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MODAL PARAMETERS IDENTIFICATION USING ASYNCHRONOUS DATA

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ABSTRACT

Operational Modal Analysis (OMA) allows one to identify the modal parameters (e.g., natural frequencies, damping ratios and mode shapes) of structure from its output-only response to ambient excitations. Modal parameters are often studied to provide information for Structural Health Monitoring (SHM): model updating, damage detection, damage localization and quantification. In vibration tests, multiple sensors are used to obtain detailed mode shape information and eigen-frequencies. Time synchronization among data channels is normally required in conventional modal identification approaches. If modal parameters can be identified precisely using asynchronous data, modal analysis tests can be more flexibly and economically conducted. In this paper, the effect of asynchronous data on operational modal analysis is investigated.

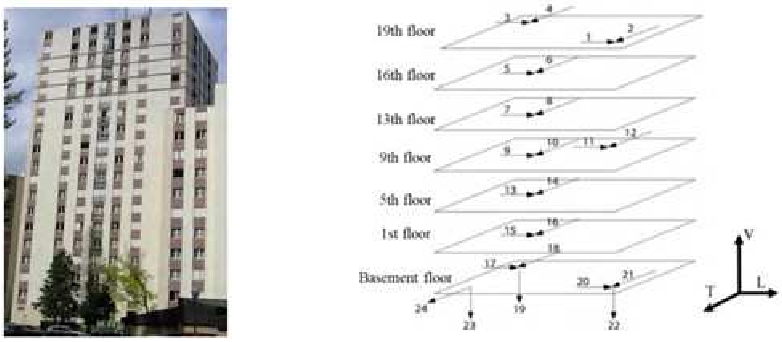
Keywords: SHM, OMA, signal processing, asynchronous acquisition.

INTRODUCTION

During their functioning, civil infrastructures are constantly subjected to man-made and natural hazards, as well as their own natural aging, which may lead to structural damage and collapse along with financial loss [1]. The commonly used SHM techniques are based on the study of the structure vibratory behaviour [2]. The structural response to ambient excitations is measured using several sensors. Conventional modal identification approaches use synchronous data, in which different channels are sampled at the same sampling rate and data in different channels are recorded simultaneously at the same time scale. To do so, conventional technique requires long cables, dating system, acquisition system and a means of data transfer [3]. In this traditional architecture, two major issues are identified: (i) sensor wiring, (ii) data transmission. In fact, for some civil structures, such as historical monuments or a multi-storey building, cabling can become a crippling problem. In light of these ascertainments, significant advantages, in terms of flexibility and economy, can be obtained if OMA would be performed based on asynchronous data. This paper investigates the behaviour of asynchronous data in OMA. Two techniques are investigated, namely SSI-COV and FDD. These techniques help identifying respectively, eigen-frequencies and mode shapes. These parameters can be used to identify and localize damages using an algorithm of damage detection and localization developed in previous works [4]. The studied data are obtained from the 18-story Ophite tower located in Lourdes, France. The tower is permanently instrumented with 24-channel system and an acquisition station [5].

THE OPHITE TOWER

The building considered in this study is the Ophite Tower (Figure 1), located in Lourdes, France. It is a reinforced concrete structure composed of 18 storeys and it was built in 1972. The sensors are chosen so as to have a representation and a sufficient description of the modal deformations. Consequently, in the longitudinal direction, the sensors 3, 5, 7, 9, 13, 15 and 17 are selected.



(a) (b)

Fig. 1 - The Ophite tower: (a) street view, (b) instrumentation layout

RESULTS

SSI-COV with asynchronous data

The SSI-COV method allows identification of eigenfrequencies. This algorithm temporally correlates the accelerations coming from several sensors supposed to be synchronized. The correlation $R_{ijk}(T)$ between two responses $x_{ik}(t)$ and $x_{jk}(t)$ is defined by [6]:

$$R_{ijk}(t) = \sum_{r=0}^{n} \frac{\Phi_i^r A_j^r}{m^r w_d^r} e^{-\xi^r w_n^r T} \sin(w_d^r T + \Theta^r) \tag{1}$$

Where A_j^r et Θ^r are constants. w_n^r is the natural frequency, ξ the damping ratio and $m^r$the mass. Φ_i^r is the ith mode shape components of rth mode.

