Automated Damage Detection in Transportation Infrastructure

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Introduction

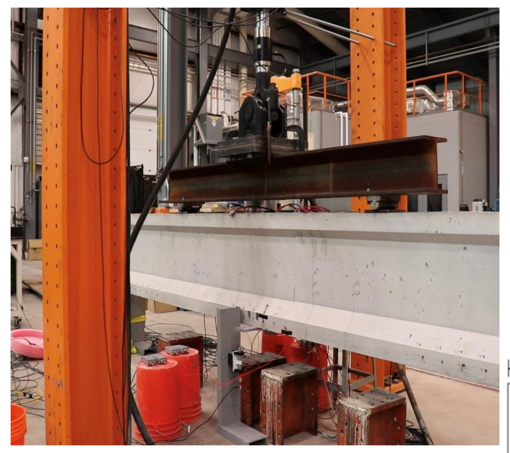
While bridges and various civil engineering structures are ageing across the world, the demand has been on a constant rise. As a result, the risk of failure and the corresponding socio-economic impacts have largely increased. Furthermore, the presence of damage that may not be detected in a timely manner can lead to catastrophic consequences. So, regular monitoring and assessment of these structures have become very crucial. While visual inspection has been the most widely used technique till now, modern Structural Health Monitoring (SHM) systems aim for more reliable and cost-effective ways. Today's technology includes various high-precision and durable data acquisition techniques and sensors but requires effective data processing techniques for damage assessment. The work herein explores the use of Machine Learning (ML) as an effective way to process and analyze the data for an automated damage detection methodology. Various supervised and unsupervised algorithms are considered. The performance of these techniques is tested by implementing them on data obtained from laboratory experimental analysis carried out on a prestressed concrete beam and steel box girder. Additionally, tests on a steel bridge girder specimen will be carried out to further verify the efficiency and applicability of the ML algorithms. Finally, the approach will be implemented in the field on an existing steel bridge.

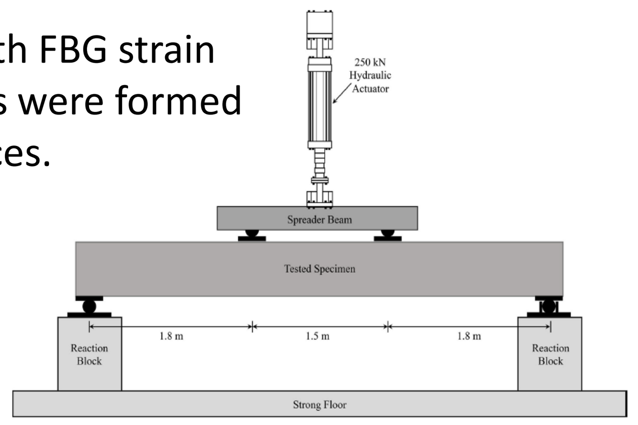
Experimental Data

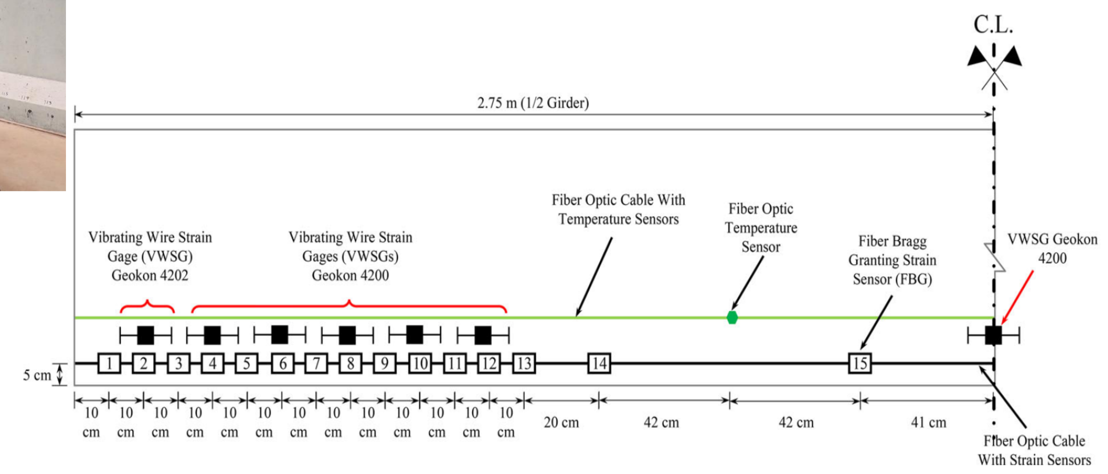
Case studies were carried out based on the data obtained from laboratory experimentations performed on two different specimens.

