NeuralSI
Structural Parameter Identification in Nonlinear Dynamical Systems

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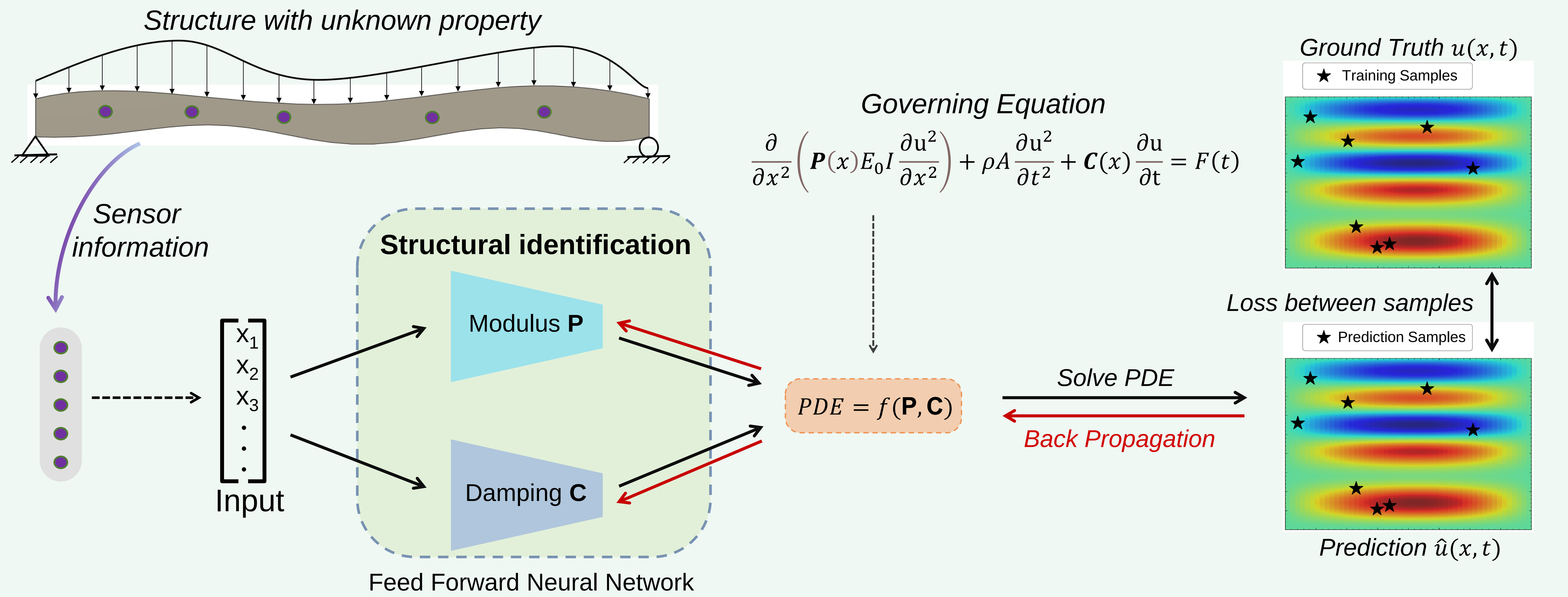
Overview



