Smart Bridge: Machine Learning to Identify Structural defects in a bridge and a moving vibration source in real-time

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Objectives

Using Finite Element Method (FEM) and Inverse Modeling we generate synthetic data to train a Convolutional Neural Network (CNN) to detect damages in a structural material and the frequency and amplitude of moving sources based on the wave responses.

Background

Guidio and Jeong (2021) used Genetic Algorithm (GA)-based join inversion to identify the material profile of a bridge structure using an unknown moving wave source (e.g. a vehicle) and measured vibration data. We solve the research problem using Neural Networks and predict aberrant structural defects and the frequency and amplitude of the moving vibration source.

Numerical Methods

This work consists of a one-dimensional Timoshenko beam supported at four locations by a hinge and three rollers as shown in Fig. 1. Its governing wave equations are the following:

$$\frac{\partial}{\partial x}\left\{GAK_s\left(\frac{\partial w}{\partial x}-\psi\right)\right\}-\rho A\frac{\partial^2 w}{\partial t^2}=-q, \quad (1)$$

$$GAK_s\left(\frac{\partial w}{\partial x}-\psi\right)+\frac{\partial}{\partial x}\left(EI\frac{\partial \psi}{\partial x}\right)-\rho I\frac{\partial^2 \psi}{\partial t^2}=0, \quad (2)$$

where $x \in (0, L)$ denotes a position in the beam (L is the total length of the beam); $t \in (0, T)$ denotes time (T is the total observation time); $w(x,t)$ is the total vertical deflection of a beam at x and t, and $\psi(x,t)$ is the slope of a beam caused by bending only; $E(x)$ is Young's modulus; $G(x)$ is the shear modulus; $\rho(x)$ is the mass density; and $A(x)$ and $I(x)$ denote the cross-sectional area and the second moment of inertia, respectively; $K_s(x)$ denotes the Timoshenko shear factor; and $q(x,t)$ is the excitation force applied from a wave source on the beam.

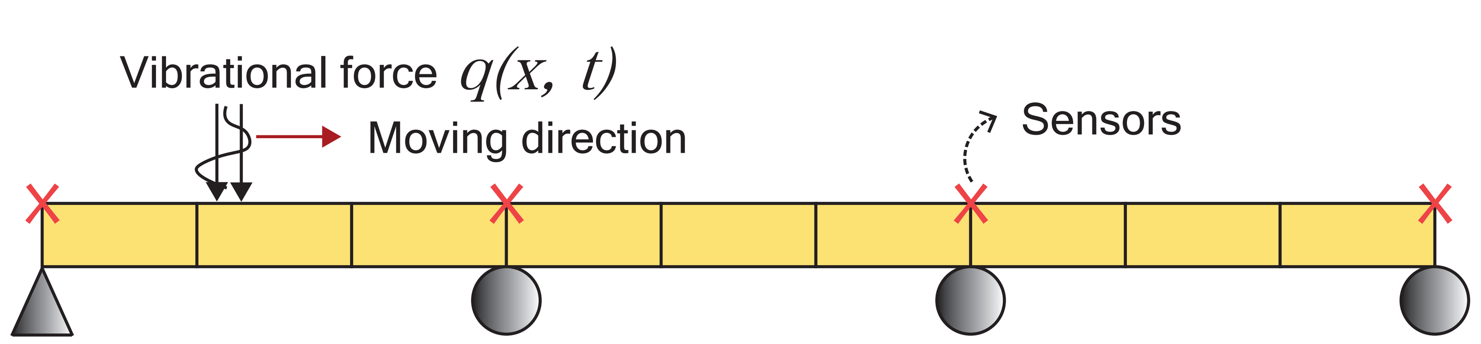


Fig. 1: A beam subject to a moving vibrational load.

We randomize the frequency, amplitude, and nine elastic moduli of the beam structure's nine segments and feed it into our wave-solver to generate displacement waves which are recorded by four-evenly-spaced sensors. We use the displacement waves as input-layer data to train our CNN to predict eleven parameters: two for a moving source (amplitude and frequency) and nine for the elastic moduli of the beam structure's nine segments.

