Application of improved artificial neural network to stiffness reduction analysis of truss joints in a railway bridge

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Abstract

Railway bridges are susceptible to the problems of fracture and fatigue because they endure millions of stress cycles under moving train load during their service life. This may lead to stiffness reduction in truss joints of the truss bridges and reduce the operational effectiveness of the bridge. In this paper, a hybrid algorithm based on Artificial Neural Network (ANN) coupled with an evolutionary algorithm, i.e. Genetic Algorithm (GA) is proposed to analyze the stiffness reduction of truss joints in a railway bridge. GA is employed to determine training parameters and overcome the local minimum problems of ANN. Natural frequencies are selected as input data, whereas output data is damage characteristics (locations and levels) of truss joints. The results demonstrate that ANN-GA determines vibration behavior and damages of the considered structure accurately, comprising single stiffness reduction of truss joints as well as multiple stiffness reduction scenarios.

Keywords: Railway bridge, Artificial Neural Network, Genetic Algorithm truss joints, stiffness reduction.

Introduction

- Nowadays, because of the rapid development of the economy, transport infrastructure is facing overload situations. This leads to an increase in damage problems of the bridges. Therefore, Structural Health Monitoring (SHM) is vital to detect damages happening in structures.
- since ANNs in particular, and ML in general, apply backpropagation (BP) techniques based on gradient descent (GD), they tend to have major disadvantages relating to local minimum issues. This problem especially occurs when the network produces several best local solutions.
- To overcome this issue, in this paper, we apply a combination of ANN and GA (ANN-GA) to determine the stiffness reduction of truss joints in a truss bridge. Training parameters of the network are calculated utilizing global search techniques of GA instead of utilizing common BP techniques of ANN. The discrepancies between calculated outputs and real ones are chosen as an objective function.
- To validate the efficiency of ANN-GA, Nam O bridge is employed. Measurement data of the bridge is collected to obtain the vibration behavior of the structure. FE model of the bridge is created to obtain the training data. Model updating is conducted to obtain a baseline model that will be used for damage identification.

Methodology

Improved ANN (ANN-GA)

ANN is a subset of models utilized in ML that provides trained network the capacity to automatically learn from experience and improve its results without being explicitly programmed. The structure of ANN consists of:

- One input layer: The input data is inserted into the input layer before transferring to other layers.
- Hidden layers: A transformation to the data is applied.
- One output layer: Data from the hidden layer is received and output data is provided.

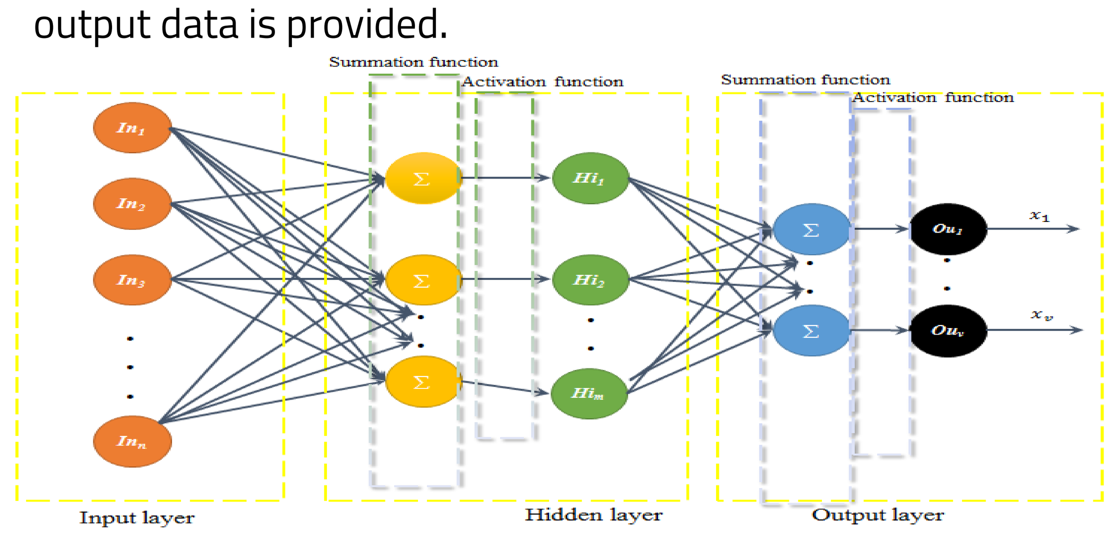


Figure 1. Example of the architecture of ANN

- In the forward process, the input layers transfer neurons to the output layers utilizing training parameters to change the values of neurons. If the discrepancies between calculated results and target ones are still large and do not satisfy the objective function, the backward process is conducted applying BP techniques.

