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# Simple Neural Network Application for Traffic Monitoring

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## Summary

Novel health monitoring strategies for highway bridges and transportation infrastructure are of primary significance to the vitality of our economy. Using the latest enabling technologies, the objectives of health monitoring are to detect, locate, and assess the level of structural damage to the civil infrastructure. This paper presents a neural network application for traffic identification within a general framework of structural health monitoring. A pilot website (http://healthmonitoring.ucsd.edu) currently depicts some elements of the envisioned integrated health monitoring analysis framework. The sample application presented herein uses neural networks as an identification tool to make available the acting traffic load "input" as well as bridge response "output." The general health monitoring framework is also summarized to illustrate the potential and role of neural networks.

## Introduction

An integrated health monitoring framework is being developed to incorporate all tasks from sensor configuration, data acquisition and control, to decision-making and resources allocation. Within this framework, neural networks, which do not require information concerning the phenomenological nature of the system being investigated, are employed to detect changes in model-unknown structures.

In the following sections, a brief summary of the overall health monitoring framework is presented. Thereafter, a neural network application for traffic identification will be introduced and discussed.

## An Integrated Bridge Monitoring Framework

As mentioned earlier, the neural network application addressed in this paper is within developments related to an integrated health monitoring framework. Such an effort not only requires collaboration among the data analysis, structural

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engineering, video processing, wireless and sensor network communities, but also requires a comprehensive approach to data management and analysis [1]. The overall research framework (http://healthmonitoring.ucsd.edu) addresses development of: (1) networked sensor arrays, (2) a high-performance database with data cleansing and error checking, data curation, storage and archival, (3) computer vision applications, (4) tools of data analysis and interpretation in light of physics-based models for real-time data from heterogeneous sensor arrays, (5) visualization allowing flexible and efficient comparison between experimental and numerical simulation data, (6) probabilistic modeling, structural reliability and risk analysis, and (7) computational decision theory. In order to satisfy these requirements, this research is making use of recent advances in: (1) high-performance databases, knowledge-based integration and advanced query processing, (2) instrumentation and wireless networking, (3) computer vision and related feature extraction algorithms, and (4) data mining, model-free and model-based advanced data analysis, and visualization.

The universe of damage detection scenarios likely to be encountered in realistic civil infrastructure applications is very broad and encompassing [2,3]. Demonstration applications based on bridge field testbeds are currently being developed. These will allow researchers interested in structural health monitoring to exercise the developed framework using real life application examples and to contribute to enhancing the "toolkit" of methods supported by the framework.

## Neural Network Application

A pilot effort currently underway integrates some of the essential elements of an automated on-line continuous monitoring framework for bridge systems [1]. Under the supervision of University of California, San Diego (UCSD) Professors V. Karbhari and F. Seible, three fiber reinforced polymer (FRP) bridge-deck panels (each measuring 4.58 meters in length and 2.29 meters in width) were installed in 1996 along a roadway on the UCSD campus, in order to monitor long-term performance under usual traffic loading conditions [4]. As shown in Figure 1, the panels are located between the two white lines traversing the road.

Figure 1. Composite Bridge-Deck Panels

Live data from selected strain gages and displacement transducers along with a video feed are now available on-line on a 24/7 basis over a web-site for worldwide access (http://healthmonitoring.ucsd.edu). Currently data from sixteen strain gages located on the UCSD composite decks is continuously streamed to a high performance database at the San Diego Supercomputer Center. The hourly peak strain time histories (each twenty seconds long) along with the corresponding video are archived within a DB2 database. Peak hourly strain data for two of the gages (Fig, 2) have been stored since February 2002 while data from all sixteen strain gages for all vehicles crossing the composite decks have been stored since October 2003. The data is made available for querying and downloading (Fig. 3) through a web portal (http://healthmonitoring.ucsd.edu).

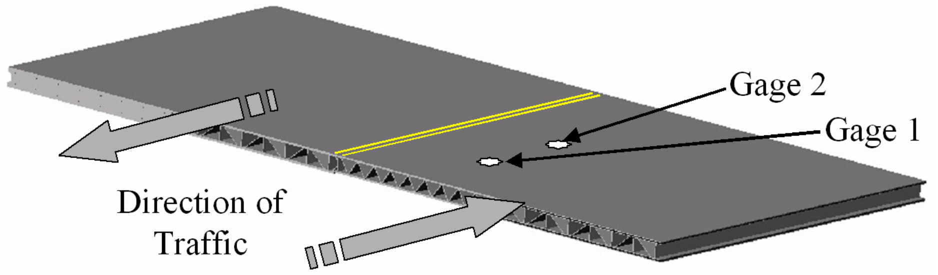

Figure 2. Location of Strain Gages on Bridge-Decks

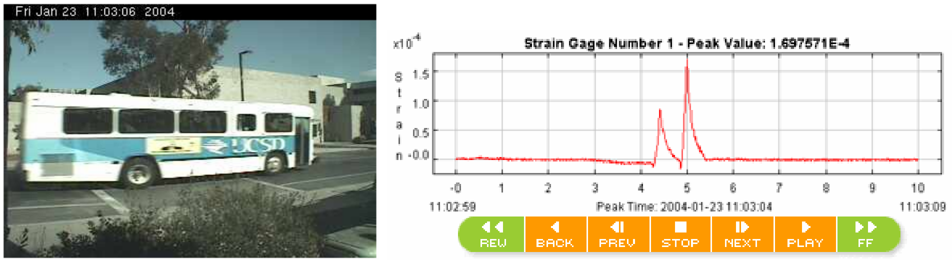

Figure 3. Recorded Video and Strain for Campus Shuttle Bus

## Traffic Identification

A pilot, simple computational model of the bridge-deck system was employed for generating simulated data to explore the potential of neural networks as a traffic identification tool based on changes in strain time histories. To simulate traffic crossing over the bridge-decks, a one-dimensional finite element model, composed of sixty beam-column elements, (Fig. 4) is analyzed using the computational framework OpenSees (http://opensees.berkeley.edu/).

