INPUT/OUTPUT VERSUS OUTPUT ONLY MODAL ANALYSIS OF A STRESS-RIBBON FOOTBRIDGE

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ABSTRACT
There is an increasing interest in the field of modal testing in civil engineering to apply measured forces in addition to the unmeasured ambient excitation, and to identify a model that accounts for both excitation sources. In these tests the amplitude of the artificial forces can be small compared to the amplitude of the ambient forces, so small and practical actuators can be used on relatively large structures. In this work an electro dynamical shaker is used to excite a stress-ribbon footbridge. Additionally, operational modal tests are carried out as well. Finally, input/output and output-only system identification algorithms based on the Expectation-Maximization algorithm are used to estimate the modal parameters from both data sets and the results are compared.

Keywords: Operational modal analysis, combined operational-experimental modal analysis, modal mass, Expectation-Maximization algorithm

1. INTRODUCTION
Recent studies in system identification for modal testing in civil engineering include the possibility to apply measured forces in addition to the operational and/or ambient loads: using impact hammers and drop weight systems [1], vertical shakers [2, 3]… This new technique has been called operational modal analysis with exogenous inputs or OMAX [4] and combined experimental-operational modal analysis [1]. The unknown excitations in OMAX are very important and they cannot be ignored, they must be included in the analysis. This fact requires the development of sophisticated system identification methods, like the reference-based combined deterministic-stochastic subspace identification algorithm [2], what extends the well known subspace methods developed in the OMA framework. Another interesting approach is to use Bayesian modal identification [3], what allows the computation of the modal parameters uncertainty.

The methodology is similar to Operational Modal Analysis (OMA): first, excitation and response of the structure are recorded; second, a mathematical model is estimated from these data; and third, the modal parameters are computed from the model, including the modal mass. The model used in the second step
along with the estimation algorithm influence the number and quality of the modal parameters obtained. In this paper, the use of maximum likelihood estimation of the state space model taking into account only-outputs (OMA) and both inputs and outputs (OMAX) is investigated. Maximum likelihood is usually achieved using Newton type algorithms. An interesting alternative is to consider the Expectation-Maximization (EM) algorithm because in modal analysis the size of the estimated state space matrices is high, and the EM algorithm is better suited than Newton algorithms for these kind of problems [5], [6].

The proposed methods are used in this work to estimate the modal parameters of a stress ribbon footbridge from OMA and OMAX tests.

2. FIELD DATA AND RESULTS

![Image](a)

![Image](b)

**Figure 1:** (a) Pedro Gómez Bosque footbridge over the Pisuerga River, Valladolid; (b) Position of the accelerometers: a\textsubscript{1} to a\textsubscript{10}; position of the shaker: sh.

The Pedro Gómez Bosque footbridge (Figure 1(a)) was built in 2011 to overpass the Pisuerga River, in Valladolid (Spain). The structure mainly consists of a corten steel band (94 m. long, 3.6 m. wide, and only 30 mm thick) that was pretensioned and anchored to both abutments.

On June 3, 2014, researchers from the Universidad Politecnica de Madrid and from Universidad de Valladolid conducted some dynamic tests in which ten vertical DOFs were recorded, and a 186 N shaker acting in the vertical direction was used (see Figure 1(b) for the sensor and shaker positions). Eleven time series of 5 minutes were collected with a sampling frequency of 2048 Hz: the acceleration recorded by the ten accelerometers and the input due to the shaker. Since the modes of interest are in the range 0-3 Hz, the data were re-sampled with new sampling frequency equal to 8 Hz.

The EM algorithm was applied to the measured data obtaining the stabilization diagrams of Figure 2. In general, both plots are very similar. Some modes identified from OMAX data are plotted in Figure 3.
Finally, these modes (and their counterpart estimated from OMA data) are compared in Table[1].

![Figure 2: Estabilization diagrams.](image)

3. CONCLUSION

The use of the EM algorithm for OMA and OMAX in a lively footbridge is explored. We would like to highlight: 1) the modal parameters identified from both data sets are very similar, so the frequency range 0-3 Hz was properly excited by the operational/ambient load; 2) what is an added value of OMAX over OMA is the possibility of computing modal masses, and therefore, scaling the mode shapes; 3) but, in any case, the results of both tests complement each other and allow us to check the feasibility of the estimated modal parameters.
**Table 1:** Frequencies, dampings ratios and MAC values corresponding to the modes presented in Figure 3 (rows: only-output data; columns: input-output data).

<table>
<thead>
<tr>
<th>Freq. (rad/s)</th>
<th>Damp. (%)</th>
<th>Freq. (rad/s)</th>
<th>Damp. (%)</th>
<th>Freq. (rad/s)</th>
<th>Damp. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>f = 1.062Hz</td>
<td>1.018%</td>
<td>m_m = 261.791</td>
<td>1.062</td>
<td>1.567Hz</td>
<td>0.276%</td>
</tr>
<tr>
<td>f = 1.567Hz</td>
<td>0.283%</td>
<td>1.774Hz</td>
<td>0.282%</td>
<td>1.774Hz</td>
<td>0.383%</td>
</tr>
</tbody>
</table>

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**REFERENCES**


