A decentralized method to detect local damage on civil structures using dynamic responses from environmental loads

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Introduction

One of the major challenges in civil engineering today is to be able to assess the health of our bridges, buildings and other structures. It is essential to know the condition of the structures, and to be able to quickly evaluate the safety of a structure after major events such as earthquakes.

The damage detection method that we propose belongs to the category of vibration-based methods. More specifically, we use the fact that any structure is always vibrating due to environmental loads such as wind, earthquakes, cars passing nearby or people walking inside a building. This vibrations are called dynamic responses of the structure.

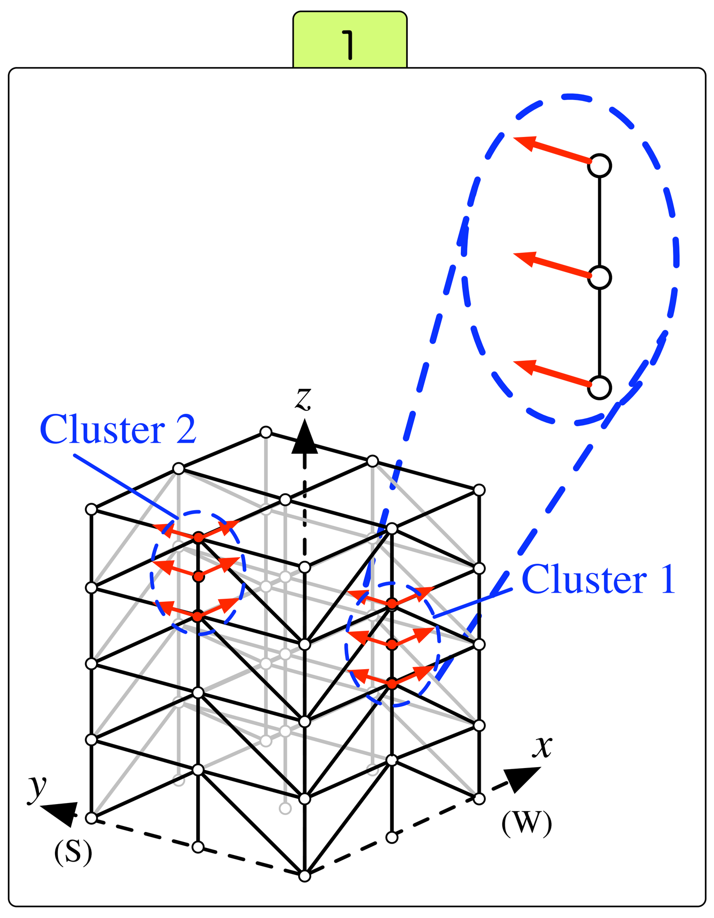
We focus on detecting local damage, which is limited to a small location of the structure, but may affect its safety. Local damage is difficult to identify with only a few sensors and a global approach. But wireless sensors are now available with promises to be cheap and small in the following years. We will be able to install a lot of them on one structure, and use them to identify local damage.

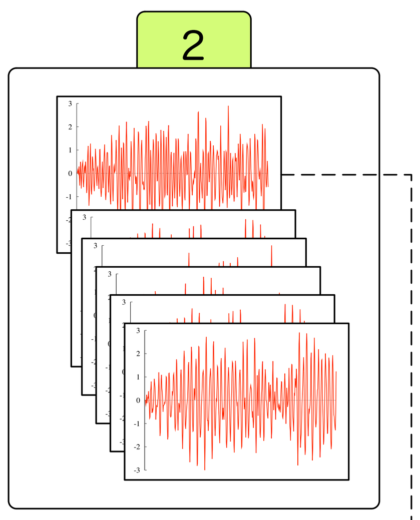
We investigate a damage detection method using acceleration data from several adjacent sensors. It is based on multivariate autoregressive models. We build a pool of reference models using data from the undamaged structure, and validate new measurements against the reference models, to detect and localize any degradation.

Method

Select an element to evaluate

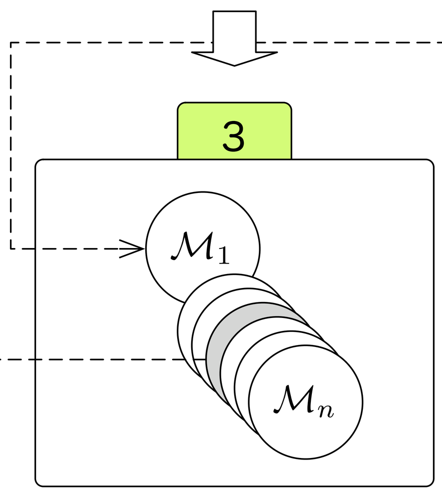
On the structural element that you wish to evaluate, set three accelerometers, on both ends and at the middle of the element. Here we consider accelerations in the y direction.





