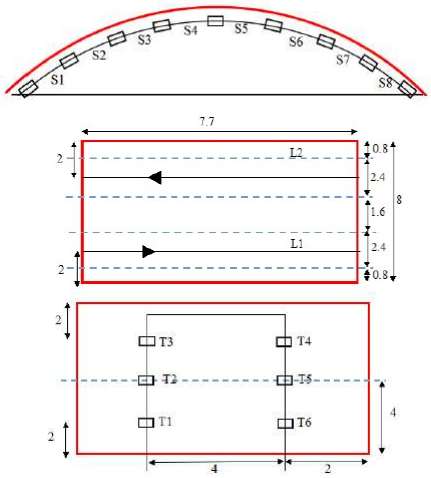
Sensing for Leeds masonry railway bridge

Fibre optics and computer vision

Sensors show speed restrictions not necessary



- Measure dynamic strain (5με error, 250Hz, 320 sensors)
- Understand load flow in longitudinal and transverse directions
- Measure arch bending strains, as well as span and crack opening

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Wireless Sensor Networks and MEMS Devices

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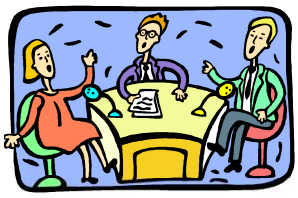
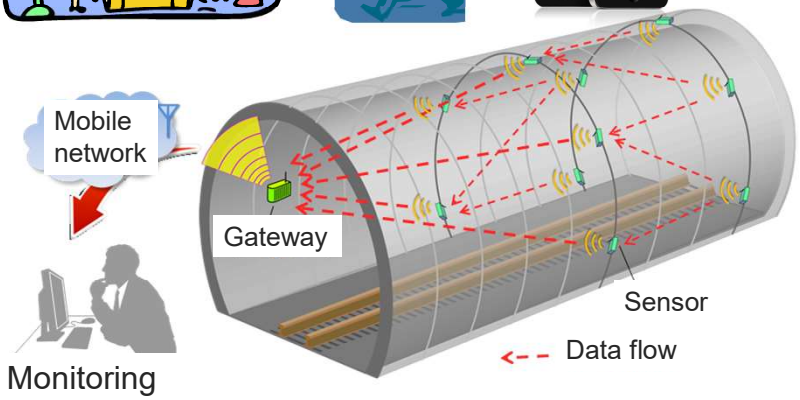
Wireless sensor networks



www.apple.com



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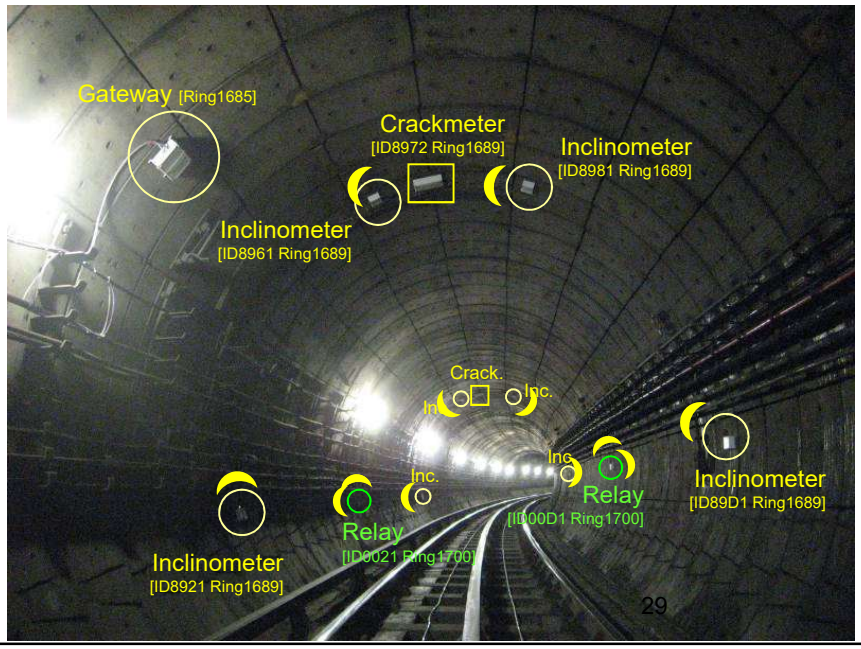
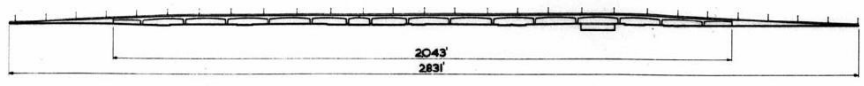
Wireless Sensor Network in London Underground Tunnel