Convolutional Neural Networks

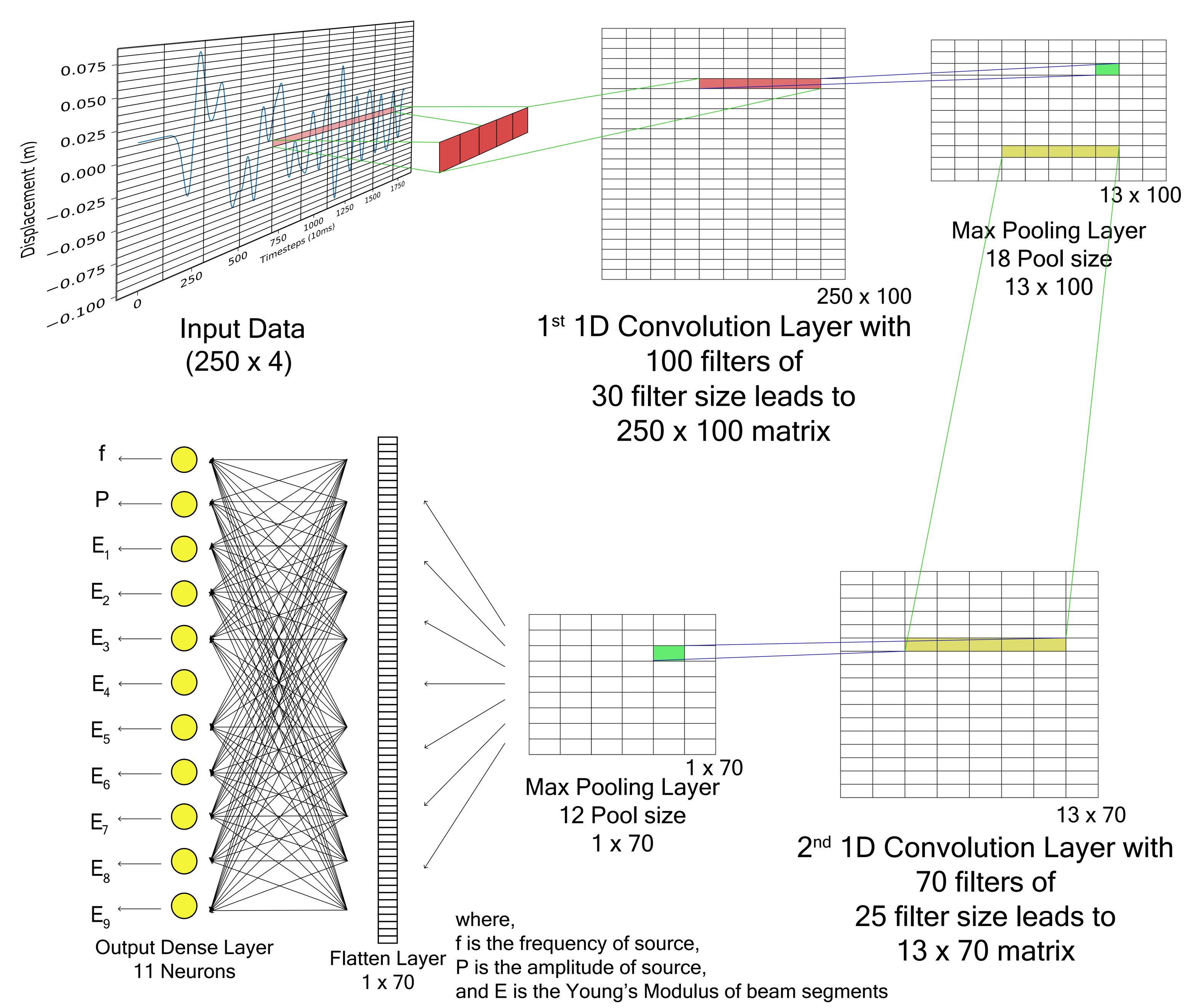


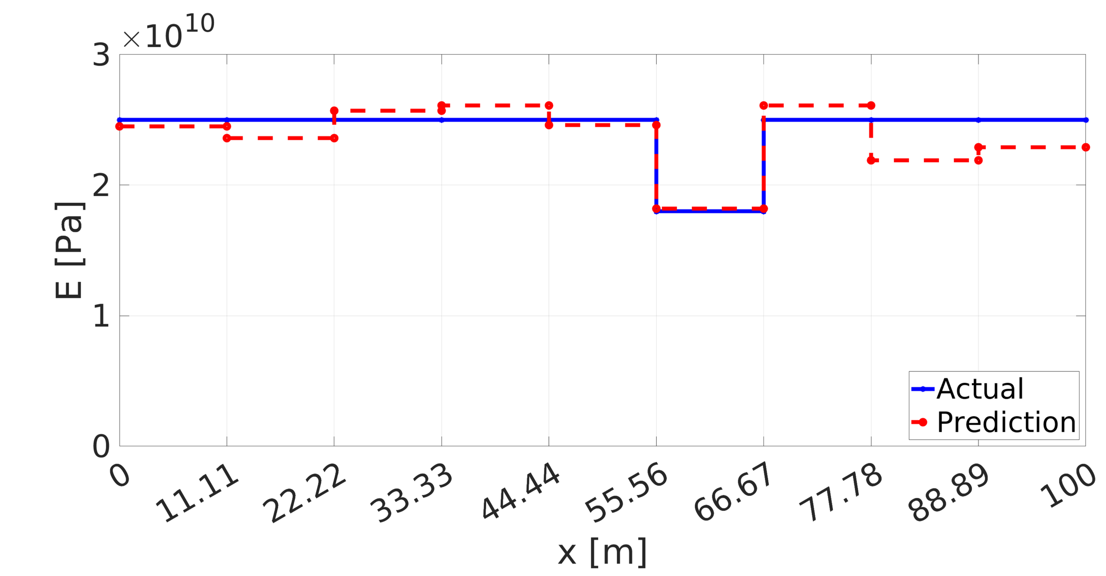
Fig. 2: Our presented Convolutional Neural Network.