Specimen 1: Prestressed Concrete Bridge Girder

A prestressed concrete bridge girder embedded with FBG strain sensors was tested in the lab under bending. Cracks were formed in the tension side of the beam due to bending forces.

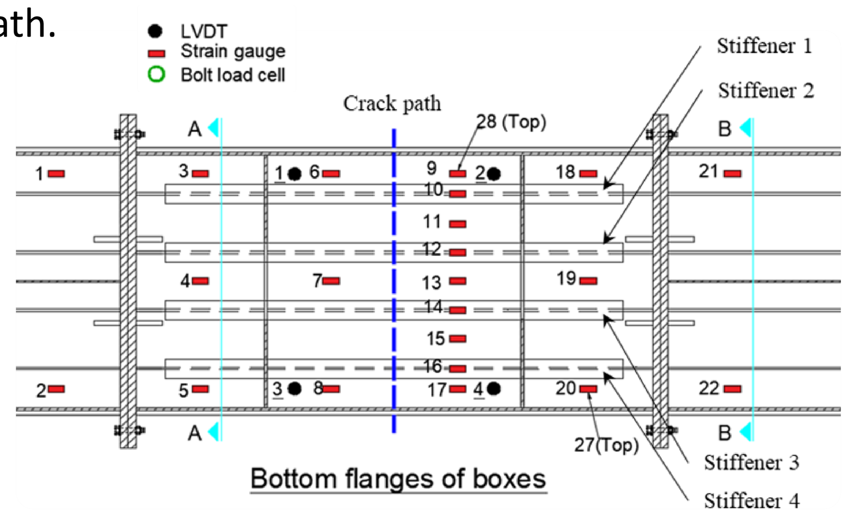






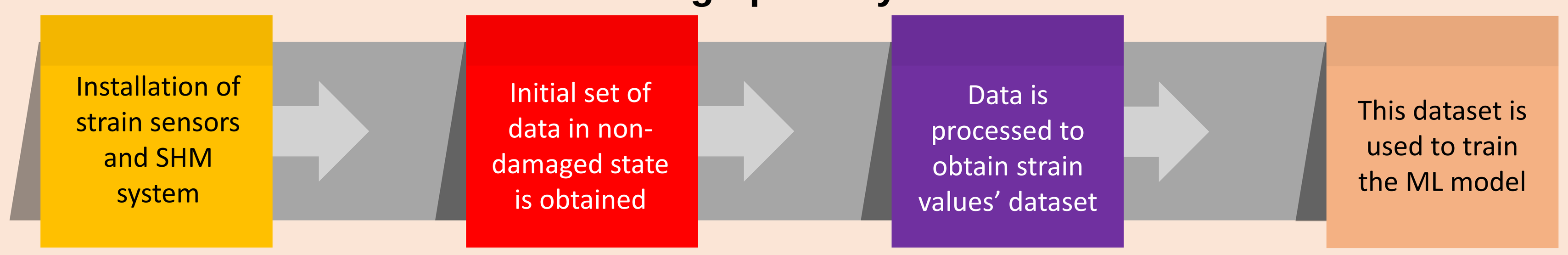
Specimen 2: Steel Box Girder with Stiffened Panels