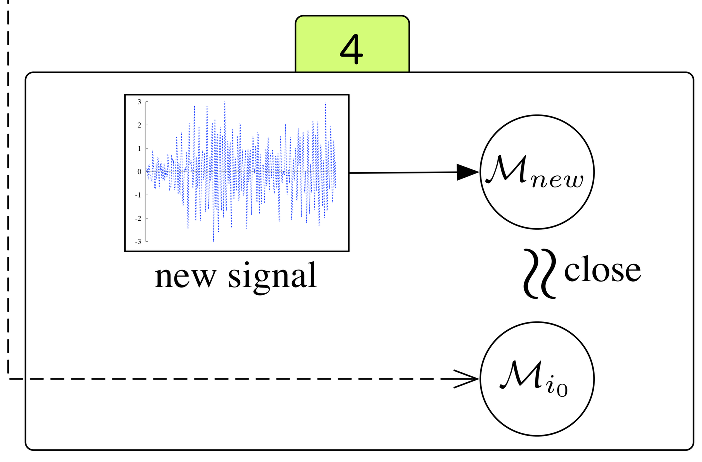
Collect reference signals

We measure the vibrations of the structure, in the form of acceleration time histories, and collect them. It is important at this point that we collect enough vibration patterns to cover a wide range of environmental conditions such as various temperatures, excitation patterns, etc.



Build reference models

For each of the time histories collected, we identify the coefficients of a model of the input-output behaviour of the measured channels. The model is a multivariate second-order autoregressive model with external input (ARX model). It is an approximation of the local mechanics of the structure. More details can be found in [1].

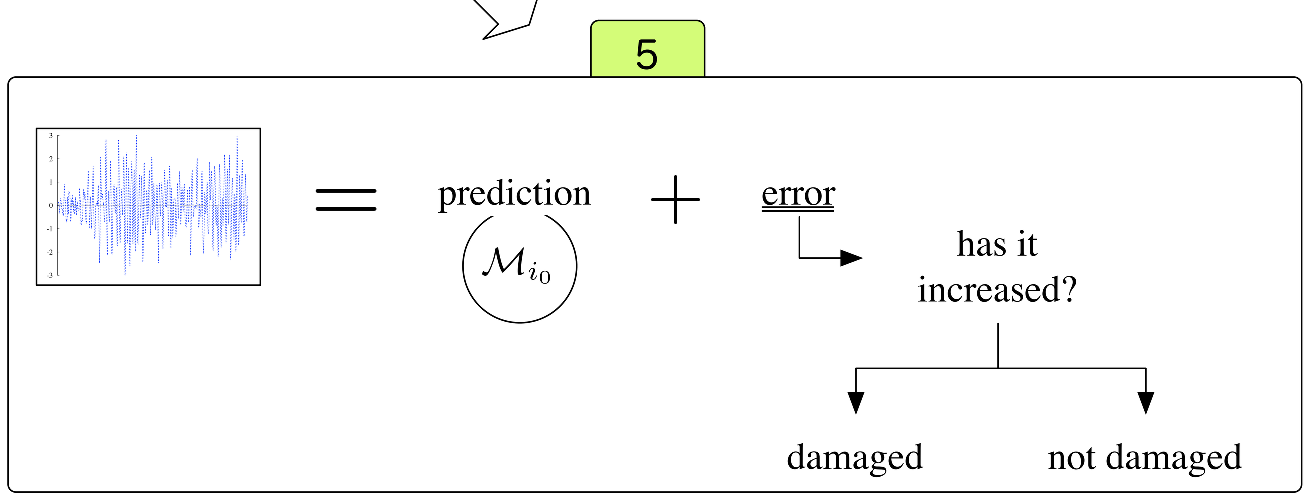


Measure a new signal and find a reference model with similar environmental conditions

A new signal is measured, and from it we identify parameters of a model, and using these parameters, look into the database to find the reference time history that has closest environmental conditions.