Assuming now that the response $x_{jk}(t)$ is recorded with a delay δt relative to $x_{ik}(t)$, the correlation function becomes [7]:

$$R_{ijk}(t) = \sum_{r=0}^{n} \frac{\Phi_i^r A_j^r}{m^r w_d^r} e^{-\xi^r w_n^r T} e^{-\xi^r w_n^r \delta t} \sin(w_d^r T + (w_d^r \delta t + \Theta^r)) \tag{2}$$

By comparing equation 1 and 2, one can see a phase shift between the two expressions equal to $w_d^r \delta t$. However, the eigen-frequency w_d^r is not influenced by the time-delay. Therefore, if δt is unknown, it is possible to identify the eigenfrequencies [8]. Considering the same measurement conditions, the time difference is introduced randomly between the sensors selected for this study. Table 1 summarizes the results of the identification of eigenfrequencies using synchronized and desynchronized data.

Table 1 - Eigen-frequencies identification of the Ophite tower using synchronous and asynchronous data

Eigen-freq.[Hz] Literature [9]	Eigen-freq.[Hz] Synchronous data	Eigen-freq.[Hz] Asynchronous data	Error %
1.74	1.70	1.70	0
2,25	2,25	2,25	0
5,82	5,76	5,77	0,17

FDD with asynchronous data

The main step in the FDD method is to compute the power spectral density matrix $G_{yy}(jw)$. By decomposing $G_{yy}(jw)$ into singular values, when $w = w_m$ (eigen-mode), it is possible to estimate the mode shape from the first eigenvector of the left matrix U. In the case where the n sensors are not synchronized, the identification of mode shapes can take place by decomposing $G'_{yy}(jw)$ as follows [10]:

$$G'_{yy} * G'^{*}_{yy} \approx U' \Sigma \Sigma^{*} U'^{*} \tag{3}$$

Where U' is the left matrix of the singular value decomposition in the asynchronous case and Σ contains the singular values of $G_{yy}(jw)$.

Analogously to the case of perfectly synchronized sensors, the first vector U_1' of U' is an estimation of the mode shape of the same mode. The normalized mode shape, taking the rth sensor as a reference, can be written in the following form [10]:

$$U_1' = \begin{pmatrix} e^{iw_m(t_1-t_r)} \dfrac{U_{1,1}}{U_{r,1}} \\ \vdots \\ e^{iw_m(t_k-t_r)} \dfrac{U_{k,1}}{U_{r,1}} \\ \vdots \\ e^{iw_m(t_n-t_r)} \dfrac{U_{n,1}}{U_{r,1}} \end{pmatrix} \tag{4}$$

Where $t_k - t_r$ is the time shift between the kth and the rth sensor.

From equation 4, it is clear that the time-delay introduces a phase shift to each of the mode shape components, which is reflected in the term $e^{iw_m(t_k-t_r)}$ for the kth component [11]. As a result, the maximum amplitude at different measurement points is reached at different times, thus causing a change in sign and amplitude of the mode shape as shown in Figure 2.

