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Bayesian Damage Classification by AR-ARX Array Expression Data

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ABSTRACT

Over the last decade, advanced optical fiber sensors and wireless sensors have made it possible to realize the dream of a sensing network for structural health monitoring. In the wake of the large amount of data collected by the sensors, research has started to focus on damage diagnosis algorithms-- the core of a structural health monitoring system. How to use the sensing networks to predict accurately the damage to structures after severe external strikes has become the most important objective of the monitoring system in the last few years.

The methodology of the proposed system is shown in figure 1. Data collected from either wireless sensors or optical fiber sensors are first used to train the autoregression-autoregression with exogenous (AR-ARX) models. A multi-array AR-ARX model is established to obtain the information required. The coefficients of the model are then used to form the AR-ARX array expression data, inspired by the DNA expression data in biology research, and saved in the database for future damage detection. To identify accurately the damage level of the structure, the naïve Bayes classifier and Golub-Slonim methods, transplanted from computer science, are applied to classify the damage conditions. Moreover, to improve the performance of the system developed, the likelihood selection and Golub-Slonim selection are used to optimize the AR-ARX array needed for precise damage detection.

The theory of the Golub-Slonim algorithm, which is applicable to data sets with two classes, is shown as

$$Class(x) = sign \sum_{coefficient\ g} \{[x_g - (\mu^g{}_1 + \mu^g{}_2)/2][(\mu^g{}_1 - \mu^g{}_2)(\sigma^g{}_1 + \sigma^g{}_2)]\}$$

Where $\mu^g{}_1$, $\sigma^g{}_1$ and $\mu^g{}_2$, $\sigma^g{}_2$ are the mean values and standard deviations of coefficient g among training samples of class 1 and 2, respectively.

The theory uses the trained AR-ARX array expression data to compute a mean and standard deviation for each coefficient of the samples for each class. The class of a test sample is then determined by how close the coefficients are to the respective mean value for each class.

The theory of the naïve Bayes classifier according to the model with maximum log a *posteriori* probability under the assumption that, given the class model, values for each component of x are independent of one another, can be described as

$$Class(x) = \arg\max\{ \sum_{coefficient\ g} [\ -\log(\sigma^g{}_i) - 0.5((x_g - \mu^g{}_i)/\sigma^g{}_i)^2]\}$$

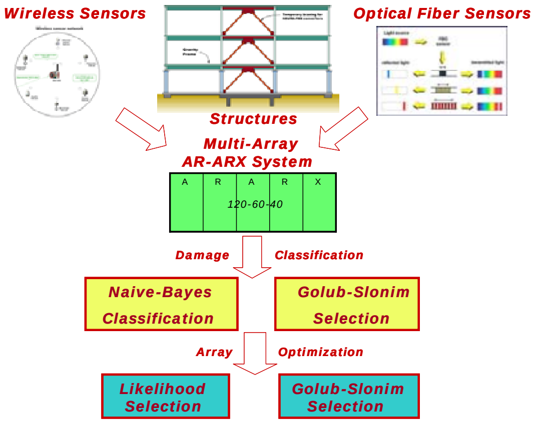

Figure 1 Flow chart of the proposed structure health monitoring sysyem

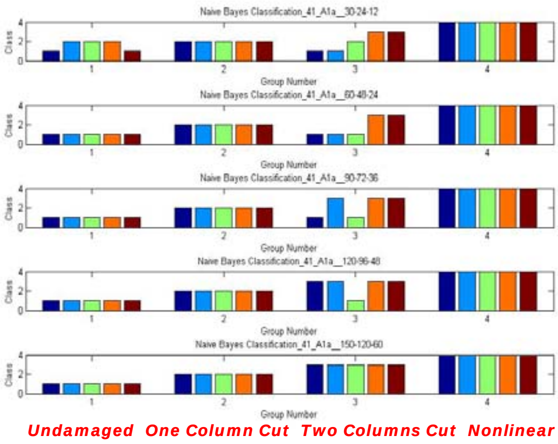

Figure 2 Experimental verification of the naïve Bayes classification

To verify the performance of the proposed system, a series of shaking table tests for a full-size, three-story, four-column benchmark structure was conducted at the National Center for Research on Earthquake Engineering (NCREE). Totally, 48 cases, including 19 undamaged; six one-column damaged; 16 two-columns damaged; and seven nonlinear cases were used in examination. The AR-ARX array expression data were established under the basis of 30-24-12 form, as shown in figure 2. The naïve Bayes and the Golub-Slonim algorithms were then applied to classify the damage conditions. The result has shown that the naïve Bayes classification can monitor the structure more reliably than the Golub-Slonim method. Moreover, by increasing the order of the array expression data to 150-120-60, the system can almost perfectly solve the four-class structural health monitoring problem. Experimental verification has shown that the new diagnosis system can accurately identify the existing damage on a structure with satisfactory results.

A new damage diagnosis system combining AR-ARX array expression data, naïve Bayes classification, and Golub-Slonim classification is proposed. To establish a robust structural health monitoring system, the technique of DNA array expression data was first transplanted from biology by extracting the information required from the trained AR-ARX models. The Golub-Slonim method and naïve Bayes classification for multi-classes was then applied to detect the damage condition of a full-size structure. Experimental verification has shown that the naïve Bayes classification can almost perfectly predict four different damage conditions by increasing the order of the array expression data. The proposed system with advanced sensors can offer strong support for the next generation of structural health monitoring.

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