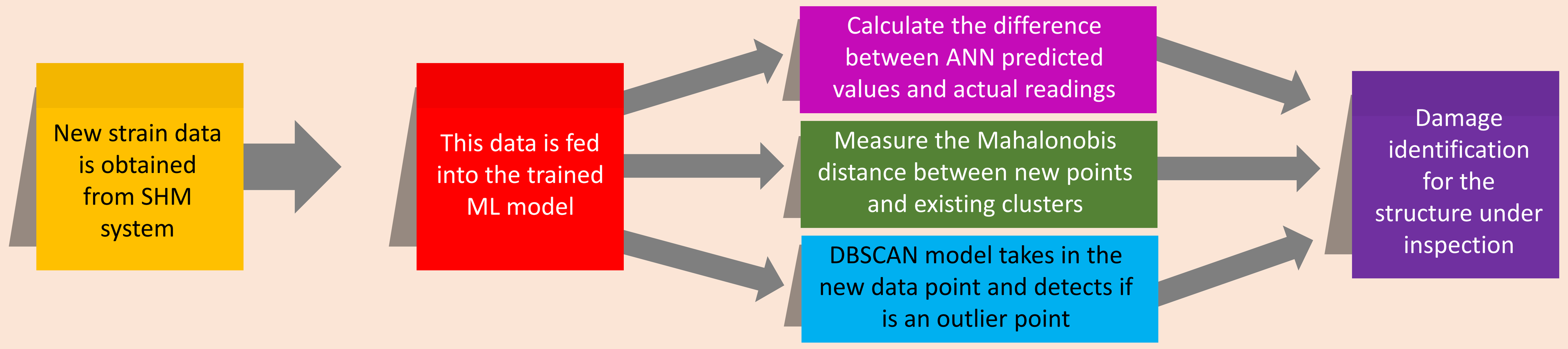
A steel box girder was tested under fatigue loading. A crack was created in the middle of the section and the specimen was exposed to positive and negative bending loads to make the crack propagate along the denoted path.



Damage Detection Methodology

- The overview of the whole process of data acquisition and damage detection methodology





- 3 different model techniques were implemented

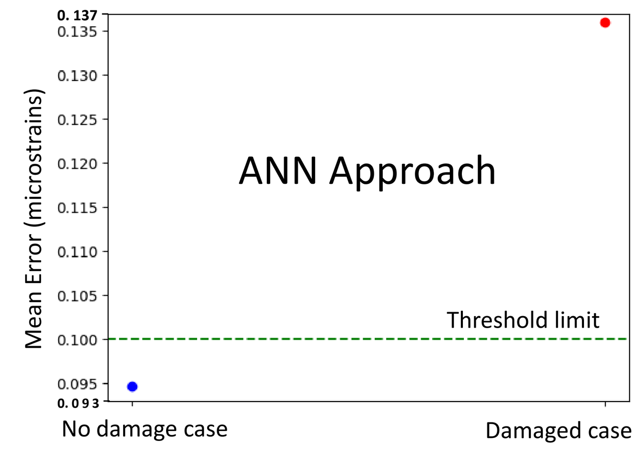
ANN Approach
- ANN stands for Artificial Neural Network.
- A supervised ML technique.
- Uses an ANN-based prediction model to predict strains at the target sensor taking other sensors' data as inputs.
- Compares the actual and predicted strains and calculates the error between them to detect damage.

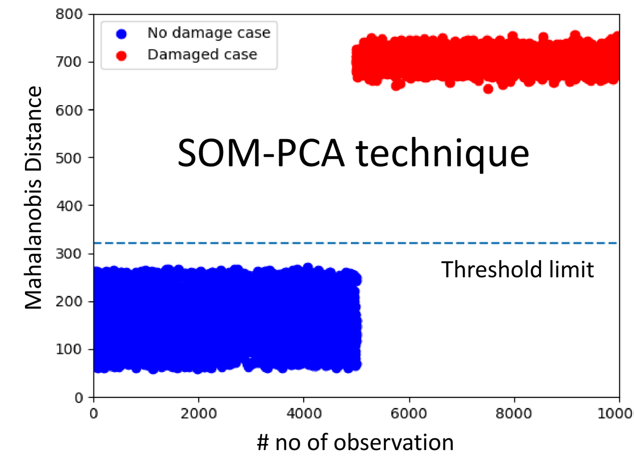
SOM-PCA technique
- SOM stands for Self Orgnising Maps. PCA stands for Principal Component Analysis
- An unsupervised ML technique.
- Forms baseline clusters training on non-damaged state data.
- Calculates the Mahalanobis distance between new data entries and the clusters.
- Mahalanobis distance measures how many standard deviations away a point is from the mean of a distribution.

