# Hybrid models for Active Noise Reduction

## IOP PEML Workshop

**Matt J. Bryan**[1], Dr Ole M. Nielsen[1,2], Dr Tore Butlin[1]

[1]Cambridge University Engineering Department
[2]Bose Corporation

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UNIVERSITY OF CAMBRIDGE
Department of Engineering

BOSE

M. J. Bryan
mjb314
@cam.ac.uk



# Active Noise Reduction (ANR)

- Active Noise Reduction (ANR) describes the use of secondary sources and control schemes to reduce unwanted noise.
- The technology is mature in headphones:

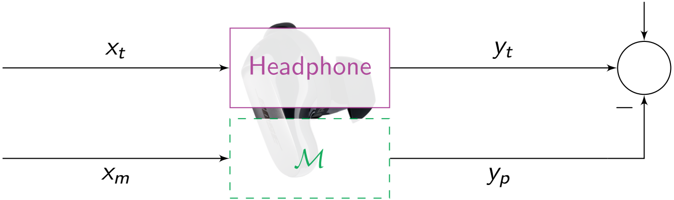


Figure 2: The modelling problem in an ANR system.

M. J. Bryan
mjb314@cam.ac.uk



# Complex systems

- Modelling the reference signal for ANR is more challenging for complex systems.
- Coherence is significantly reduced in cases like automotive systems.
- This is due to the presence of **nonlinearity** and **multiple connections**.

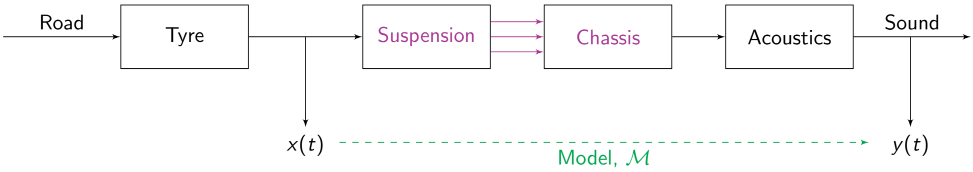


Figure 3: Block diagram of a transmission pathway.

- Such a system is an ideal candidate for **physics-informed** machine learning (PIML) approaches: *low latency* and *high accuracy* are both essential.

M. J. Bryan
mjb314
@cam.ac.uk


# Benchmark system



- PIML methods can be used to separate linear and nonlinear system behaviours.
  - ...which can be used to focus model complexity.
- An abstraction of the car model is used as a benchmark system to test schemes:

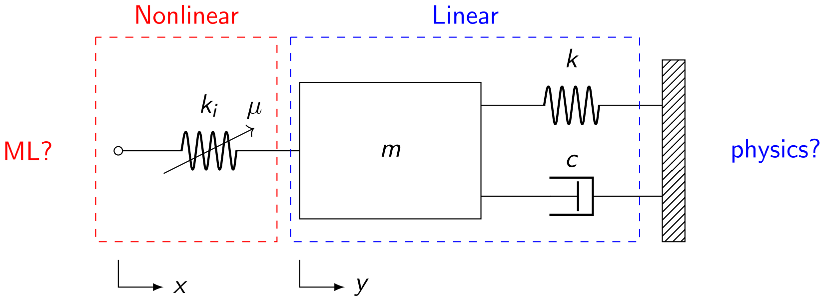


Figure 4: Benchmark nonlinear system with displacement input.

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mjb314
@cam.ac.uk



# Case study

- Two black box models (CNN, RNN) and a PIML model were trained on simulated time-series data ($N = 2000$) from the benchmark system with *moderate nonlinearity*:

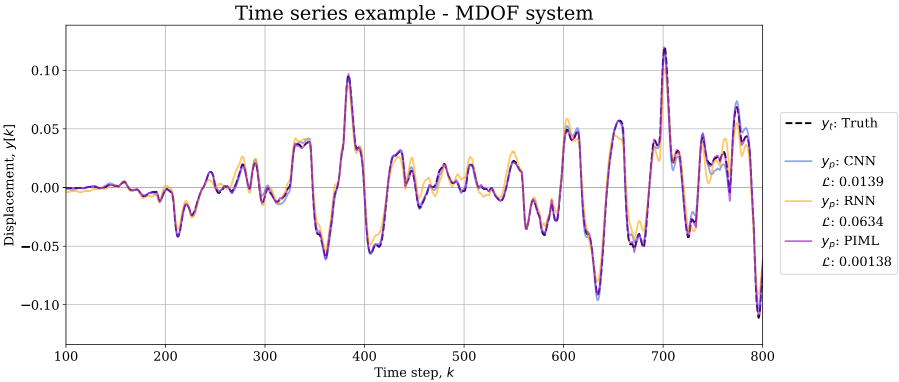


Figure 5: Time domain case study with final validation loss.

# Comparison with data driven methods

- The benefit is most apparent in the nonlinear coherence:
  - Linear coherence between the model prediction $y_p$ and true output $y_t$.
  - *'how much of the nonlinearity is captured by the model'*

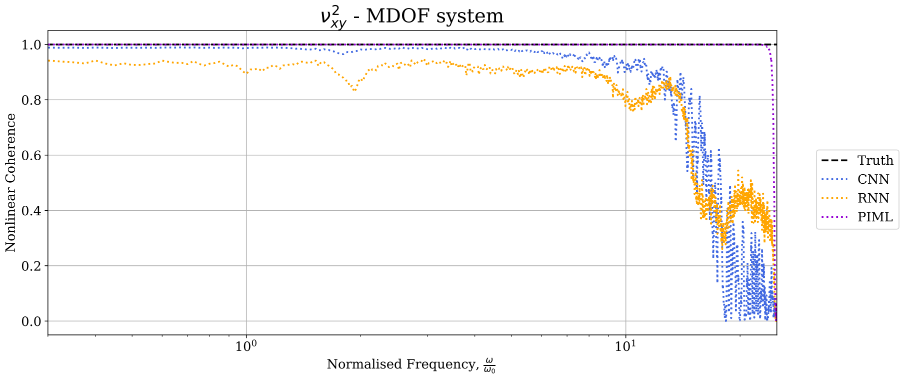


Figure 6: Performance comparison via nonlinear coherence.

M. J. Bryan
mjb314 @cam.ac.uk



# Conclusions



1. Hybrid models can be used to separate linear and nonlinear behaviour in an abstracted benchmark system.
2. Using this physics-informed approach can improve model accuracy compared to purely data-driven methods.
   - ...provided that the form of the nonlinearity is well understood.

**PIML models** are a promising approach for ANR in complex systems.

Future work:

- More complex systems.
- Experimental validation.

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# Nonlinear coherence definition



## Linear coherence

$$\text{Linear coherence} = \gamma_{xy}^2 = \frac{|\mathcal{S}_{xy}|^2}{\mathcal{S}_{xx}\mathcal{S}_{yy}}$$

where $\mathcal{S}_{xy}$ is the cross-spectral density between signals $x$ and $y$.

- This describes 'how much of the behaviour can be described by a linear model'.

## Nonlinear coherence

$$\text{Nonlinear coherence} = \nu_{xy}^2 = \gamma_{y_t y_p}^2 = \frac{|\mathcal{S}_{y_t y_p}|^2}{\mathcal{S}_{y_t y_t}\mathcal{S}_{y_p y_p}}$$

- which describes 'how much of the nonlinearity is captured by the model'.