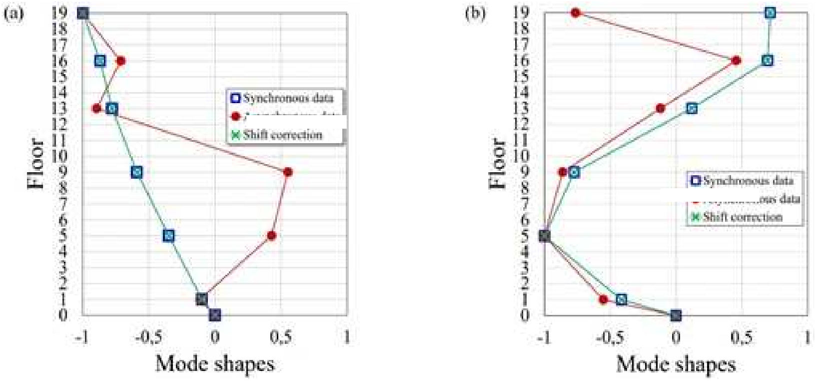


Fig. 2 - Mode shapes identification using synchronous and asynchronous data

CONCLUSIONS

In this study, the effect of sensor desynchronization on the identification of civil structure dynamic characteristics is studied. Through a mathematical development, it was found that the SSI method makes it possible to identify the eigen-frequencies with a very high precision, using asynchronous data. The application on the accelerometric data of the Ophite was satisfactory. In the case of mode shapes identification, the FDD method showed more sensitivity to the time shift between the signals. Indeed, the latter causes a phase change, and therefore a change of sign and amplitude in the components of the mode shape.

Efforts continue to be deployed to solve the problems related to the identification of modal deformations using asynchronous data. A feasible approach would be to use a bayesian formulation for asynchronous data and to determine the most probable value (MPV) of modal parameters [12].

REFERENCES

[1] Shaladi R, Alatshan F, Yang C, An overview on the applications of structural health monitoring using wireless sensor networks in bridge engineering. In Proceeding of Int Conf Adv Sci Eng Technol Nat Resources, 2015, pp.4-11.

[2] Yan YJ, Cheng L, Wu ZY, Yam LH, Development in vibration-based structural damage detection technique. Mech Syst Signal Process, 2007, 21, pp.2198-2211.

[3] Zhu YC, Au SK, Spectral characteristics of asynchronous data in operational modal analysis. Structural Control and Health Monitoring, 24, 2017.

[4] Frigui F, Faye JP, Martin C, Dalverny O, Pérès F, Judenherc S, Global methodology for damage detection and localization in civil engineering structures. Engineering Structures, 2018, 171, pp.686-695.

[5] RESIF is a national Research Infrastructure, recognised as such by the French Ministry of Higher Education and Research. RESIF is managed by the RESIF Consortium, composed of 18 Research Institutions and Universities in France. RESIF additionally supported by a public grant overseen by the French National Research Agency (ANR) as part of the "Investissements d'Avenir" program (reference: ANR-11-EQPX-0040) and the French Ministry of Ecology, Sustainable Development and Energy.

[6] Xie Y, Liu P, Cai GP, Modal parameter identification of flexible spacecraft using the covariance-driven stochastic subspace identification (SSI-COV) method. Acta Mechanica Sinica,2016, 32, pp.710-719.

[7] James GH, Thomas G, Laufferet JP *et al.*, The natural excitation technique (NExT) for modal parameter extraction from operating structures. The International Journal of Analytical and Experimental Modal Analysis, 1995, 10, p.260.

[8] Nagayama T, Spencer BF, Structural health monitoring using smart sensors. Technical report, Newmark Structural Engineering Laboratory. University of Illinois at Urbana-Champaign, 2007.

[9] Mikael A, Evaluation des paramètres physiques des bâtiments : amortissement, fréquence et modes de comportement des structures de génie civil : approche expérimentale. PhD thesis, Sciences de la Terre, Université Grenoble Alpes, 2011.

[10] Yan G, Dyke SJ, Structural damage detection robust against time synchronization errors. Smart Materials and Structures, 19, 2010.

[11] Noel AB, Abdaoui A, Elfouly T, Ahmed MH, Badawy A, Shehata MS, Structural health monitoring using wireless sensor networks: A comprehensive survey. IEEE Communications Surveys & Tutorials, 2017, 19, pp.1403-1423.

[12] Zhu YC, Au SK, Bayesian operational modal analysis with asynchronous data, part I: Most probable value. Mechanical Systems and Signal Processing, 2018, 98, pp.652-666.