Motivation

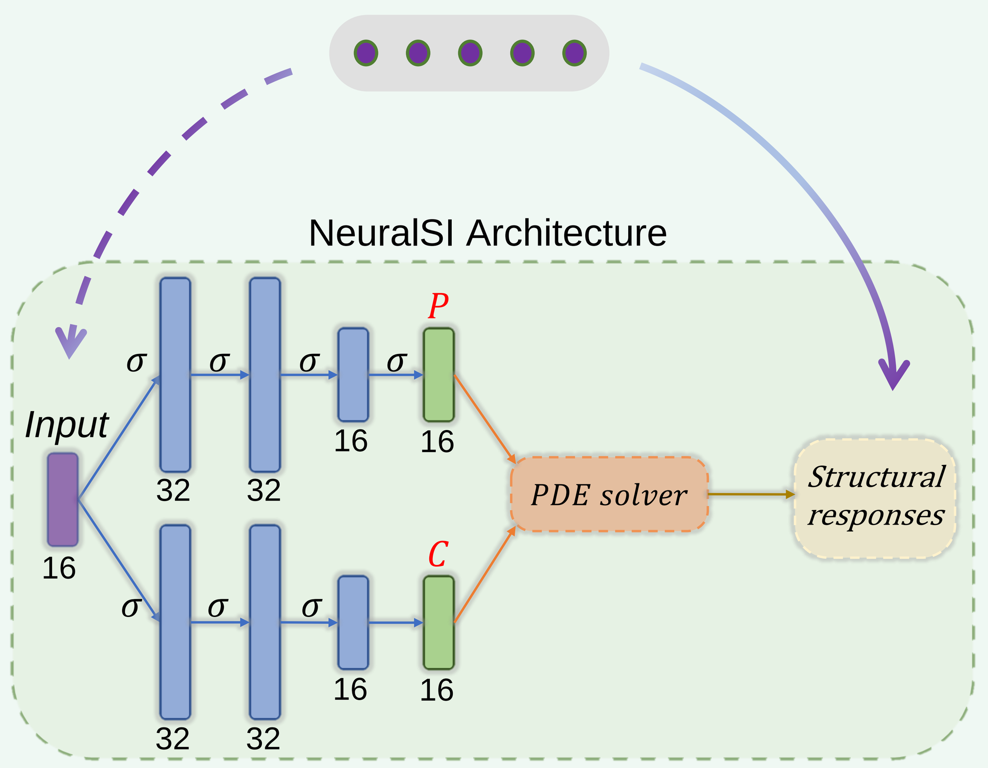
- Structural parameters mismatch between design, lab testing, and real-world.
- Structural systems are often hard to monitor in complex-built environments.
- There is a lack of accurate baseline structural models in real-world.
- Conventional data-driven methods are difficult to train and learn.

Highlights

- Proposed a neural differential equation-based method to **learn unknown structural parameters** from fundamental governing equations.
- NeuralSI achieves much more **accurate dynamic response** predictions compared to PINN-based baselines.
- The learned parameters can be used for accurate temporally dynamic response **extrapolation**.

Proposed Method

- **Information from sensors** can be used as **input** to the NeuralSI network.
- The **network predicts parameters** that control the structural response.
- We find the governing equation for the structural system and solve for response predictions.
- **Loss** is calculated between predicted response and ground truth measured from sensors.



Structural Problem

- **Euler-Bernoulli beam equation:** widely used in civil engineering to estimate the strength and deflection of beam structures.

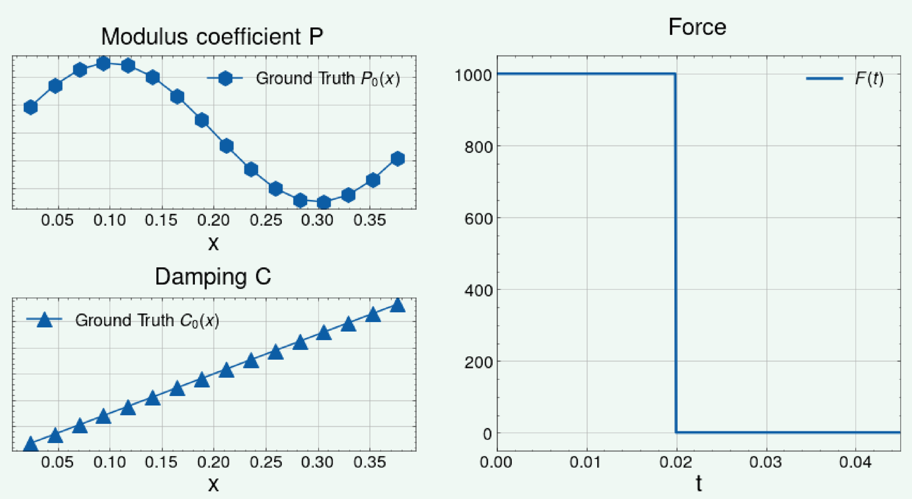
$$F(t)=\frac{\partial^2}{\partial x^2}\left(P(x)E_0I\frac{\partial^2 u}{\partial x^2}\right)+\rho A\frac{\partial^2 u}{\partial t^2}+C(x)\frac{\partial u}{\partial t}$$

- **Boundary Conditions & Initial Condition**: We choose a simply supported beam that starts from static state.