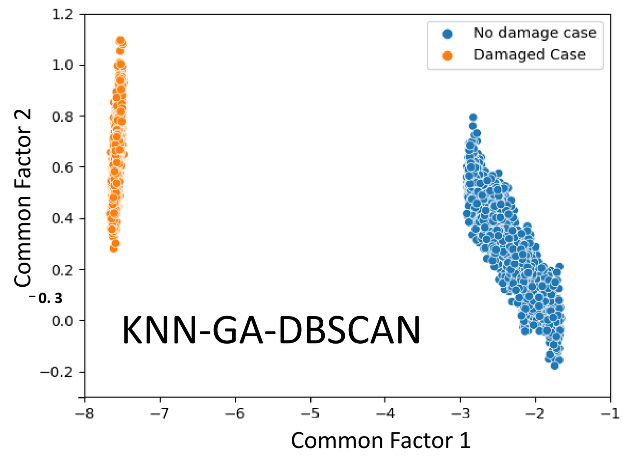
KNN-GA-DBSCAN
- KNN: K Nearest Neighbour, GA: Genetic Algorithm, DBSCAN: Density Based Spatial Clustering of Applications with Noise.
- Another unsupervised ML algorithm like SOM-PCA
- Forms baseline clusters and classifies if new data points belong to the cluster or not.
- Uses DBSCAN for clustering and its inherent ability to detect noise.

Results

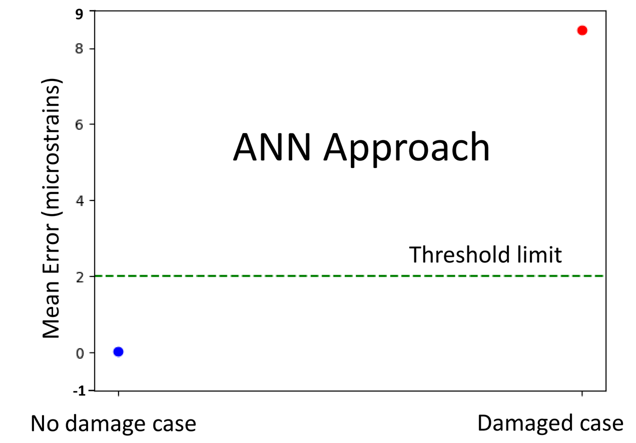
Detecting Cracks due to Bending Stresses in Prestressed Concrete Bridge Girder