Data and Results

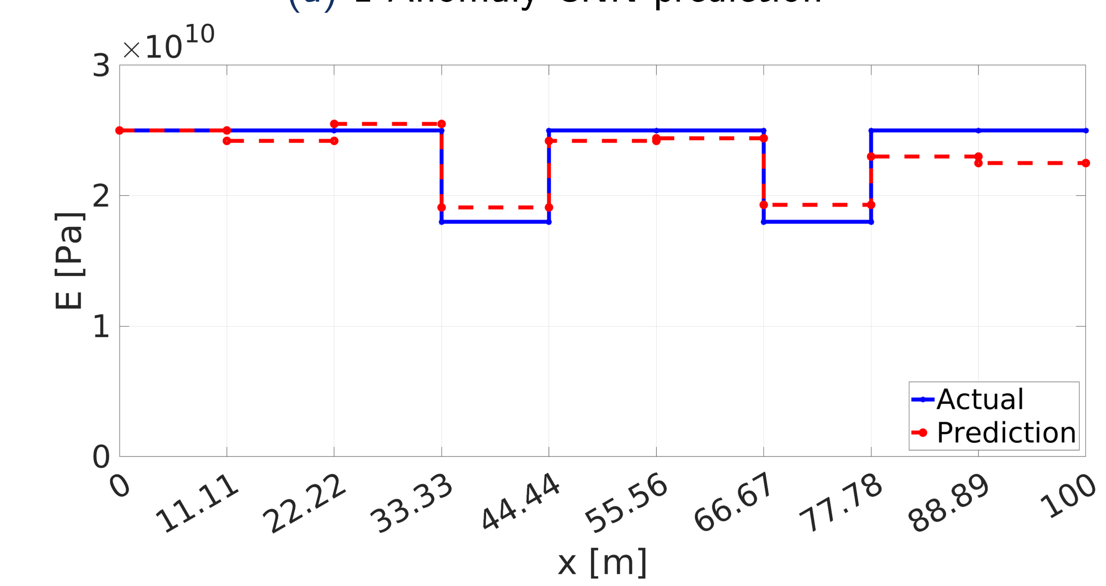
The performance of our CNN on the test dataset is presented in Table 1. Furthermore, we generated blind-test dataset to simulate multiple anomalies in beam structures to identify how well our CNN can detect damages in a beam structure. The prediction results of 1 anomaly and 2 anomalies in the beam structures is shown in Fig. 3a and 3b, respectively.

Dataset	f	P	E1	E2	E3	E4	E5	E6	E7	E8	E9
Mean	1.16	1.41	2.44	2.66	1.86	1.51	1.62	1.65	1.74	2.37	2.18
Median	0.95	1.09	2.03	2.10	1.49	1.24	1.32	1.32	1.38	1.82	1.73
Maximum	7.22	9.14	15.52	20.00	18.02	12.38	10.62	10.26	16.55	20.61	13.59

Table 1: Table listing the error statistics in percentage.



(a) 1 Anomaly CNN prediction



(b) 2 Anomalies CNN prediction

Fig. 3: CNN predictions on blind-test dataset.

For blind test 3a, the error in CNN prediction of frequency and amplitude of moving source are 1.63% and 0.37%, respectively. Furthermore, for blind test 3b, the error in CNN prediction of frequency and amplitude of moving source are 1.32% and 5.81%, respectively.

Conclusions and Future Studies

This research problem addresses the limitations of Guidio and Jeong's (2021) GA-based inversion which takes several hours to produce an output compared to our CNN which achieves better results in less than a second. As has been noted, Fig. 3a and 3b clearly showcases the remarkable prediction results in predicting multiple anomalies in 1D-beam structures. The authors plan to expand this problem using CNN in a multi-dimensional setting.

Acknowledgement and Publication

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References

Guidio, B., & Jeong, C. (2021). On the feasibility of simultaneous identification of a material property of a Timoshenko beam and a moving vibration source. Engineering Structures, 227, 111346.