How sensors can be utilized to build a decision support system for bridge maintenance

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1 Introduction

The probability of a bridge to fail increases over time until it is no longer considered safe for use. Maintenance of a bridge is typically carried out when something goes wrong or according to a preventative maintenance schedule based on expert knowledge, neither approach making the best use of limited maintenance resources. Sensors can provide useful real-time information without the delay or cost of a manual maintenance check. How sensors can be utilized to build a decision support system for bridge maintenance is the topic of this thesis.

Sensors on bridges can provide real-time measurements of the responses of the part of the bridge on which they are installed. Depending on the sensor-type this measured response may be translation, rotation, vibration or one of many other types of response. In this thesis the focus is on a single bridge, bridge 705 in Amsterdam. The reason bridge 705 was chosen is because a 3D finite element model (FEM) is available for the bridge, and a field test was conducted where known loads were applied to the bridge and the corresponding sensor measurements recorded. The FEM is useful so that sensor measurements for a known load can be simulated without having to conduct a field test, the measurements from the field test allow us to verify this data generated by simulation.

A decision support system for bridge maintenance must provide information on the damage status of the bridge to the user of the system or policy maker. Thus it is necessary to transform the responses measured by the sensors into a damage report of the bridge. To accomplish this a model will be built that generates a damage report based on two methods which will be referred to from now on as abnormal condition classification (ACC) and similar structure similar behaviour (SSSB).

The goal of ACC is to determine if the condition of the bridge has deviated from the normal range of conditions. To build an ACC system it is necessary to first find out what the range of sensor measurements are during normal operation of the bridge. This will be achieved by applying a normal range of loading conditions to the FEM and recording the simulated sensor measurements. Then a one-class classifier can be applied to the simulated responses and be used to decide if any subsequent sensor measurements fall within the expected normal range of responses or not.

The SSSB method is based on the assumption that similar structures should behave in a similar manner when subjected to the same load. Bridge 705 in Amsterdam has seven spans each with the same dimensions, ignoring the small differences due to construction and time in operation. To develop an SSSB system loads must be "driven" across the bridge in the FEM, then an analysis must be performed on the difference between sensor measurements from sensors at equivalent positions on each substructure.

The end-goal of this thesis is to outline how sensors can be utilized to build a decision support system for bridge maintenance. To accomplish this a model will be built (consisting of the AAC and SSSB methods) to determine if sensor measurements represent an abnormal condition of the bridge . Research will be conducted to ascertain what types of sensors and what sensor placement is optimal for detecting such an abnormal condition. A finite element model will be used to simulate sensor measurements in order to address the lack of available data. Due to the safety requirements of any bridge it is necessary to quantify the uncertainty we have in our damage estimates. Once the capabilities and limitations of the model are understood, we will suggest a decision support system for policy makers which includes the model and present a cost-benefit analysis thereof. Finally (stretch-goal) we will investigate how such a system can be generalized to bridges other than bridge 705.

2 Literature review

This section contains a review of relevant literature studied during this thesis project.

2.1 Combining Data-driven Methods with Finite Element Analysis for Flood Early Warning Systems

2.2 Neural Clouds for Monitoring of Complex Systems

In one-class classification, a classifier attempts to identify objects of a single class among all objects by learning from a training set that consists only of objects of that class. One-class classifiers are useful in the domain of system condition monitoring because often only data corresponding to the normal range of operating conditions is available. Data corresponding to the class of abnormal conditions, when a failure or breakdown of a system has occurred, is often not available or is difficult or expensive to obtain.

The Neural Clouds (NC) method presented in TODO:REF is a one-class classifier which provides a confidence measure of the condition of a complex system. In the NC algorithm we are dealing with measurements from a real object where each measurement is considered as a point in n-dimensional space. First a normalization procedure is applied to the data to avoid clustering problems in the subsequent step. The data is then clustered and the centroids of the clusters extracted. The centroids are then encapsulated with "Gaussian bells", and these Gaussian bells are normalized to avoid outliers in the data. The summation of the Gaussian bells results in a height `h` for each point `p` on the hyperplane of parameter values. The value of `h` at a point `p` can be interpreted as the probability of the parameter values at `p` falling within the normal conditions represented by the training data. In comparison to other one-class classifiers, the NC method has an advantage in condition monitoring in that it creates this unique plateau where height can be interpreted as probability of the system condition. Figure TODO:FIG shows this plateau in comparison with other one-class classifiers.

2.3 Similar Substructures on Sydney Harbour Bridge