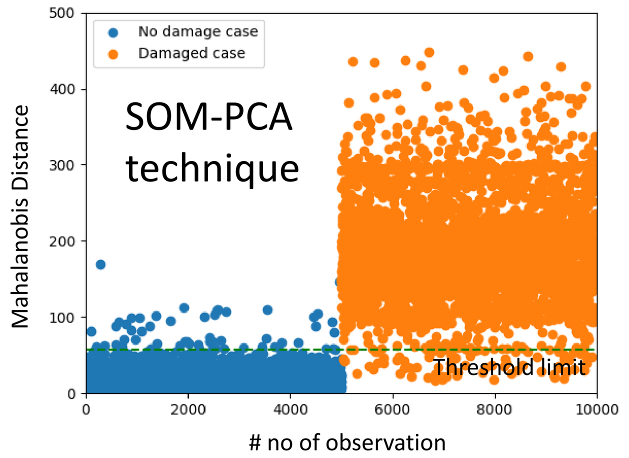


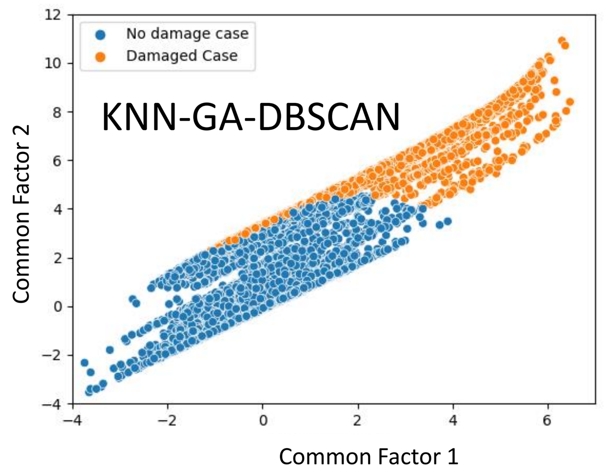




Detecting Crack Propagation in Steel Box Girder with Stiffened Panels





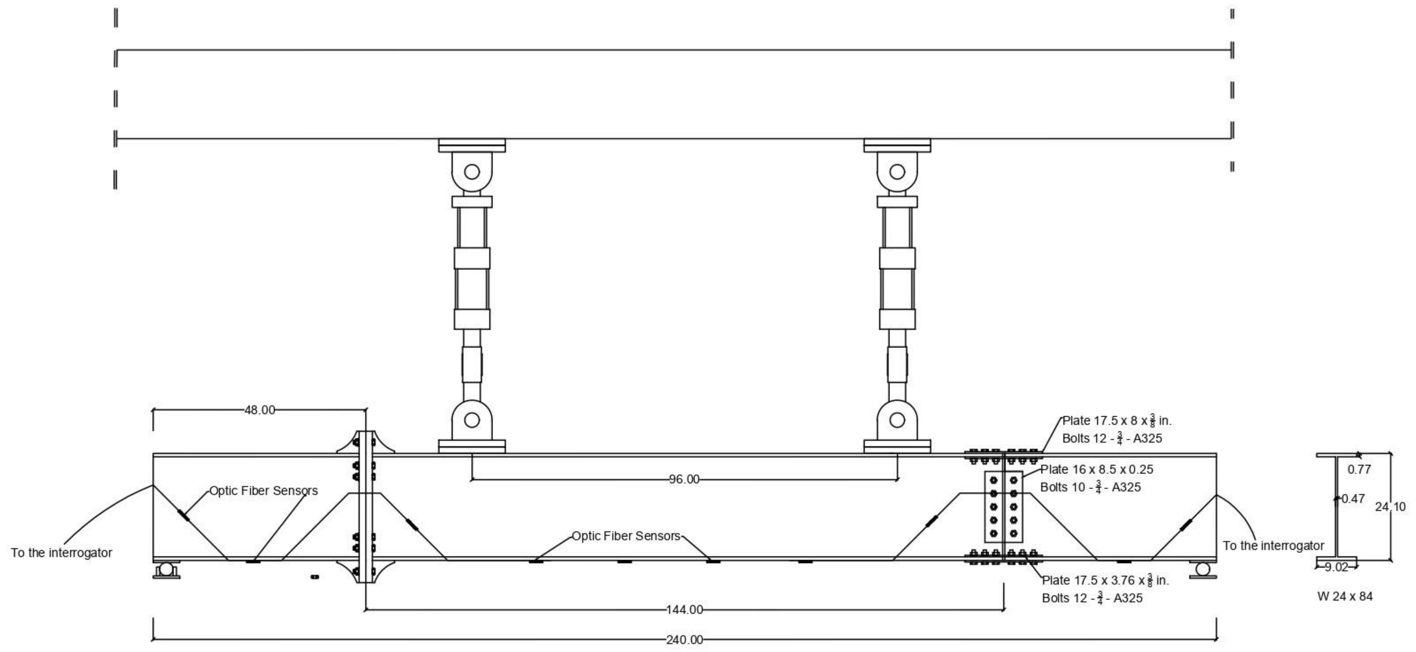


Observations & Conclusions

- From the results obtained it can be inferred that the three ML algorithms can detect damage from the recorded strain readings.
- Each technique has its own set of advantages and limitations.
- The ANN model can only detect damage in the region of the target sensor, not globally.
- SOM-PCA classification technique addresses this limitation as it can detect damage globally.
- Both these techniques have an ML model that needs to be designed and various model parameters which need to be fine-tuned appropriately for good performance.
- Additionally, the final damage identification step involves a threshold value which needs to be carefully defined for reliable results.
- As a result, these methods would need to be optimized for each set of data to yield appreciable performance and results.
- The KNN-GA-DBSCAN approach is a fully automatic approach that doesn't require any such parameter optimization. Even if the data changes, it can adapt itself without the need for any external involvement.
- But, this algorithm, like SOM-PCA classification, cannot perform damage localization
- Training KNN-GA-DBSCAN requires a much larger time.

Future Work

The testing will be carried out on a 20 ft steel beam specimen designed such that under a specified load from the actuators, it will simulate the similar levels of stresses that actual bridges will experience. The specimen has an end plate and a splice plate connection so that various kinds of damaged can be induced without any destructive operation over the specimen.



Along with this, some additional beams will also be used for destructive testing.