Hammersmith Flyover



"should not cost a halfpenny to maintain over the next hundred years"

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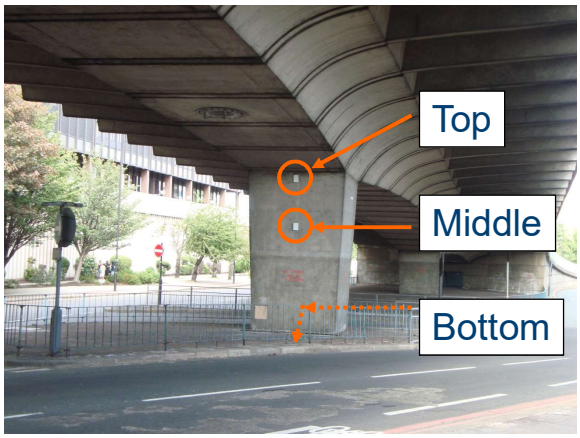
Hammersmith Flyover:
wireless sensors on piers

- Displacement
- Inclination
- Strain
- Temperature
- RH



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Hammersmith Flyover

Movement?

Bearing

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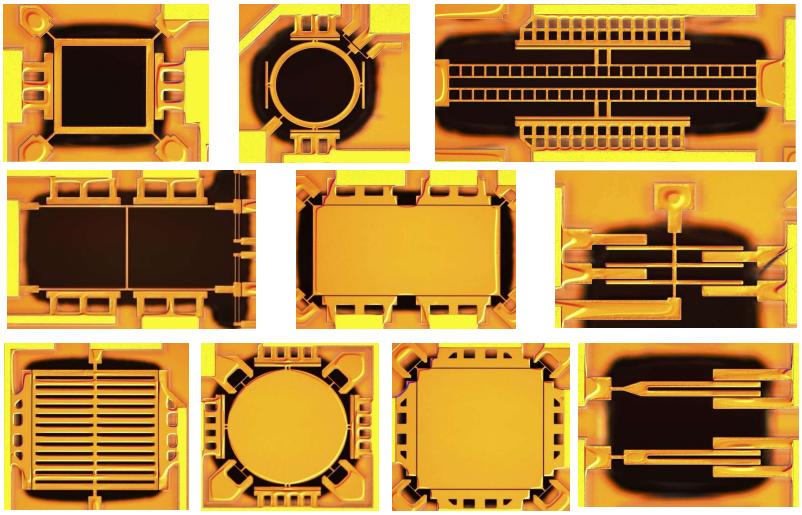
MicroElectroMechanical Systems (MEMS)
Topologies of MEMS Strain Sensors



Ashwin Seshia, Jize Yan and Kenichi Soga

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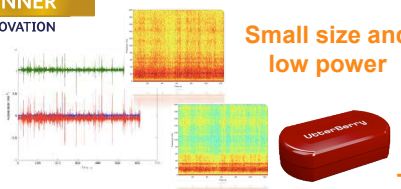
CONSTRUCTING EXCELLENCE in London and the South East AWARDS 2015 WINNER INNOVATION

CIOB INNOVATION & RESEARCH AWARDS WINNER 2014

GROUND ENGINEERING AWARDS 2015

IET AWARDS The Institution of Engineering and Technology · INNOVATION

NCE TA AITES INTERNATIONAL TUNNELLING AWARDS 2013 WINNER



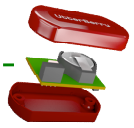
Small size and low power

Power by 32-bit CPU

Designed and manufactured in UK

Accelerometer

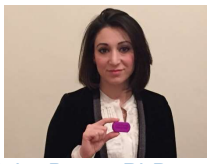
Temperature



Humidity

Angle

UTTERBERRY



Heba Bevan PhD student supervised by Kenichi Soga

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Innovative Sensing for Resilient City Infrastructure

- Distributed strain optical fibre systems
  - Versatile, widely applicable
- Embedded MEMS sensors
  - Low power and low cost
  - High resolution
- Energy harvesting
  - Miniature energy harvesting devices
  - Use of low grade energy available in the environment (vibration, wind, pressure fluctuation, heat)
- Wireless Communication
  - Easy installation
  - Robust networks

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Intelligent Infrastructure and Condition Monitoring

- **Sensors** and 'smart' infrastructure deliver value when they are exploited for managing assets throughout their life – roads, tunnels, bridges, sewers, flood defenses, buildings
- Enable full understanding of performance of **assets** – both during construction and throughout design life
- Greater efficiencies in design and performance, rational strategies for **whole-life** maintenance and asset management
- Huge potential for **city** infrastructure – both old and new

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