Compare the new signal with the reference signal

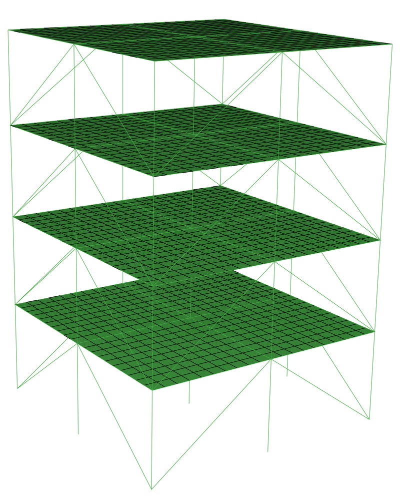
Having found the *closest* reference model, we use it to predict the new signal. If the prediction error is high, it means that the model does not accurately describe the input-output behavior of the new signal. Therefore, we use a statistical test, called F-test, to estimate whether the variance of the prediction error for the new signal is greater than that of the prediction error for the reference signal.



Numerical validation

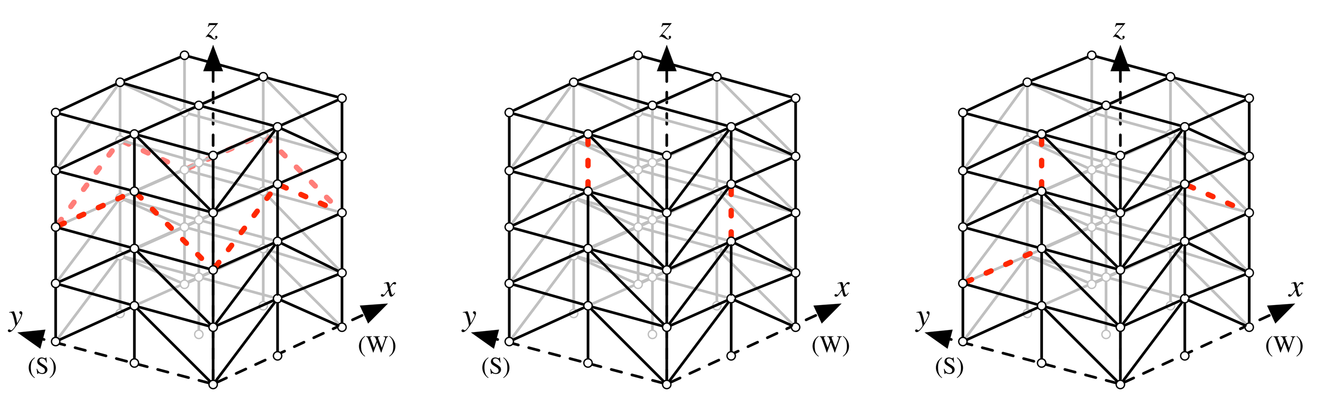
Model

We used a 4-story building model to generate data and apply our damage identification method. Using this model, we simulated the dynamic response of the building, using three types of excitations presented in [2]. Acceleration data was generated at a sampling rate of $5000\ Hz$, for a duration of 5 seconds. 60 of these time histories were generated for the undamaged structure, and 30 time histories were generated for each damage case.