The goal of this research is to apply the neural network to identify/predict traffic speed and wheelbase based on strain time histories. If successful, these techniques will be applied in future research to actual measured data with the ultimate goal of reducing uncertainty during the system-identification analysis phase (by limiting the scope of possible causative load configuration scenarios).

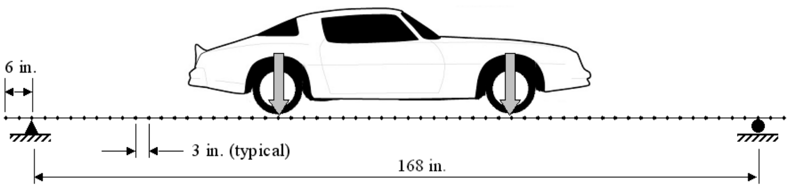

Figure 4. Finite Element Model of Composite Bridge-Decks

Considering the range of vehicles likely to be encountered on the bridge-deck system, two classification scenarios were chosen for this initial study. The first data set consisted of the situation where the vehicle type (axle weight and wheelbase) was kept constant and the speed varied in quarter mile-per-hour (MPH) increments from 5 to 65 MPH. For each of these scenarios, strain time histories (Fig. 5) are generated at middle and quarter span. In this study, a single vehicle passing over the bridge-decks is simulated by ignoring the interaction between the beam and vehicle, instead considering only the moving forces [5]. This simulation replicates the situation where a campus shuttle bus crosses the decks at a speed somewhere between 5 and 65 MPH (Fig. 3). Of the 241 scenarios generated, 201 were selected and served as the training sets for the neural network. The remaining 40 cases were reserved as a test set to evaluate the network performance.

In addition, a second class of scenarios was considered in which the vehicle's speed and axle weights were held constant and the wheelbase varied from 5 to 30 feet (in 0.25 foot increments). For this class, 81 of the scenarios were used for training and the remaining 20 for testing.

Prior to applying the neural network for estimating vehicle properties, Principal Components Analysis (PCA) was employed for feature extraction [6]. For each pair of time histories corresponding to one particular event, the number of features was reduced from 20,000 (each time step in each of the two strain time histories is a feature), to the first ten principal components. These ten PCA features were used as input in the neural network.

The neural network was then defined with the 10 input units, 15 hidden units (preliminary studies showed 15 to be sufficient), and a single output unit (corresponding to normalized speed or wheelbase). The backpropagation learning algorithm [7] was used to train the network, and adjust the weights by minimizing the error between network outputs and targets (corresponding desired values for the outputs). Comparing the network outputs with the targets for all patterns in the test set (Fig. 6), the average error in the speed estimation was 0.28 MPH. For wheelbase estimation, the average error was 0.30 feet.

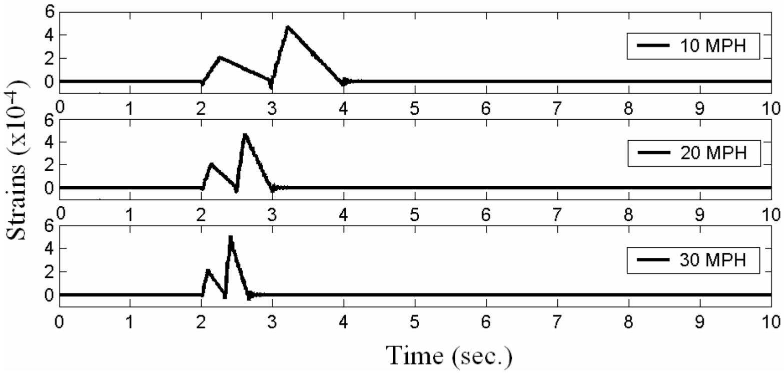

Figure 5. Comparison of Quarter Span Strains for Increasing Speeds and Constant Wheelbase and Weight

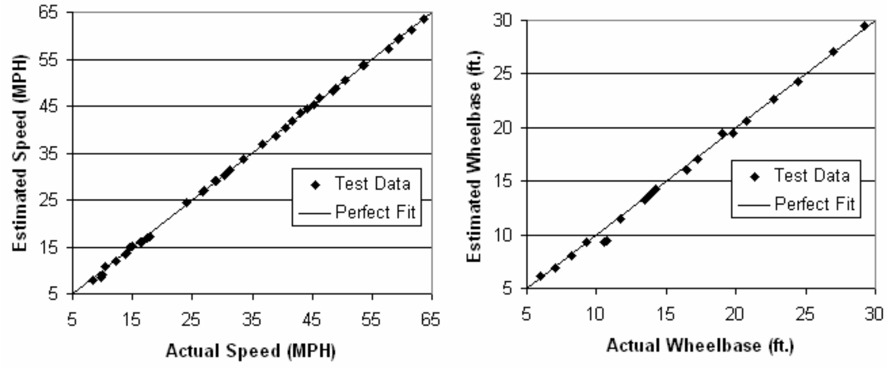

Figure 6. Comparison of Estimated and Actual Speeds and Wheelbases

## Conclusions

To date, a simple bridge-deck finite element model was used for generating data to explore the potential of neural networks as a statistical pattern classifier to identify vehicle parameters, on the basis of system response (strain time histories) to external excitation. Encouraging preliminary results were achieved, and the feasibility of such an approach was demonstrated. Further research currently underway involves more complex and realistic situations by varying the axle weight, introducing noise, addressing the issue of modeling uncertainty, within a more elaborate finite-element modeling environment.

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