Identification of Steel Frame Vibration Properties Using Defective Sensor Data

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INTRODUCTION

Sensor networks and data acquisition systems implemented for structural health monitoring (SHM) are imperfect; yet the data they provide is relied upon to infer important attributes of infrastructure (Lynch and Loh 2006), e.g. their natural vibration properties. Sensing malfunctions yield incomplete or erroneous data sets that often halt the analysis procedure and prompt subsequent data collection attempts. Intuition expects that missing data points degrade the estimation accuracy of structural features suggesting that the incomplete data would not supply the desired information. The omission of the missing data problem leaves a gap in the utility of SHM methods and risks the loss of irreparable structural condition information following a natural disaster.

The recently developed STRIDE algorithm (Matarazzo and Pakzad 2016) formally accepts incomplete data sets and has proven that structural modal properties (frequency, damping, and mode shapes) may be computed with high accuracy despite data losses as great as 82%. SHM methods that support data sets with missing observations are valuable to immediate structural assessments following an extreme event.

EXPERIMENTAL SETUP

In this study, ambient vibrations of a three-story, two-bay steel frame structure (shown in Figure 1) are measured using a network of nine accelerometers. After data collection, a large number of observations are erased to simulate a systematic sensor network malfunction. This defective data is processed for modal identification using the STRIDE technique, since it is the only method that accepts such data. The objective is to compare modal identification results, mode shapes in particular, between the perfect data case (baseline) and three sensor-failure cases.

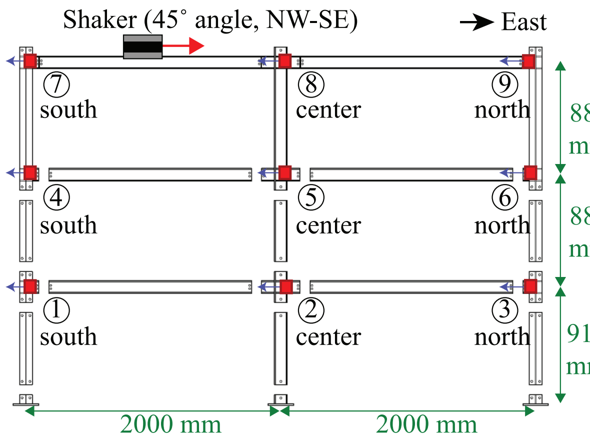

Figure 1. Three-story steel frame structure with shaker and configuration of nine accelerometers

The baseline data set consisted of nine channels, each with 3,367 samples recorded at 50 Hz. The defective data sets were assumed to be a result of a systematic data-acquisition malfunction. More specifically, after 183 samples (3.66 sec) a group of three sensors failed and did not record acceleration for the remaining 3,184 samples. In other words, three sensors lost 95% of the data and overall, only 68% of the data were available in comparison to the baseline. The following cases subject three different sensor groups to this failure: Case 1: sensors 1 – 3 fail; Case 2: sensors 4 – 6 fail; and Case 3: sensors 7 – 9 fail.

RESULTS AND DISCUSSION

Each data set was analyzed using STRIDE with a model order equal to four. Table 1 displays the identified frequencies for the first four structural modes, for the baseline and three missing data cases.

The frequency estimates of the missing data cases were highly accurate, within 0.30% of the baseline values. That is, the defective data provided nearly perfect frequency information about the structural system in spite of the 32% data loss (28,656 samples).

Table 1. Identified frequencies (Hz) for four modes

Mode	Baseline	Case 1	Case 2	Case 3
1	4.631	4.632	4.631	4.628
2	10.018	10.022	10.021	10.017
3	11.411	11.416	11.409	11.405
4	13.868	13.854	13.860	13.876

The three missing-data cases were selected primarily to investigate the influence of sensor location on mode shape estimation. The mode shapes estimated in each case were compared to the baseline results using the modal assurance criteria (MAC) metric – which, in short, is the correlation between the modal ordinates. A MAC value greater than 0.90 indicates good mode shape consistency while a value of 1.00 indicates a perfect match.

In Table 2, the MAC values computed between the baseline case and each missing-data case are provided. When the defective sensors were at the first (Case 1) or third (Case 3) story, all four mode shapes were successfully identified. All MAC values for Cases 1 and 3 exceeded 0.90 and, for the 3rd and 4th modes, surpassed 0.99. In Case 2, three out of four MAC values exceeded 0.95; however, the 2nd mode shape was incorrectly identified.

Figure 2 compares the first two mode shapes from the baseline to those from Case 2 to better illustrate the inaccuracy when the sensors at the second story malfunctioned. As anticipated, modal ordinates 4 – 6, corresponding to the defective sensors, were incorrect. Additionally, locations 7 – 9 were incorrect; they were accurate in magnitude however, reverse in direction. For very high missing-data magnitudes, defective sensor data seems to indirectly affect the phase of adjacent sensors. Therefore, to ensure accurate phase estimation, it may be beneficial to also analyze a data set with the defective sensors removed.

Table 2. Shape correlation with baseline (MAC)

Mode	Case 1	Case 2	Case 3
1	0.9867	0.9541	0.9065
2	0.9094	0.0286	0.9301
3	0.9995	0.9998	0.9981
4	0.9963	0.9821	0.9995

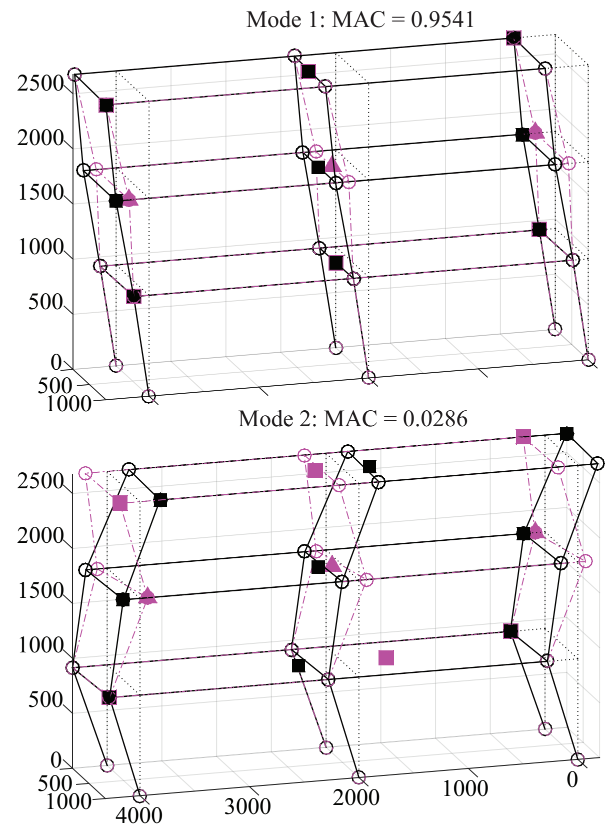

Figure 2. 1st and 2nd mode shapes for the baseline case (black) and Case 2 (purple). Squares and triangles indicate working and defective sensors, respectively.

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Lynch, J. P., and Loh, K. J. (2006). “A Summary Review of Wireless Sensors and Sensor Networks for Structural Health Monitoring.” *The Shock and Vibration Digest*, 38(2), 91–128.

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