Physics-informed digital twin of large infrastructures

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

Digital twin for SHM

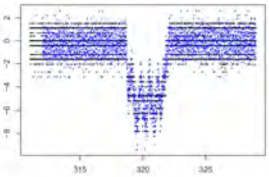
- Advanced sensing technology enables the creation of digital twins for structural health monitoring (SHM)
- Decision making related to maintenance and performance improvement requires highly skilled interpretation

Fibre Bragg Grating sensors (Butler et. al.)

Satellite active remote sensing (Bakon et. al.)

Challenges

- In engineering practice, data is usually scarce and noisy
- Expensive data analysis to support decision making



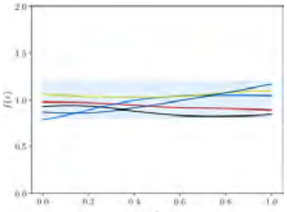
Noisy FBG measurement

Objective

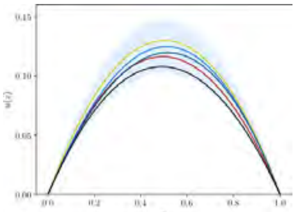
- To develop a smart digital twin using physics-informed finite element (FE) for a more accurate and reliable prediction

Statistical finite elements

- Based on standard FE prevalent in engineering design
- Ability to propagate input uncertainties (force, material, geometry) to the FE outputs (displacements and strains)



Loading with uncertainty



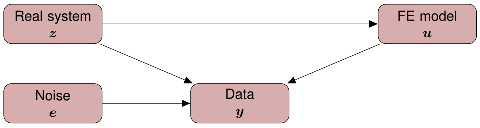
Displacement with uncertainty

- Improved uncertainty quantification of structural response (in comparison with the standard safety factors)

Physics-informed digital twins

- Uncertainties in data, FE model, observation noise, and model parameters are represented using probabilities
- Statistical model representing the digital twin:

$$\boldsymbol{y} = \boldsymbol{z} + \boldsymbol{e} = \rho \boldsymbol{P} \boldsymbol{u} + \boldsymbol{d} + \boldsymbol{e}$$

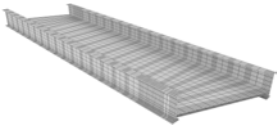


- Bayesian inference of true system and model parameters given the statistical FE density $p(u)$ and data y

$$p(\boldsymbol{u}|\boldsymbol{y}) = \frac{p(\boldsymbol{y}|\boldsymbol{u})p(\boldsymbol{u})}{p(\boldsymbol{y})}$$

Smart digital twin of Staffordshire railway bridge

Staffordshire railway bridge



Digital twin representation

FBG sensors

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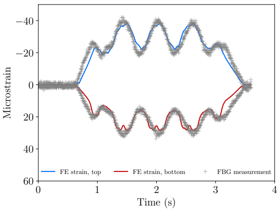
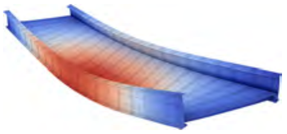
Statistical FE

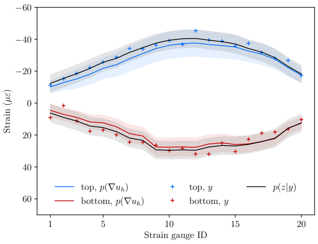


Strain data



FE strain density

Bayes rule



Inferred true strain on the east I-beam

Key attributes:

- Mean of the inferred strain lies between statistical FE and data
- Uncertainty of the inferred strain is smaller than the statistical FE

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