$$\frac{\partial u(x=0,t)^2}{\partial x^2}=0,\ \frac{\partial u(x=L,t)^2}{\partial x^2}=0$$

$$u(x=0,t)=0,\ u(x=L,t)=0$$

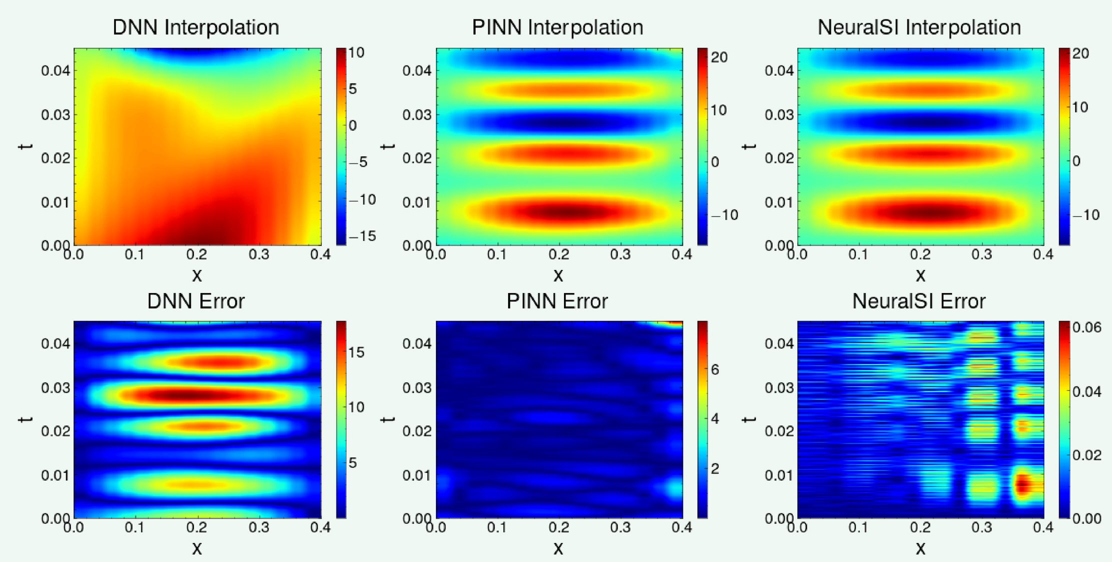
- Target parameters and given force:



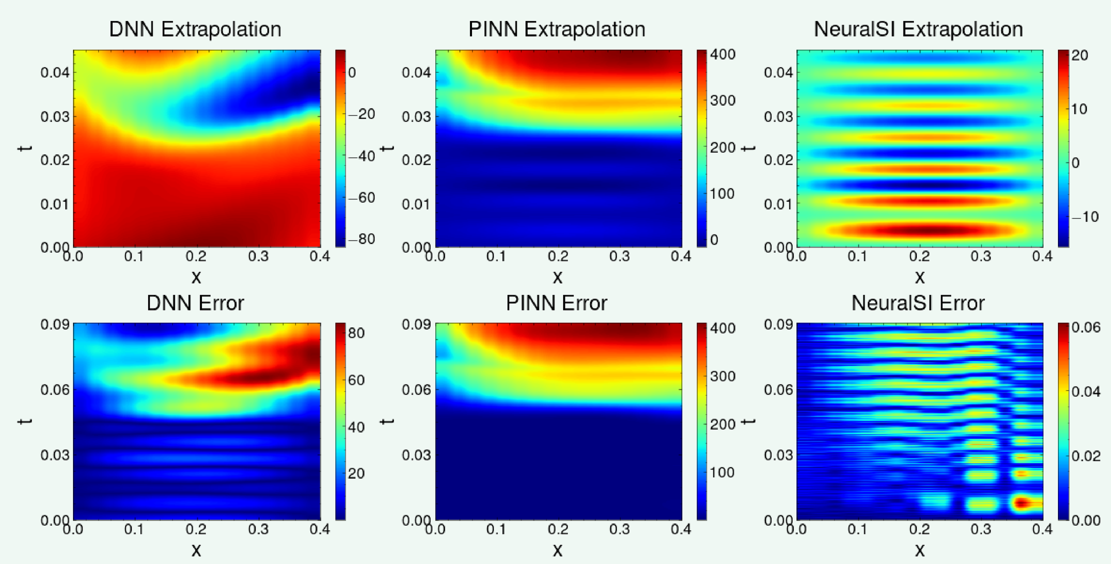
NeuralSI vs PINN

- NeuralSI dynamic response predictions are compared with deep neural networks (DNN) and Physics Informed Neural Network (PINN).