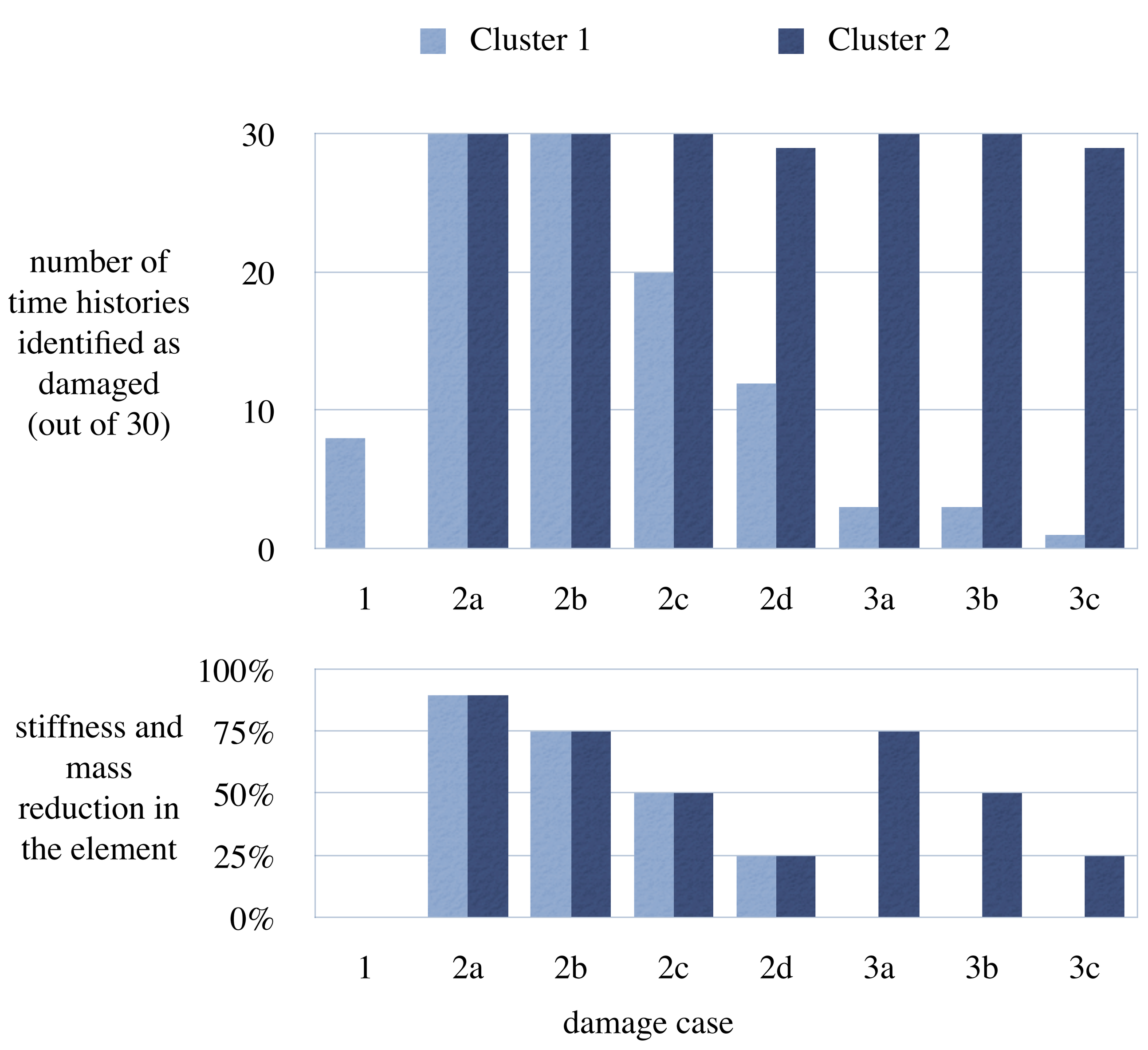


Damage cases

We defined 3 damage cases, in which damage is represented by reduced stiffness and mass. The damaged elements appear in the red in the figure. For damage case 1, the reduction is 90% in all the braces of the third floor. For damage cases 2 and 3, we refined the cases by varying the reduction from 90% to 25%, as can be seen in the results table.



Damage case 1 Damage case 2 Damage case 3



Damage identification results

The bottom table shows the reduction coefficient (the damage) in the two concerned clusters for each damage case. The top table shows the damage identification results. For each damage case, the algorithm was run for each of the 30 time histories to determine whether the structure is damaged or not.

For Cluster 2, almost all time histories are identified as damaged for damage cases 2 and 3, even when the stiffness and mass reduction is only 25%. None of the time histories for damage case 1 are identified as damaged.

For Cluster 1, all time histories are identified as damaged for damage cases 2a and 2b. However, not all time histories are identified as damaged for damage cases 2c and 2d. Also, false-positive damage identification results are observed for the other damage patterns.

Conclusions

A decentralized method for local damage identification was proposed and examined on numerical data. The method is based on second-order multivariate ARX models as an approximation of a local behavior of the structure.

The method was applied to numerical data from a building finite element model similar. It was shown that damage on individual structural elements can be identified and localized.

Although there are false-positive and false-negative results, the method shows promise as a simple local damage identification algorithm. Further research is underway to improve it.

Literature cited

1. Evan Monroig and Yozo Fujino. Multivariate autoregressive models for local damage detection using small clusters of wireless sensors. In *Proceedings of the Third European Workshop on Structural Health Monitoring*, Granada, Spain, July 5-6 2006.
2. Evan Monroig and Yozo Fujino. Damage identification based on a local physical model for small clusters of wireless sensors. In *Proceedings of the First Asia-Pacific Workshop on Structural Health Monitoring*, Yokohama, Japan, December 4-6 2006.

Further information

Please contact Evan Monroig at `monroig@bridge.t.u-tokyo.ac.jp`. More information on this and related projects, as well as a PDF version of this poster, can be found at `http://www.bridge.t.u-tokyo.ac.jp/monitoring/`.