- This process is iterated until the objective function is satisfied. Training parameters of the network are changed via iterations to reduce the discrepancies between the real and target results. Nevertheless, due to the application of BP techniques utilizing GD techniques, ANN may trap into local minima. This problem especially occurs when the network produces too much the best local solutions.

- To overcome this issue, in this paper, we propose combining GA with ANN to tackle optimization problems.

Results

- To investigate the effectiveness of ANN-GA, a railway bridge is used. Nam O bridge (Figure 2) is located at Danang city (the middle of Vietnam) opened to the traffic in 1985

Figure 2 . Nam bridge

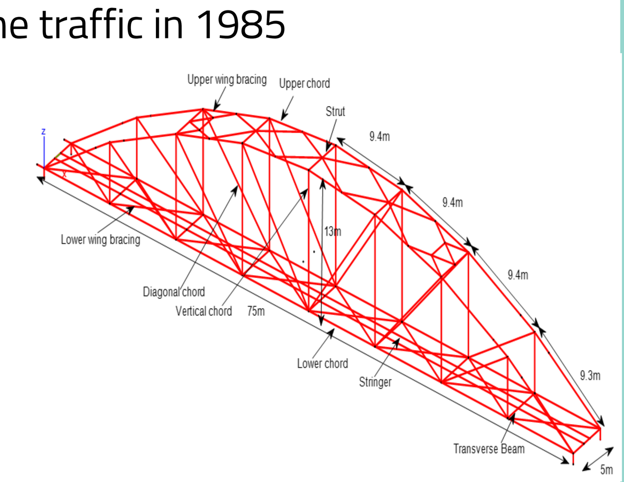


Figure 3. Main structural elements

- In the context of this paper, only the span connecting abutment *A0* and pier *P1* is selected for data measurements

Figure 4

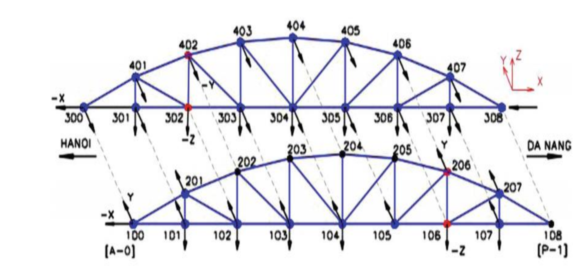


Figure 5

- A FE model of the bridge is constructed as shown in Figure 6. This model consists of 45 nodes and 146 elements

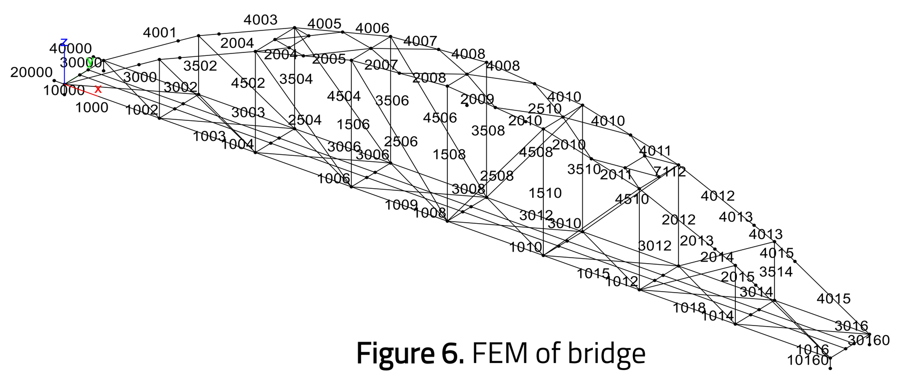
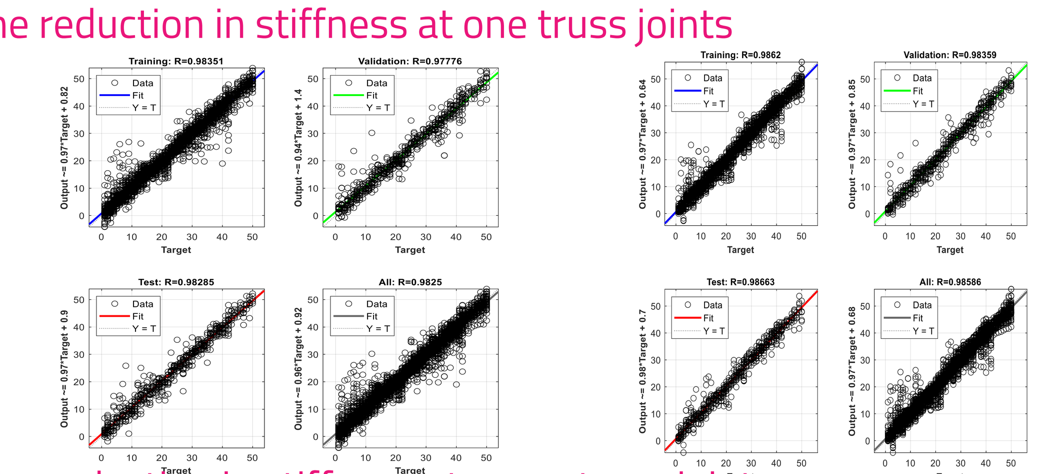