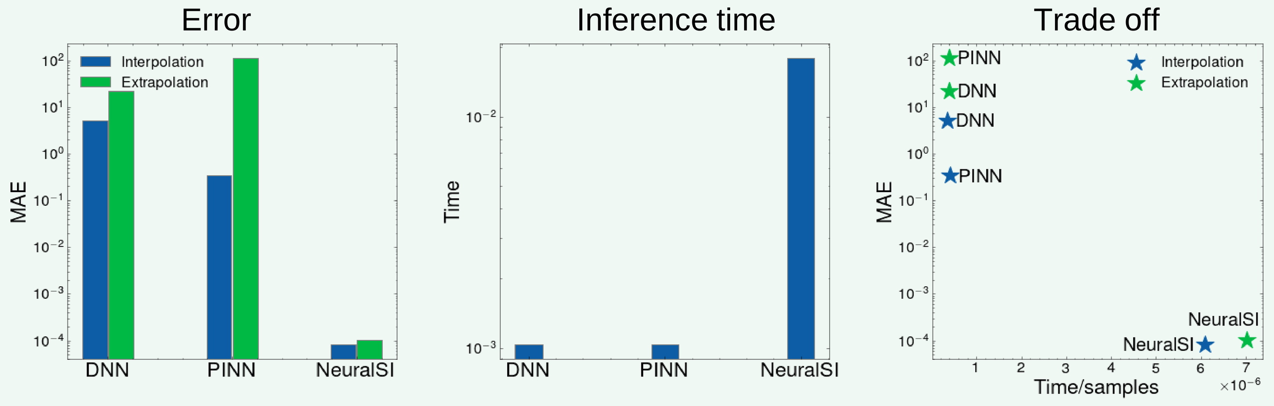
- **Interpolation**



- **Extrapolation**

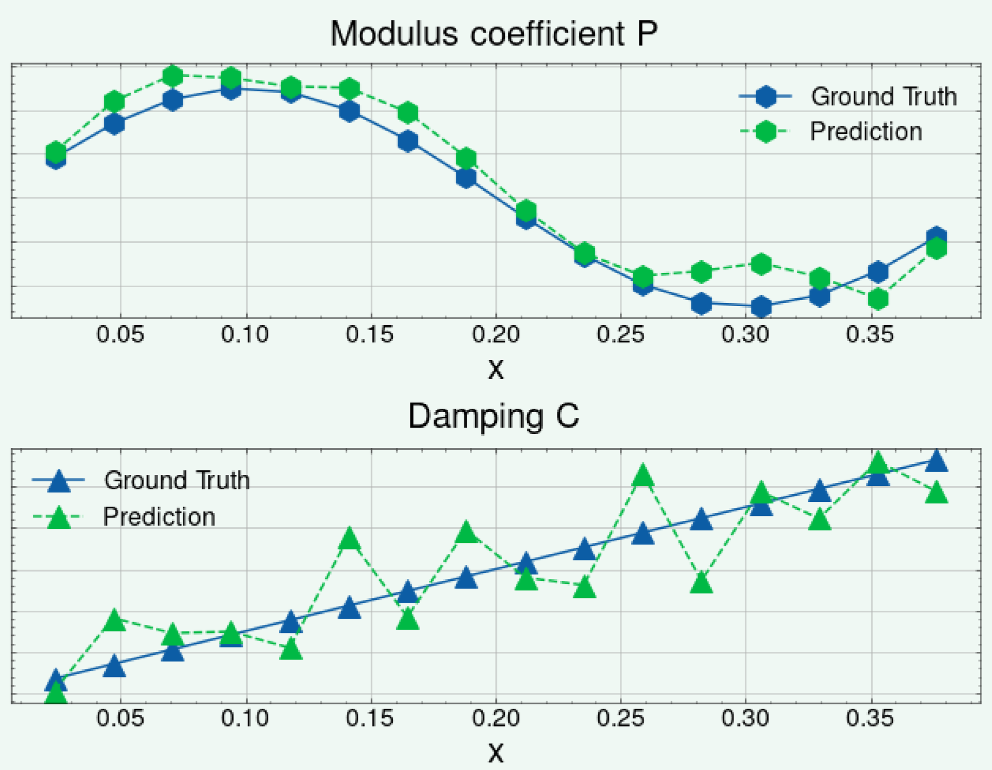


- **Trade-off between accuracy and inference time**



Structural Identification Results

- The predicted parameter matches the ground truth parameters well



Conclusion

- NeuralSI models the **unknown hard-to-measure parameters** via a learnable neural network and embeds it within a partial differential equation.
- The model is **versatile and flexible**, it can be successfully extended to **any PDEs** with high-order derivatives and nonlinear characteristics.
- The estimated structural parameters and the dynamic response variations **match well with the ground truth.**
- In this structural dynamic system, **NeuralSI outperforms** direct regression, **DNN and PINN** methods by three to five orders of magnitude.