Figure 6. FEM of bridge

Damage detection

- Damages in the FE model are introduced by decreasing the stiffness of one or more specified truss joints of the bridge. In the case of single reduction, the stiffness of truss joints is reduced from 0% to 50% with an interval of 1%, whereas others are intact. In case of reduction in several truss joints, the stiffness reduction is assigned randomly for 3 truss joints at the same time. The stiffness is reduced from 0% to 50% with an interval of 1%.

The reduction in stiffness at one truss joints



The reduction in stiffness at many truss joints

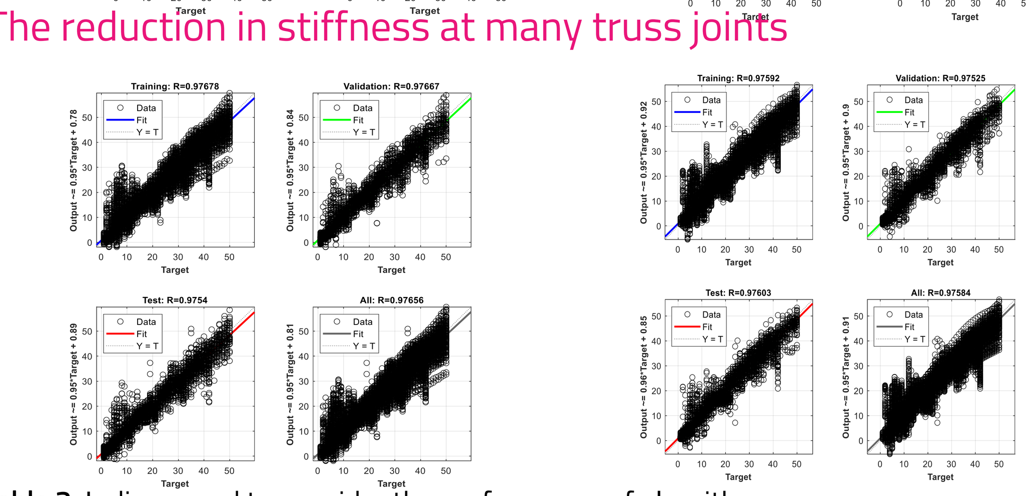


Table 2. Indices used to consider the performance of algorithms

Algorithm	MSE- Values	R- Values	Time (sec)
GA	4.831		56324
ANN	3.2134	0.9765	1342
ANN-GA	3.0503	0.9758	1465

- *R*-value calculated by ANN-GA (0.9758) is higher than that calculated by ANN (0.9765). The difference between calculated and real values (error) of ANN-GA is lowest, at 3.0503, whereas those of ANN and GA are is 3.2134 and 4.831, respectively. In terms of computational time, ANN and ANN-GA spend 1342 and 1465 seconds to look for the best solution, whereas GA expends 56324 seconds for this process.

Conclusion

A hybrid algorithm (ANN-GA) is proposed in this research to identify the stiffness reduction of truss joints. Some main conclusions can be summarised as follow:

- All algorithms consisting of GA, ANN, and GA-ANN can determine exactly the damage location of the considered bridge.
- GA spends too much time for looking for the best solution because it is based on stochastic techniques and too many parameters have to be adjusted in the search process.
- ANN makes some errors in the identification of damage level because it traps into local minima.
- GA-ANN outperforms GA and ANN in terms of both computational time and accuracy because it applies both advantages of ANN and GA. ANN has advantages in reducing computational time, whereas GA can deal with the problem of local minimal of machine learning

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